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TITLE:
MODELLING RAIL TRACK DETERIORATION AND MAINTENANCE: CURRENT PRACTICES AND FUTURE NEEDS

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ABSTRACT

As commercialisation and privatisation of railway systems reach the political agendas in a number of countries, including Australia, the separation of infrastructure from operating business dictates that track costs need to be shared on an equitable basis.

There is also a world-wide trend towards increased pressures on rail track infrastructure through increases in axle loads and train speeds. Such productivity and customer service driven pressures inevitably lead to reductions in the life of track components and increases in track maintenance costs.

This paper provides a state-of-the-art review of track degradation modeling, as well as an overview of track maintenance decision support systems currently in use in North America and Europe. The essential elements of a maintenance optimisation model currently under development are also highlighted.

1. INTRODUCTION

1.1 Background

Rail transport in Australia represents about 1 percent of GDP, with freight revenue of around $A2.6 billion in 1991/92 (Bureau of Industry Economics, 1993). Although Australian rail systems have achieved considerable productivity gains in the last decade, unit operating costs are still well below world's best practice. In 1993/94 track maintenance productivity lagged behind such benchmarks by an estimated $A80 million. This represents 16 percent of potential operating cost savings available if world's best practice is achieved (Bureau of Industry Economics, 1995).

There are significant productivity gains to be realised in track maintenance through capital expenditure in both the maintenance task itself (e.g. mechanisation), and by moving to higher quality, lower maintenance track. However, there is also a need to ensure that maintenance of existing networks is undertaken according to a plan which maximises overall net benefit to the rail operator. This need for maximum resource productivity is coupled with the need to improve our understanding of track deterioration causes.

As commercialisation and privatisation of railway systems reach the political agendas in a number of countries, including Australia, the separation of infrastructure from operating business dictates that track costs need to be shared on an equitable basis. Such separation has implications for investment, as well as for day-to-day operations, as discussed by Williams and Ferreira, 1995. When several operators compete for the use of track owned by a separate business unit, it is important to know the damage being caused by each user, both in the short and long term. The infrastructure owner needs to maximise profit subject to satisfying the levels of performance required by each user. Such performance requirements may well be in conflict with optimum maintenance practices (e.g. scheduling maintenance windows in conflict with marketing needs). In addition, the world-wide trend to heavier axle loads and increased speeds is being followed in Australia as a result of customer service and operating cost pressures.

Efficient maintenance planning requires an up-to-date, locally relevant decision support tools. This paper focuses on three vital aspects which need to be considered when developing such a tool:

(a) the physical factors which affect track deterioration and therefore costs of rectification or renewal;

(b) the scope and capabilities of existing track degradation and maintenance planning models; and

(c) the parameters which must be included in the optimisation processes to take into account engineering as well as business related factors.

The paper focuses primarily on track degradation issues and related maintenance decision support tools. Such a focus is thought to be important in the Australian context where such tools are yet to be embraced in practice. Adequate databases for track data, which include asset condition and maintenance history, are the building blocks for track management decision support systems. Such databases are yet to be developed in Australia.

Other track related issues not covered in the paper are essential to the achievement of high productivity at the lowest cost. As we move into a period when vertically integrated railways give way to separate track companies with several train operators competing with each other and using common fixed infrastructure, the demands on the track provider will increase significantly. Track design standards, safety strategies, renewal and maintenance technology, staff productivity, cost management systems, and cost and quality of materials used are all areas which will come under close scrutiny, as train operators and shareholders demand benchmarking of key performance indicators. In the Australian context, the bulk of the research priority areas put forward in ARRDO, 1982, are still very much relevant today.

1.2 Track Related Modelling

Before reviewing the most significant research undertaken both in Australia and overseas on the modelling of track related issues, it is useful to provide a framework for such a review. Figure 1 shows in an hierarchical form the main categories of models which have been developed. At one end of the hierarchy are the detailed or ‘microscopic’ models dealing with the forces on specific track components (eg. rail, sleeper, and ballast). Such models, which are usually based on engineering ‘judgment’ or empirical evidence, can be used mainly for design purposes. At the other end of the spectrum are decision support systems for maintenance planning and overall system simulation models used mainly by rail planners to undertake cost-benefit analysis of proposed new corporate or operational strategies. Between those two main levels there exists a large number of models which attempt to predict component deterioration given engineering relationships established by ‘microscopic’ models or by engineering ‘judgment’.

