Application of System Dynamics to Unsealed Pavement Maintenance

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ABSTRACT: Most pavement maintenance management systems tend to be either non-analytical databases or statistical correlation models. However, pavement maintenance is part of a complex system comprising the road pavement, the environment, diverse users, the maintenance authority and Local/State/Federal Governments. This system has significant feedbacks, making it a suitable field for system dynamics enquiry.

This paper discusses a system dynamics based pavement management model that was prototyped originally by engineering students at the Australian Defence Force Academy (Hyde 1996, Jackson 1997) and refined on contract with the Australian Government. The current model was rebuilt in Powersim Studio and refined in collaboration with a Victorian rural Shire Council. The model analyses the pavement deterioration over time of 530 individual segments of unsealed rural road, prioritising rehabilitation treatments based on user preferences and budget constraints and identifies the consequences of different budgetary approaches. Feedback to the decision makers includes the number of households served by very rough roads, the number of user complaints and roughness related accident costs and vehicle operating costs.

Keywords: Pavement maintenance management; pavement life cycle costing; unsealed road maintenance; transport economics; economic evaluation; system dynamics.

Introduction

With the public sector reforms of the past two decades, Australian Road Authorities have had major functions trimmed, outsourced or simply chopped. Probably more than most areas of Government, road asset managers are being required to work 'smarter'. The 'outsourcees', road maintenance companies, are under a twin squeeze - to win maintenance management contracts in a very competitive environment and to satisfy shareholders concerned with return on investment. Both road asset managers and maintenance contractors require tools to assist in 'whole-of-life' cost optimisation in respect of road maintenance.

Over this period two approaches to computer based pavement management system (PMS) have gained widespread use. The first approach is a database PMS, which catalogues the current state of pavements and facilitates budget decision-making. The database PMS has little predictive capability and provides little guidance on alternative policy levers or the implications of such choices. The second approach utilises sophisticated statistical correlation modelling based on data relating to diverse factors including pavement type, environment, vehicle loadings, vehicle usage, maintenance and rehabilitation patterns. The World Bank's HDM-4 model set the conceptual pattern for this approach. (Austroads 2008) These models are applied in a predictive sense, based on the assumption that the identified correlations will persist into the future. They are widely used for highway planning and top level budgetary planning but, despite urging from Federal Government agencies, have found little favour at the Local Government level, where database PMS are more common. In respect of gravel roads, the situation is even more unscientific. A study between 2000 and 2002 found that fewer than 15% of Australian Local Councils with at least 50 km of unsealed roads used any form of pavement management system. (Austroads 2006)

At the Local Government level, politics is important, alongside economics and engineering, when concerns arise about road conditions. This highlights another set of stakeholders, the road users, whose input to the maintenance decision process operates within the much fuzzier and qualitative political environment, and whose desire for quality roads is balanced by their desire for other public

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goods and/or lower taxes. ‘Hard systems’ operational research tools, such as HDM-4, are not suited to this environment. There is a need for analytical and decision support tools for road asset managers which can address both the ‘hard’ quantitative dimensions and the ‘soft’ qualitative dimensions.

Of hard systems, soft systems and system dynamics …

Within the diverse systems disciplines the distinction between ‘hard’ and ‘soft’ systems is important to the understanding the value added of system dynamics modelling techniques.

Hard systems are characterised by:

- clear and unambiguous objectives;
- widespread agreement with the objectives;
- high degree of agreements on the facts; and
- high degree of knowledge concerning the principles of operation.

In such situations the technical decision paradigm is optimisation and traditional operations research techniques have a good track record.

Soft systems, on the other hand are characterised by:

- multiple objectives which may be fuzzy or conflicting;
- multiple stakeholders who may have multiple and/or conflicting interests;
- no clear agreement on the objectives; and
- complex inter-relationships between system elements which may not be well understood or which may even be subject to dispute between competent professionals.