The model classification shown in Figure 1 can only be seen as a convenient simplified means of categorising what in practice is a complex web of inter-related approaches to rail track analysis, planning and appraisal. Some of the ‘macro’ models such as maintenance planning tools, make use of modules containing a higher level of detail, such as track force analysis. It is also difficult to be precise when categorising models according to their functionality. For example, some of the ‘macro’ models can be used for maintenance planning, as well as technology appraisal and track investment evaluation.

Section 2 deals with research at the ‘microscopic’ level into dynamic effects, axle-loads, speed and other effects on components. Section 3 is devoted to a discussion of decision support systems at a more aggregated or ‘macroscopic’ level where the total system is being modelled and the future maintenance plan is being developed. The extension of a planning model to include the optimisation of maintenance strategies to achieve a given level of customer service within a budget constraint, is the subject of Section 4. It is this overall maintenance planning function including the satisfaction of business related objectives, which is seen as the principal aim of future research.

2. PHYSICAL DEGRADATION FACTORS

2.1 Dynamic Effects

Traffic on most rail lines in Australia comprises many different forms of vehicle, varying from high speed passenger units (electric and diesel), to medium speed heavy haul coal wagons and locomotives, to lower speed mixed freight consists. Track is therefore subject to a wide range of bearing and bending stresses in the rails, pads, fasteners, sleepers, ballast and subgrade.

These stresses come about not only because of the static mass of a vehicle, its wheelsets and the cargo (freight or passenger), but also due to dynamic actions such as lateral centrifugal forces on curves, longitudinal acceleration and braking forces, rocking of the vehicle about 3 axes (roll, pitch and yaw), vertical inertial forces from the motion of the wheelset and its suspension, vibrational forces induced from imperfections in the rail surface (corrugations, joints, welds, defects) and in the wheels (flats and shells), and from the dynamic response of the track components to these actions.

The consequences of the frequently large forces generated by these actions are many and varied. Fatigue cracking in rails, plastic flow or shelling out of the rail head, uneven wear of the rail head, cracking or splitting of sleepers, loosening of fasteners, grinding and redistribution of ballast, and variations in track alignments and gauge are the major deleterious effects. Such effects result in poor riding quality, reduced train speed, increased fuel consumption, potential derailment, increased maintenance, delays and reduced level of service, and loss of revenue in the longer term.

Not surprisingly, Baxter, 1993, amongst others, has identified dynamic actions (i.e. the forces and stresses due to these actions) to be the key to reducing track maintenance demands. It is for good reason that rail authorities spend a large part of their maintenance budget on rail grinding (to reduce corrugations, and reform the worn rail head to a the correct shape; see Marich et al, 1994) and on ballast tamping (to re-establish alignments thereby reducing train body motions and consequent forces on the track). Furthermore, dynamics of vehicle/track interaction are the cause of noise and vibration which have become issues of environmental concern. Minimisation of high (noise) and low frequency (disturbance of surrounding structures) force vibrations therefore has engineering, financial and societal benefits.

Baxter, 1993, went on to suggest, however, that understanding of dynamic and impact forces and track/vehicle vibrations is still insufficient. Furthermore, Knothe and Grassie, 1993, expressed the same opinion about understanding of the dynamic behaviour of sleeper pads; Tajaddini, 1993, about ballast behaviour; and Singh and Punwani, 1993, about vehicle body motions at higher wagon mass. The recently completed Eurobalt project, for example, with funding of ECU5m (approx $A11m) focussed almost exclusively on the response of ballast to dynamic forces, in particular for trains travelling at speeds up to 400km/h (Huille, 1994).

Many researchers over the past 3 decades have developed analytical dynamic models of the vehicle/wheel/rail/pad/sleeper/ballast/formation system and interactive forces, with a corresponding large body of associated literature, but there is still need for a simple and reliable tool for simulating track dynamic forces.

In more recent work, Knothe and Grassie, 1993, reviewed the state of dynamic modelling and declared the impossibility (at present) of predicting the dynamic behaviour of rail pads or ballast. Thambiratnam and Zhuge, 1993, used finite elements to mimic oscillations of the track structure and claimed good correlation with measured macro performance of the track.

Cai and Raymond, 1992, have developed a model using beams for rails and springs and dashpots for each non-rail component and have fused them into one comprehensive tool; the model is cumbersome but work is continuing to enable it to run on a PC. Current research at the Association of American Railroads is considering using finite elements for rail and track in its popular track force analysis system (NUCARS) to allow “along-track” properties to be modelled (Dembosky, 1995).

2.2 Train Speeds

Increasing the speed of trains has many effects on rail and track behaviour and degradation, and has long been considered in regard to the level of noise and vibration experienced near rail lines (eg Bubel, 1977). Eisenmann's 1972 impact factor equation makes some allowance for speed and is commonly used in Australia in estimating dynamic vertical forces. Murray and Griffin, 1993; deduced that higher speeds cause greater track deflections, and Kearsley and Vanas, 1993, showed that the speed of a train can significantly influence the deterioration of track geometry; other work in Australia, however, concluded that speed may not influence dynamic vertical wheel loads (Antulor, 1991).

Ford, 1994, examined the profile of track and showed that large vertical wavelength deviations of the rail top produced dynamic forces which varied widely depending on the speed of a train. Furthermore, analytical models have shown that vehicle speed is one of the key factors affecting the wheel/rail impact loads; these loads produce very high bending stresses in rails and in sleepers (except where attenuated by resilient pads), and can lead to fatigue and/or cracking in vehicle axles and bearings.

Many studies of rail head corrugations have examined the effect of train speed on forces generated by them, earlier examples being Grassie, 1982 (short wavelength corrugations), and Mair et al, 1978 (long wavelength). More recently, Grassie & Kalousek, 1993, proposed six categories to describe the origins and nature of the various types of corrugation that can occur. Despite many years of research, however, even the very reasons for the existence of corrugations are still being debated (Clark, 1991) though train speed is known to be a vital factor (Tan and Yu, 1993).

Track which deviates too much from design alignments causes increased friction between wheel and rail (poor lateral alignment) and excessive bumping of suspension elements, in proportion to train speed; Williams and Schmidt, 1993, established that rail running surface defects result in fuel use increasing as speed increases.

Clearly there are many sources of dynamic forces and the effect of train speed upon these forces has not been established definitively. It is certain, however, that higher train speeds result in greater operating costs for rolling stock and increased track maintenance activity.

2.3 Axle Loads

Axle loads affect rail head wear, fatigue of the rail steel, and plastic flow and shelling in the running surface between wheel and rail head (Hagaman, 1989). A great deal of work has been done and is continuing around the world to produce models for the complex conditions existing at the wheel/rail contact point (eg Grassie, 1992).

Pioneering work into use of very heavy axle loads was undertaken by Australian mining rail systems: Mitchell & Walker, 1989, found that raising axle loads from 30 to 32.5 tonnes (with 40 tonnes being the ultimate goal) need not increase costs, provided smooth wheel and rail profiles were maintained. To maintain such profiles is nevertheless more expensive when axle loads increase. Axle load and train speed have been shown by Sankar et al, 1994, using a finite element model, to be the two main factors controlling wheel/rail impact forces.

Greater axle loads lead to increased wheel wear and higher bending stresses in rails and sleepers, as well as higher bearing stresses in ballast and subgrade. Extensive work has been conducted by the Association of American Railroads (AAR) over twenty years through its accelerated testing (FAST) and Heavy Axle Load (HAL) programs, accumulating more than 1.5 billion gross tons of traffic on its test track. Earlier conclusions from this comprehensive program (Hargrove, 1990) were, that under favourable conditions there is sufficient net benefit to warrant detailed evaluations of heavier axle loads for specific services, depending on factors such as the service plan, route, specific capabilities of the car designs, and commercial factors.

Reiff, 1990, suggested from AAR studies that routine maintenance demands were 60% greater for a 20% increase in axle load, though the penalty in total capital and maintenance costs in these same studies has been given more recently by Kalay, 1995, as closer to 30%. Newman et al, 1991, discussed the effect of increased axle loads on maintenance of way and train operations at Burlington Northern Railroad, concluding that a 9% increase in axle load led to a 14% increase in total track costs, which is an outcome similar to the AAR work. Vanselow, 1993, examined a wide range of positive (economic and operational) and negative (deterioration and maintenance) factors in assessing the impact of increased axle loads on "efficiency and safety" of Hammersley Iron's operations, but noted that "much work remains to be done". That the effect of axle loads is still an important topic of study is evidenced by work continuing to be reported in the literature.

2.4 Other Factors

There are many other factors influencing the behaviour of track and consequent maintenance activity required; for example Ebersohn et al, 1993, reported that track maintenance increased by 183 percent for a reduction by half in subgrade stiffness. It is not possible in this paper, however, to discuss in detail the factors of ballast type and quality, ballast fouling, type and geometry of sleepers and rail pads, and the effect of defects in rails and wheels.