In soft systems, human rather than technical issues dominate, and *the paradigm is one of mutual learning between client, project team and diverse stakeholders*. An example of a soft systems problem would be that of urban accessibility. To the highway engineer a freeway may seem an obvious solution. Some house owners might agree, at least when caught in peak hour traffic - provided the road is located in someone else’s backyard. Others may be concerned about environmental issues and support public transport solutions. Yet others may consider the problem to be one of work place location - bring the jobs to the people rather than vice versa. Whilst economists might argue that the ‘real problem’ is the lack of an appropriate road pricing strategy.

Road maintenance and system dynamics

At first glance, the maintenance of roads might seem to be a classic ‘hard system’

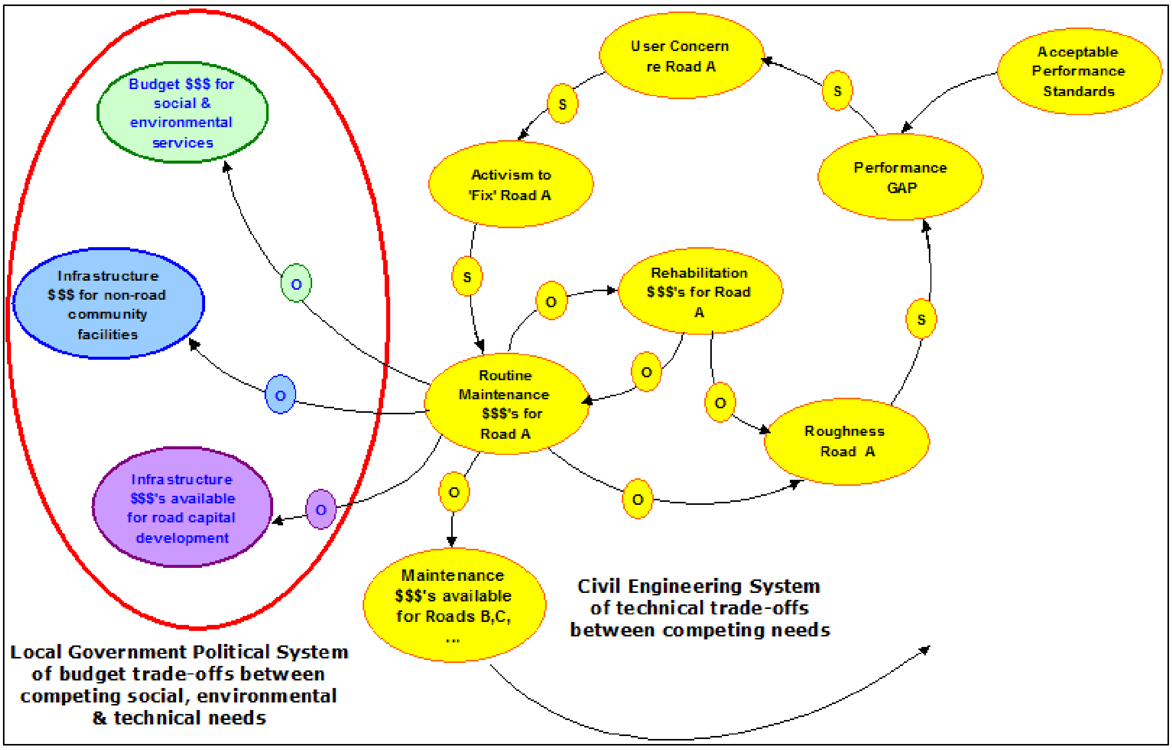
- the objectives are clear and unambiguous - *pavements should be safe & smooth*;
- there is widespread agreement with the objectives - *there is no ‘pothole protection society’ or ‘save the roughness’ campaign;*
- high degree of agreement on the facts - *both engineers and the public can agree on what constitutes a rough driving surface, and understand that maintenance reduces roughness;* and
- high degree of knowledge concerning the principles of operation - *at the least, this is one field where the public will defer to engineering competence.*

However, it’s not that simple. Pavement roughness is the consequence, inter alia, of trade-offs between routine maintenance decisions, pavement reconstruction and decisions relating to overall network investment, which influence traffic intensity on particular road links. In addition, there is a fundamental trade off between roads related expenditure and expenditure on other community infrastructure and social services. This is illustrated in the causal-loop diagram, Figure 1, below.

(One interprets the causal diagram as follows: An ‘S’ represents a causal change in the [S]ame direction, whilst an ‘O’ represents a change in the [O]pposite direction. Thus an increase in ‘Routine Maintenance $$$’s for Road A’, all else being equal, leads to a decrease (i.e., a change in the opposite direction) in the ‘Roughness of Road A’.

Figure 1 also indicates two related systems – that of the technical managers, the assets engineering staff, and the political decision makers, the Shire Councillors. Beyond this are the State and Federal political systems which have many more resources and which are also subject to influence by the local residents and their representatives. Investment decisions on road system maintenance and rehabilitation, based on short term budgetary considerations, can have very significant implications for diverse social goals, especially in the rural Local Government sphere. (Austroads 2007)

Figure 1: Causal Interrelationships Within & Between the Political & Engineering Systems



System dynamics is particularly useful in understanding the linkages between the qualitative and the quantitative aspects of road asset management. System dynamics modelling employs a set of techniques that allow both quantitative and qualitative factors to be incorporated..

Elected decision maker focus of the model

Local Government is applauded because it is the level of Government closest to the people. Local Councillors have the difficult task of allocating scarce resources among many worth competing demands in both the engineering area and in the human services area. All too often, engineering needs are presented in a highly technical mathematical fashion, which are much harder for the individual Councillors to discern than the social data.

One valuable aspect of system dynamics modelling is that it affords a mechanism to communicate the implications of the technical results, for example, the number of households which will be served extremely rough gravel roads or the number of residents who are expected to lodge complaints regarding the state of the roads. More to the point, it becomes possible to highlight which particular roads are likely to be deficient over time. A named road has far more impact on a decision maker than an anonymous road.

As illustrated in Figure 1, the elected official is a critical part of the feedback loop which comprises the model. The simulation model provides information to the decision maker on the road system implications of budget options, and on the numbers of taxpayers affected and to what degree.

Background to the development of the simulation model

Preliminary work on the application of system dynamics modelling to road maintenance management was undertaken by the author in the mid 1990's at the Australian Defence Force Academy (ADFA). The current model grew out of work with a Victorian rural Shire in 2008.

The Shire had participated with the Australian Road Research Board, over a period of 5 years, in the development of statistical correlation based road pavement deterioration models. (ARRB 2006).

In 2008 the Shire undertook a review of its unsealed road assets, including sampling of pavement depth, pavement crossfall and the condition of drainage. As indicated in Table 1, the study showed that the unpaved road system (approximately 40% of all roads in the Shire) has seriously deteriorated.

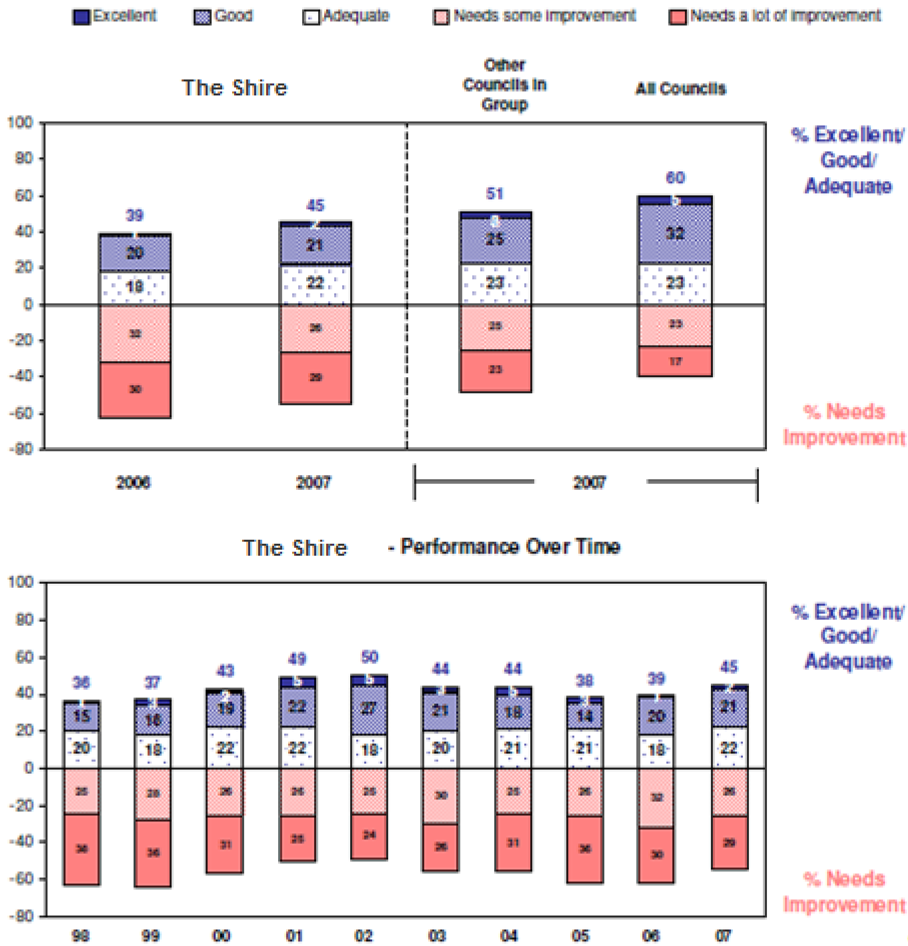
Table 1: Pavement Thickness, Shape and Drainage Shortfall – Categorised by Traffic Volumes