Many researchers are examining the effects of these factors on railway maintenance and repair; adoption of world best practice in maintenance in Australia needs to draw on this work rather than attempt to conduct wholly local studies. Nevertheless, the results of many overseas test programs have limited application to Australian railways because of differences in vehicle and track characteristics which have been identified as key parameters (Anon, 1991). It is therefore necessary to combine the results of others' research with appropriately targeted studies in Australia, in order to establish relevance to local conditions.

3. MAINTENANCE DECISION SUPPORT MODELS

A review of computer aided rail track maintenance and renewal systems identified nearly 20 tools of varying scope currently used in different countries.

The most comprehensive maintenance decision support model is the MARPAS system of British Rail (see Hope, 1992, for example), which relies on an extensive database of all of BR's track and rolling stock (now privatised into different operating and leasing companies). MARPAS accounts for engineering factors in track maintenance through degradation models based on relationships using axle loads, speeds, and train consist, allowing short and long term "what if" studies of maintenance costs by operation managers considering changes in equipment or procedures. The need to program MARPAS to include virtually all costs involved in keeping track and surrounds to a nominated standard lead its developers to include, for example, painting of marker posts, clearing of growth on the right of way and even the cost of fatalities as a consequence of derailments (estimated at around $A4million per fatality in 1995 dollars); British Rail found that such an approach could lead to significant modifications in maintenance scheduling.

Some other models which require a readily usable database of a system's characteristics are as follows:

- Burlington Northern (BN) has its Advanced Railroad Electronics System (ARES) developed primarily for train scheduling (Ferguson, 1991) but storing details of bridges, track geometry, and rail characteristics; BN also has its Track Management System (TM$) used for forecasting track condition (Hide et al, 1991).
- The Track Management Advisory System (TMAS) of Canadian Pacific (CP Rail) requires a database of track segments, normally a complete curve or 150m of tangent (Roney and McIlveen, 1991).
- Trask and Fraticelli, 1991, reported on Canadian National Rail's (CNR) Track Degradation Model (TDM) which uses the engineering department's databases that contain physical plant and track component condition information (visual and automated).
- A Track Management model was developed by BHP for use in Australian heavy haul railroads (Tew & Twidle, 1991) and which utilises historical data covering rail wear and track geometry deterioration rates from track recording cars. Most rail track in Australia is owned by state authorities, who by and large they have not produced readily usable electronic databases of their systems' physical characteristics.
- TRACS, the Total Right-of-way Analysis and Costing System described by Martland and Hargrove, 1993, is a generic system which requires the user to have information about specific equipment and track characteristics if it is to be applied to a particular route. TRACS (and other North American systems to a large extent) are based on models of deterioration developed by the Association of American Railroads.
- Stead and Martin, 1994, discussed the functional descriptions of assets adopted by City Rail in New South Wales in its Technical Maintenance Plan, using asset management techniques borrowed from the aerospace industry.
- ECOTRACK is being developed in Europe by the International Union of Railways together with the European Rail Research Institute (ERRI, 1995). It is a decision support system for track renewal and maintenance based on expert systems technology. It requires a high degree of sophistication in the quality and scope of input data related to track component condition and traffic variables, together with user specified rules regarding renewal and maintenance policies.

For these and other models, there are other common characteristics. MARPAS, TM$, TRACS and TMAS predict the condition of track into the future, depending on traffic and maintenance practices; Chrismer, 1989, is illustrative of ballast degradation models which consider traffic and other factors; Ebersohn et al, 1993, developed relationships for predicting deterioration of track condition due to increasing traffic over low stiffness subgrade, and discussed the use of measured track deflections as a maintenance planning tool.

Tew and Twidle's, 1991, track maintenance planner focussed in part on rail wear and fatigue, and is indicative of models which attempt to predict individual component life; MARPAS also has component life relationships built into it for rail, sleepers, pads and ballast. These and other models also consider trade offs between maintenance and operating costs for determining best practice; TDM (amongst many others) allows consideration of axle load changes in balancing degradation against maintenance. The AAR's comprehensive axle load studies (conducted at its FAST/HAL test track facility in Colorado) led to development of models which consider engineering and business factors in trading off increased maintenance costs against equipment savings (Hargrove, 1990; Kalay, 1995).