Average Daily Traffic (ADT)	Total Length of Gravel Pavement (kms)	PAVEMENT DEFICIENCY APPROACH 2 Substandard Pavement Thickness (Less than 50mm)		Substandard Surface Shape (kms)	Substandard Drainage (kms)
		Length (kms)	Volume (Cu m)	(Too flat to shed water)	(Table Drains too shallow)
200 – 500 vpd	12.9	2.3	2198	7.1	1.9
100 – 200 vpd	36.6	14.8	11207	14.8	4.3
50 – 100 vpd	121.1	59.6	41840	58.8	21.0
20 – 50 vpd	226.9	148.3	88010	135.7	72.3
Less than 20 vpd	137.2	105.2	53612	100.1	46.5
TOTAL	**534.8**	**330.2**	**196867**	**316.5**	**146.0**

- 103 km of gravel road, or 19% of the gravel road network, effectively have no gravel left – they are down to the clay sub-base;
- 330 km of gravel road, or 60% of the gravel road network, have less than 60mm of gravel, which is well below the desirable 'trigger' for resheeting;
- 425 km of gravel road, or 60% of the gravel road network, have at least a 100mm shortfall below the desirable design thickness;
- 316 km of gravel road, or 60% of the gravel road network, has lost its surface shape such that, if it rains, water will pool and the surface will deteriorate;
- 146 km of gravel road, or 27% of the gravel road network, has inadequate table drains such that, if it rains heavily, the pavement risks collapse.

This pen-picture of the road network is mirrored in resident dissatisfaction. Over the past 5 years, State Government surveys showed that Shire's ratepayers have a higher level of dissatisfaction with roads than with any other service provided by the Shire, and that the Shire performed worst amongst other Councils in its demographic grouping (Department of Victorian Communities 2007).

Figure 2: Community (Dis)Satisfaction with Roads



In 2007, the most recent Customer Satisfaction Survey, 55% of respondents considered that Shire's performance in this area was inadequate. The findings of these surveys are mirrored in the Shire's 'customer request' records. An analysis of 5 years data from the Shire's customer request records found over 650 complaints per year concerning gravel roads, from 250 to 300 residents per year (i.e., some residents raised multiple concerns). Table 2 summarises the reasons cited for their concerns.

Table 2: Key Roads Concerns In Community Satisfaction Survey

Reasons Cited re Need for Improvement in Roads	Number of Respondents 189
More frequent/ better re-surfacing of roads	40
Improve/More frequent grading etc of unsealed roads	19
Improve standard of unsealed roads (loose gravel, dust, corrugations)	17
More frequent/ better slashing of roadside verges	14
Fix/ improve unsafe sections of roads	12
Fix/ improve edges and shoulders of roads	5
Improve/ Fix/ Repair uneven surface of footpaths	28

Table 3: Analysis of Residents Concerns Re Gravel Roads in the Shire: Mar 2003- Jan 2009

	Needs grading	Pot Holes	Dust	Corrugations	Please Seal Road	All issues re Gravel Roads [1]
Letters & Emails	321	586	608	515	455	2080
Telephone Calls	555	869	238	684	82	1851
TOTAL	876	1455	841	1199	537	3931

Notes: 1. Some requests identify multiple issues, hence totals for specific issues do not equal the 'All Issues' total.

With this level of concern, it was decided to develop a model which could relate community concerns to the technical conditions of the unsealed road network and to the level of resourcing. .

Structure of the model

The model is constructed in Powersim Studio (ver. 7.0). The Powersim model is in five parts:

- roughness progression & roughness rehabilitation modules;
- a gravel loss & gravel pavement rehabilitation modules;
- client impact & complaints modules;
- roughness related accident and vehicle operating costs modules;
- net present value module and budget modules.

The model is designed around an array structure which permits analysis on a road by road basis. In this particular example, the Shire identified 530 specific road segments. Some 28 data elements in relation to each segment was imported into the model from an Excel based road register.

Figure 3: Structure of Road Register Data Imported into Powersim Model

	B	F	G	H	I	J	L	M	N	P
1	Road Asset No	Section Length (m)	Section Width (m)	Section Area (m^2)	Init Roughness (IRI)	Time Since IRI Survey (days)	ADT (veh/da)	%HV	Light Trucks as % Trucks	Design ESA
2	Asset Reg	Asset Reg	Asset Reg	Asset Reg	Assumed based on 'Time since Grading'	Set arbitrarily at 'Time since Grading'	Survey Data & Estimated	Survey Data & Estimated	Survey Data & Estimated	Computed based on *source*
3	331	400	2.4	960	12.343194	120	70.0	9.8	1.00	119500
4	529	720	3.5	2520	11.731946	120	30.0	19.7	0.83	112000
5	559	4900	2.7	13230	6.4208686	60	20.0	9.8	1.00	34500
6	264	1710	2.7	4617	10.509923	180	20.0	9.8	1.00	34500
7	572	3450	3	10350	10.196094	120	100.0	2.9	0.91	53500
8	694	1370	3.6	4932	10.893582	120	61.1	6.9	0.81	81000
9	331	220	2.8	616	10.189509	120	67.9	4.7	1.00	56500

	Q	R	S	T	U	V	W	Y	AB	AC
1	Design Pvt Depth (mm)	Init Gravel Thickness (mm)	Init Shape Loss %	Init Drainage Poor %	Time Since Grading (days)	Grading Strategy	Grading Max No per Year	Nos Properties Served	Priority Score Grading	Priority Score Resheet
2	Computed based on *source*	Survey Data 2008	Survey Data 2008	Survey Data 2008	Works Data	Model	Works Data	GIS based analysis	Model	Model
3	240	0	1.0	1.0	120	2	3	10	101	2294
4	240	0	1.0	1.0	120	2	3	5	83	922
5	220	7	0.7	0.4	60	2	3	3	14	168
6	220	0	1.0	0.3	180	2	3	3	29	173
7	230	28	0.5	0.2	120	2	3	15	60	1233
8	230	10	1.0	0.0	120	2	3	9	73	1244
9	230	27	1.0	0.0	120	2	3	10	59	892

In addition there are a number of other initialisation variables maintained in the supporting Excel spreadsheet which are imported into the model, including:

- Climatic data (average monthly rainfall)
- Soils data (average sub-base bearing capacity – California Bearing Ration or CBR)
- Gravel pavement data (gravel size and plasticity index etc)
- Intervention levels for grading or resheeting
- Client complaint data

The model has report modules corresponding to each of the above model modules. In addition, the model exports roughness and pavement condition data to Excel spreadsheet, from where the data is linked to the Shire's MapInfo geographic information system. Using thematic layers it is then possible to produce map overlays, as a means of communicating which roads are likely to suffer distress under specified budget scenarios.