Most of these models and predictor systems are based (to varying degrees) upon historical data obtained from local measurements of track condition and of maintenance activity and costs, expected lifetimes of track components, and locally developed algorithms which extrapolate the data for future maintenance planning; other models are centred mainly on stresses in rails and sleepers. In these models, dynamic forces are derived for calculation of stresses in some of the components of the track for factors such as axle load, train speed, and gross tonnage of traffic. The stresses are then related to expected deterioration of the track component derived in part from historical trends.

Due to enormous variations in response of track to the passage of traffic, even in nominally identical track segments (Shenton and Tunna, 1991), and the close relationship between existing models and local conditions, applicability of any given overseas model to Australian railways is unclear. It is necessary to establish relevance to local conditions as a first step.

4. MAINTENANCE OPTIMISATION

4.1 General

Operations Research techniques, such as the Markov decision process, have seen application in the development of planning systems for deteriorating assets such as road pavements (Ben-Akiva et al, 1993; White, 1993; and Feighan et al, 1988). Those techniques are increasingly seen as providing the theoretical framework for road pavement management systems. Such models take into account the fact that pavement condition is difficult to forecast with precision. Therefore knowledge gained about the condition of the system through regular inspections is incorporated into the modelling formulation.

Madanat, 1993, makes use of stochastic dynamic programming to solve pavement maintenance optimisation models based on a markov decision process. The models minimise total life-cycle costs including maintenance, repair and replacement, inspection, and user costs. A proxy is used for user costs in the form of a condition constraint (minimum allowable state). The models consider maintenance and inspection decisions jointly. The objective function to be minimised includes decisions about when an inspection should be undertaken, as well as what type of maintenance activity should be carried out. Three levels of constraints for the objective function are tested, namely: a model without inspection decisions; a decision model with a set inspection decision frequency (once per time period); a model where the decision of when to inspect is one of the outputs of the algorithm rather than a constraint. This approach insures that an inspection is made only when its cost is offset by a resultant reduction in expected future costs.

A simple example is used to demonstrate the benefits of increased model complexity. Those benefits are greatest when it is assumed that forecasts of pavement deterioration are error free. As the uncertainty in those forecasts increases, the number of inspections required increases. The results of a model which has frequent inspections, approach those of a more complex model where the timing of inspection decisions is one of the variables to be determined. This has implications for rail track maintenance modelling, since the costs of frequent track inspections can be high. This is the case if expensive inspection equipment is used, and the network consists of track segments which are remotely located.

Davies and Van Dine, 1988, report on a road pavement optimisation model, whose objective function minimises user costs. The model is solved using a probabilistic linear programming formulation.

Feighan et al, 1988, have also developed an optimisation model based on probabilistic dynamic programming. A markovian decision procedure is used to predict future pavement condition and associated maintenance costs. Sections in the network are categorised into 'families' according to common characteristics. Ten states, based on ranges of pavement condition index are defined, and each section can only be in one of these ten condition states.

4.2 Applicability to rail track maintenance

Figure 1 shows the elements of a decision support system for track maintenance planning. An important element of such a model is the explicit inclusion of risk variables to deal with the impact of track condition on train transit times, reliablity of arrivals, accident/derailment potential, and ultimately rail business revenue. The effect of train delays due to unexpected events related to track, the trains themselves, and stations/terminals, has been successfully modelled as part of a train scheduling optimisation model (Higgins et al, 1995). The latter developed a means of quantifying the risk of delays, for the case of single track train operations. In this way train plans can be optimised with respect to journey time, as well as arrival time reliability. Risk has also been incorporated into road pavement models by Kazakov and Cook, 1988. However, road pavement related models are mainly concerned with the risk associated with the predictions of future pavement condition. In the case of track related risk it is important to consider the likely impact on users of a given track condition state. The risk associated train delays, accidents and business levels, which may result from sub-optimal maintenance planning decisions, needs to be part of the objective function to be optimised.

As shown in Figure 1, the optimisation model needs to take into account the dynamic nature of the relationship between track condition and maintenance activity. Equations (1) and (2) highlight that relationship. For each line segment, the maintenance activity required at time period c is a function of observed track condition during time c-1; traffic related variables; risk related variables; and environmental factors. Track performance in time period c is a function of the amount of maintenance activity since the last major rehabilitation, as well as traffic and environmental factors.

$$\mathrm{TC_c} = f(\sum_{t=1}^{c} MA_t, \sum_{t=1}^{c} TK_t, AX, S) + e_1 \qquad (1)$$

$$\mathrm{MA_c} = f(TC_{c-1}, TK_{c-1}, \sum_{t=c}^{T} R_t, AX, S) + e_2 \qquad (2)$$

Where:

TC = Track condition; MA = Maintenance activity;
TK = Traffic task; R = Set of risk related variables;
S = speed regime; AX = Axle load regime;
t = time period; c = current period; *T* = ultimate planning horizon; and
e_1 and e_2 are error terms.