Prioritisation computations module

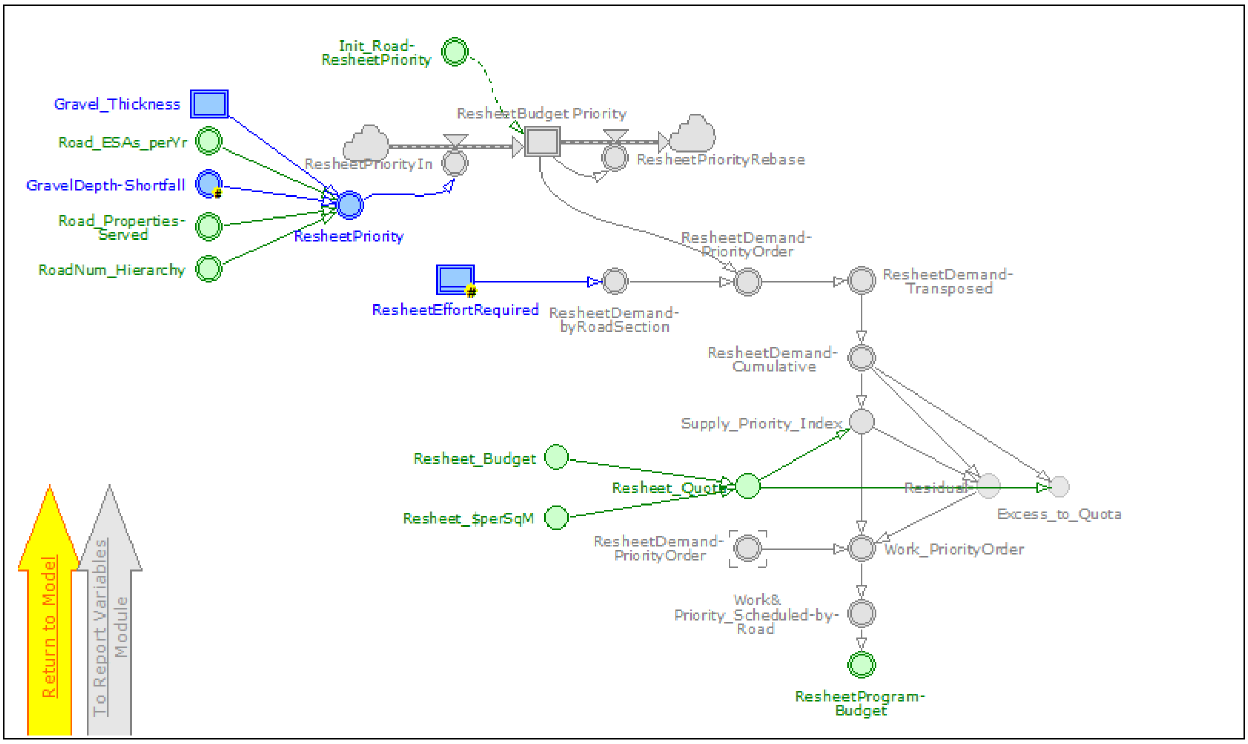
As the model is based on modelling the behaviour of individual roads, rather than an amorphous summary, it was essential to be able to allocate resources to rehabilitating specific roads (for example by grading or resheeting) according to the decisions on priorities applied in practice.

Because priority ordering changes over time, as maintenance work progresses or rehabilitation is undertaken, prioritising sub-models were developed for both grading and resheeting, allowing the model to reassign works priorities at the start of each financial year in a manner consistent with actual practice. (The author has loaded an 'unlocked' version of the prioritisation module into the Powersim User Group Yahoo site.)

(http://tech.groups.yahoo.com/group/powersimtools/files/Design%20Challenge%20%232/ .)

Priorities are re-computed at the start of each year of the simulation, based on actual practice, taking into account traffic counts, % heavy vehicles, whether the road is a school bus route, gravel depth shortfall and number of properties served. Projects are then 'undertaken' in the model on a monthly basis, based on actual work throughput parameters, until the budget is exhausted.

Figure 4: Gravel Resheet - Prioritising Projects Within Resource Constraints



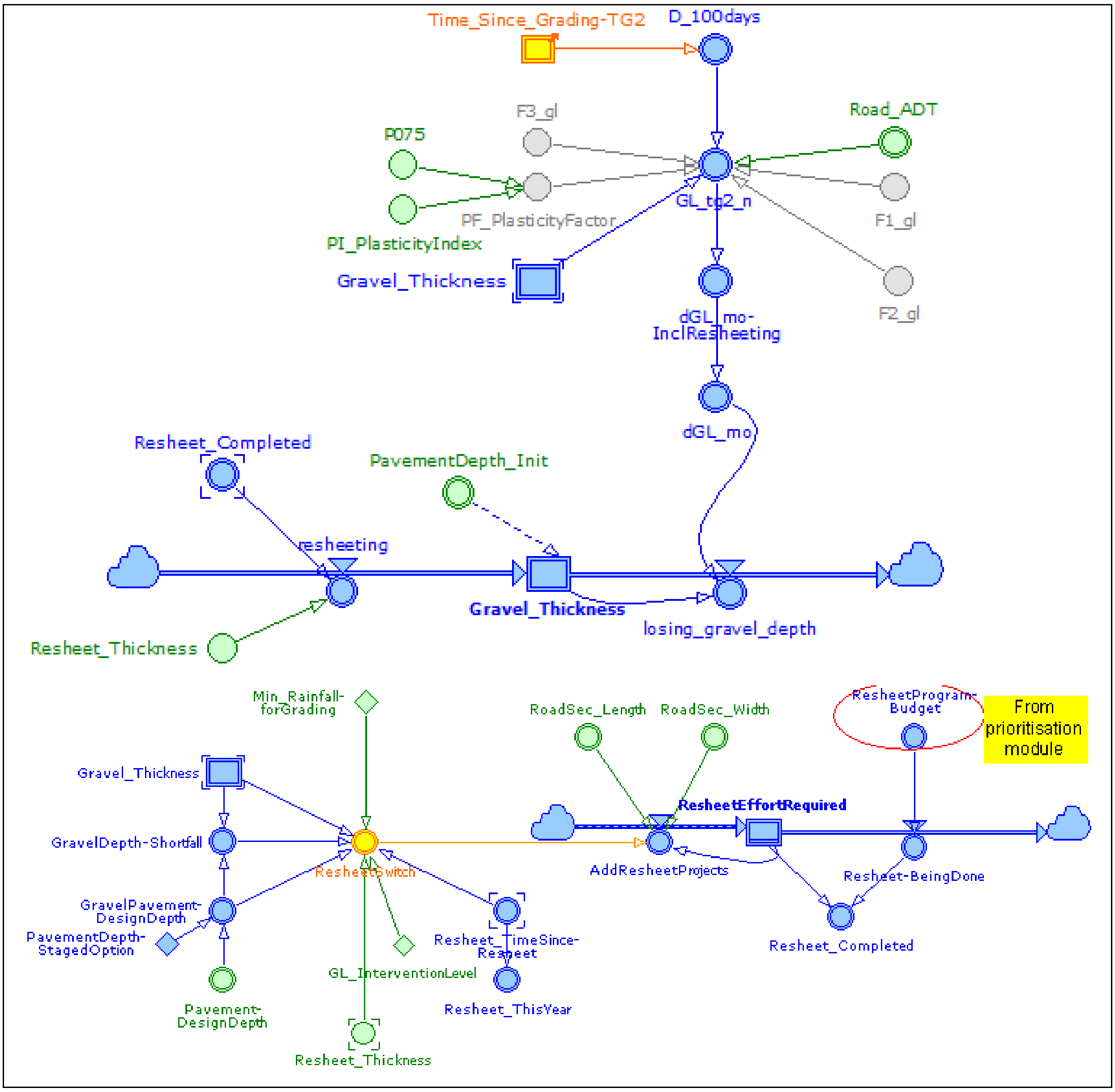
Gravel loss & gravel resheeting (rehabilitation) module

This part of the model does not purport to introduce any new insights into the pavement engineering relationships. These are based on Australian Road Research Board (ARRB) research into roughness (ARRB 2006) and related research embodied in the HDM-4 models (Austroads 2008).