4.2 Towards a Decision Support System for Australian Conditions
In Australia, decisions related to investment in new track, as well as maintenance of existing track have been based mainly on engineering factors (Bell and Marsden, 1990). The concept of planning future maintenance schedules for an entire network, based on predicted future traffic task by track segment, has yet to be implemented in practice.

Research in Australia has shown that there is insufficient knowledge within the Australian context of the forces generated by moving trains (in particular those with axle loads above 25 tonnes); and therefore of the consequent deformations (static and dynamic) of track components (Muller, 1985, Hagaman, 1989; Murray and Griffin, 1993).

A current collaborative research project between the authors and Queensland Rail (QR) aims to develop a maintenance decision support model for use by railway systems in planning operational changes and estimating the financial consequences of such changes (especially in terms of increased maintenance due to higher axle loads and train speeds).

The overall aim is to develop a tool which can be used to evaluate alternative maintenance strategies and to prioritise maintenance effort across a railway network. The model can also be used to investigate the benefits of changes in traffic characteristics (eg. higher speeds and axle-loads); changes in track design standards; changes in track components (eg. rail, sleeper types); and to simulate the likely effect on business activity of changes in track maintenance policies and design standards. As well as track degradation modules, the maintenance optimisation model will include business risk such as delay costs, accident and derailment risk. Such a model is likely to lead to very significant track productivity gains. This is particularly so in cases where current practices rely on traditionally very conservative engineering judgment. Considerable research needs to be done to better understand the effect of track forces on deterioration so that future condition can be predicted and appropriate maintenance strategies applied. However, the current research project will make use of available ‘microscopic’ models to serve as analytical tools within a total system approach to planning future maintenance requirements.

Model development will be based on data collected for a sample of QR's line segments, selected to represent types of traffic as well as track characteristics and condition. For each line segment the following data will be collected: physical characteristics of track structure; traffic task related variables (gross-tonne-km, axle loads, operating speeds); track condition indicators mainly in the form of track geometry index as measured by a track recording vehicle; track maintenance costs on an historical basis; track standards; environmental conditions; and past maintenance policies. Data on track related train delays and associated costs will be collected specifically for this project. In addition, QR has a strong program of investigation and research in track related areas such as ballast condition analysis. The results of such analysis will be progressively used in the current project.

An advisory group consisting of representatives from other Australian Railways is being set-up early in 1996. This group will provide input into the development of the model, as well as its implementation. In this way, the results should be applicable to other rail systems.

5. CONCLUSIONS
The world-wide trend is towards the formation of rail infrastructure entities as separate businesses supplying services to operators, which will draw increasing attention to track design and maintenance issues. This trend has also become evident in Australia, especially in

the wake of the recent political agreements to increase competition within the transport sector (Hilmer et al, 1993). The changes in track ownership arrangements, coupled with increased demands on the assets, make it essential that adequate track related databases be developed by rail systems. Such databases will form the bases for the development of asset management and maintenance planning tools capable of delivering a high level of efficiency and safety at the lowest possible cost. In addition, failure to demonstrate 'due diligence' in performing the track planning and maintenance task may ultimately lead to legal action on the part of track users.

Market share increases are closely related with level of service which each operator can offer. In this respect, transit times and reliability of arrivals have an important part to play. Both these two levels of service attributes are associated with track infrastructure design and maintenance standards. Therefore, the ability of operators to perform efficiently, and to gain market share, is closely tied to their ability to strike an effective contractual arrangement with the infrastructure owner.

Whether infrastructure is privately or publicly owned, it is important to ensure that the owner has sufficient incentive to move towards the most productive maintenance methods, as well as the most effective long-term track standards. This will require investment decisions to be made related to assets which might have an economic life of 50 years (eg. concrete sleepers). Long-term commitments from operators will be required in such cases. There is a danger that existing low levels of track maintenance productivity in Australia (Bureau of Industry Economics, 1993), will not be significantly altered if owners are left in a position of passing on costs to operators without short-term productivity incentives or long-term contracts.

If there is more than one operator, the infrastructure owner faces potentially different demands for track maintenance, design and capital needs. More particularly, different market segments (freight v. passengers) will require different maximum speed and axle-load standards which have investment and ultimately user charges implications. The owner will need to provide a 'level playing field' so that each operator can gain access to track at the appropriate time and cost. The issue of time of access is important for a number of reasons. Conflicts of access to track are likely to occur between users who may be competing against each other in the market place. Such conflicts are currently resolved according to internal railway rules about traffic priorities. If separate companies are involved, those rules need to be spelt out clearly and unambiguously. The question of limiting track capacity at peak times will involve a user charging system which can take into account the risk of delays at such times.

Track maintenance policies have traditionally been viewed as engineering led decisions. There is a need to focus effort into the development of tools to assist track maintenance planning in the context of maximising the overall net financial benefit to rail users. This overall aim can be achieved by combining research into track degradation with well established Operations Research techniques. Although such approaches have been successfully applied to the maintenance of road pavement and other deteriorating systems, they have yet to see application in track maintenance management.

The results of such research has the potential to bring benefits in terms of lower operating costs for rail infrastructure users, as well as improved transit times and reliability of train arrivals.

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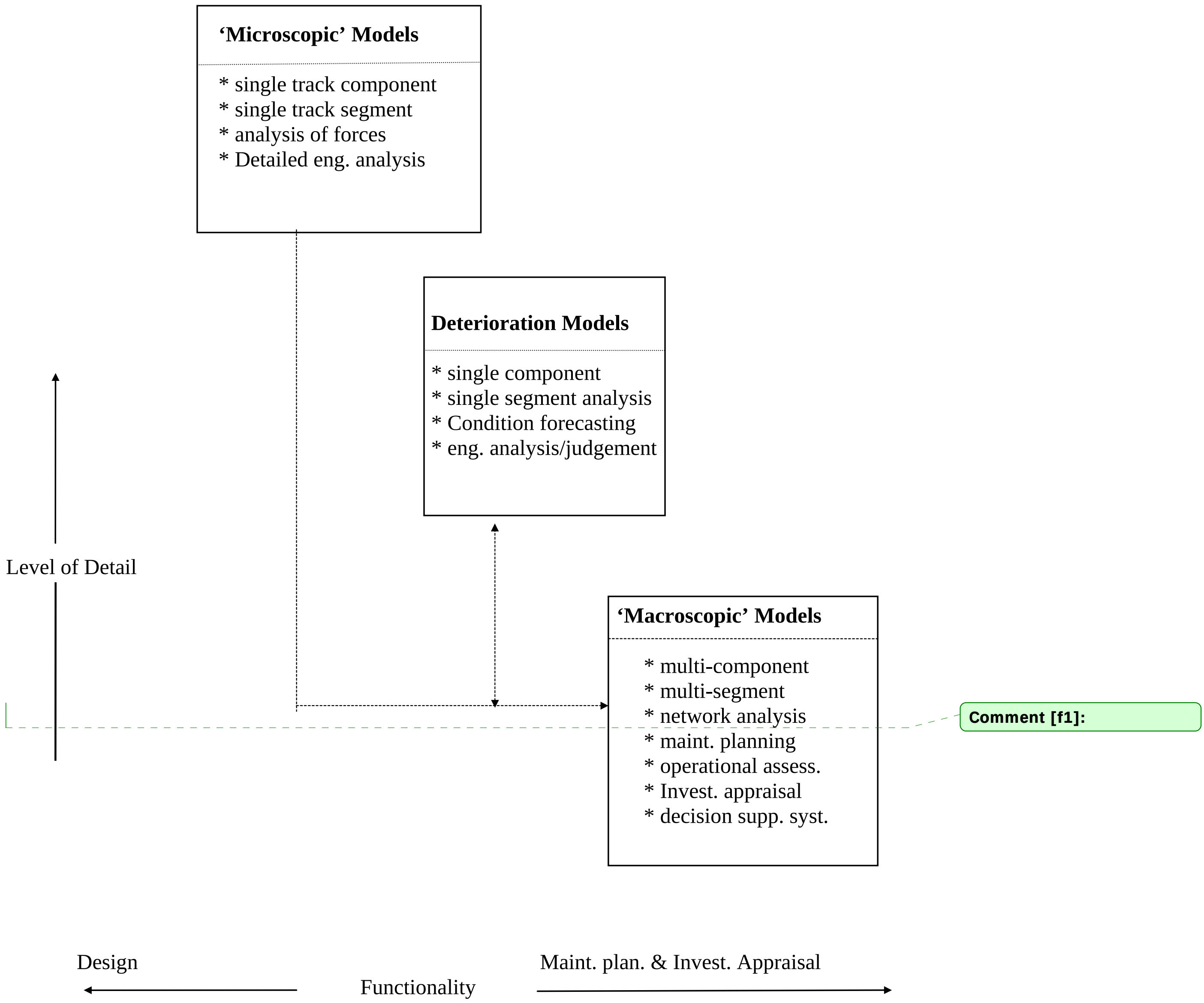

Figure 1. Track Modelling Hierarchy

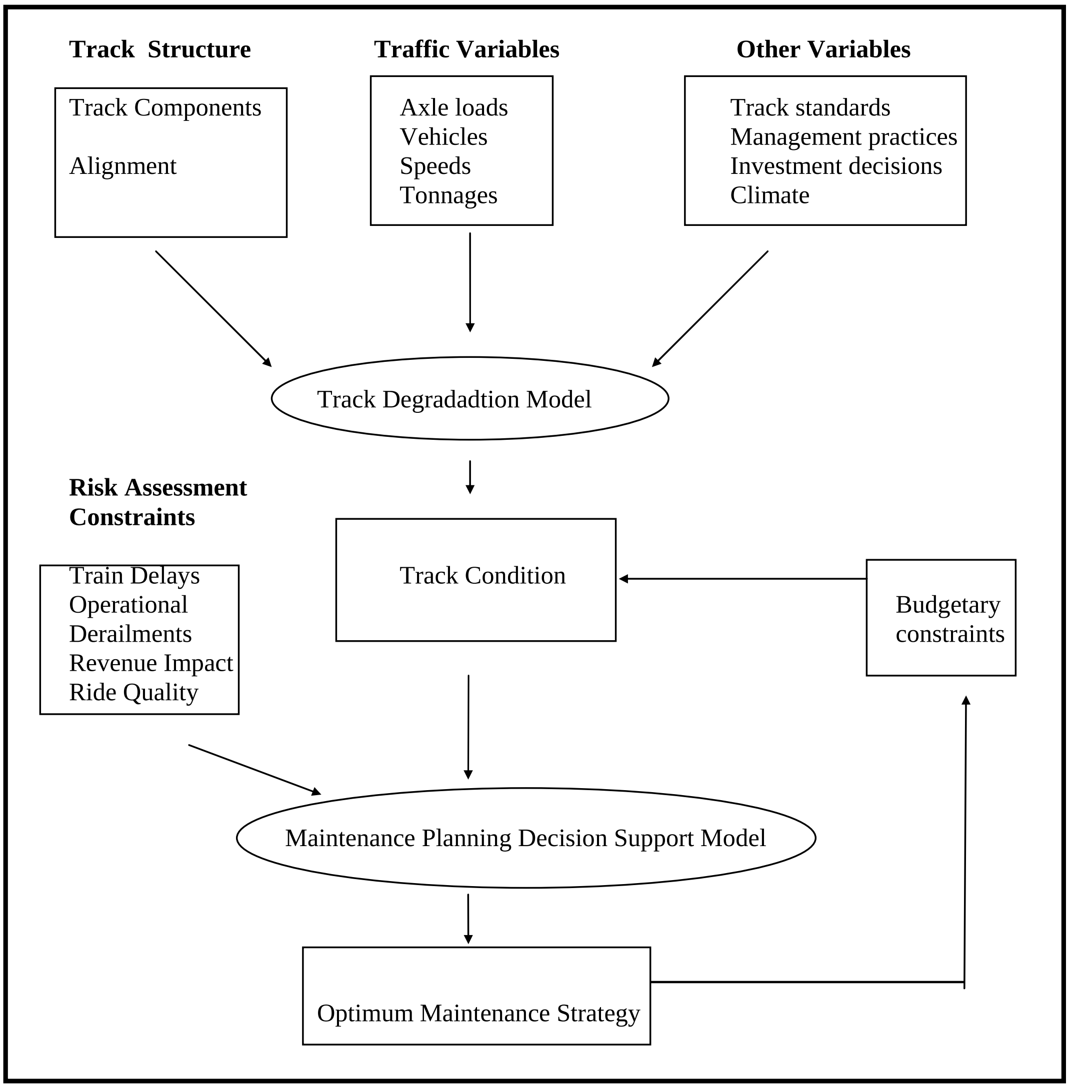

Figure 2. Track Maintenance Optimisation Parameters

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