The specific deterioration algorithms in respect of pavement gravel loss used in the Shire study were derived from ARRB empirical research. However, the model is designed such that it can incorporate other pavement deterioration algorithms, such as that used in HDM-4. The data was incorporated into the model to provide an estimate of monthly gravel loss (in mm of pavement depth) for each of the 530 road segments, based on the respective road segment data on traffic volumes, average rainfall and gravel characteristics.

This primary stock in this module is pavement thickness, by road. On average, some 10mm to 12mm of gravel is lost per year as a result of erosion due to traffic, wind and rain. This gravel is replaced by resheeting, subject to budget constraints. Construction practice is that, when resheeting occurs, a 100mm layer is placed. Based on the typical loss rate, this means that, on average, a pavement has a life of about 8 to 10 years.

Figure 5: Gravel Resheet Module

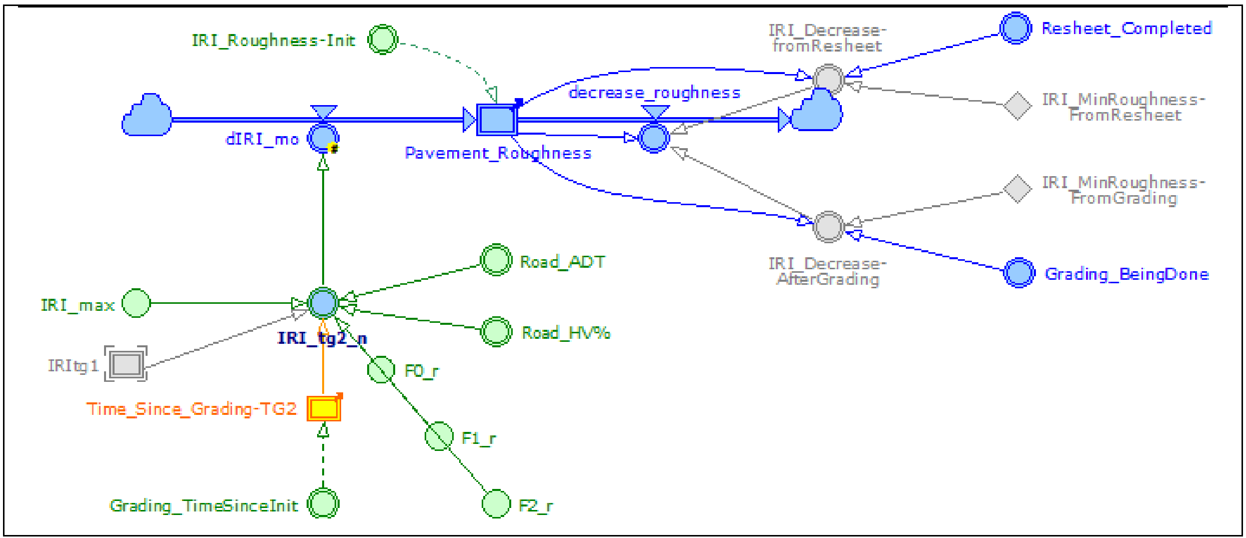


Resheeting occurs provided the ‘Resheet switch’ is set to 1 for the given road (based on gravel depth shortfall, appropriate weather conditions and the intervention levels for gravel depth being met) and when the prioritisation module identifies that resources are to be allocated to this particular road.

Roughness progression & road grading (rehabilitation) module

The roughness progression algorithms were also derived from ARRB empirical research. (Again, the module is designed to take similar models from other sources such as HDM-4.) The data was incorporated into the model to provide an estimate of monthly roughness progression for each of the 530 road segments, based on the respective road segment data on traffic volumes, the percentage of heavy vehicles, mean monthly rainfall etc.

Figure 6: Roughness Progression & Grading Module



The key stock in this module is 'Roughness', as measured by the 'International Roughness Index' (IRI). Roughness is added each month for each individual road by the flow variable dIRI_mo, based on the ARRB algorithms. Roughness is decreased either by resheeting of the road or by periodic grading. In the absence of other research, the effect of grading in decreasing roughness was based on Paterson 1987.

Economic Evaluation (Net Present Value) Module

The costs of the annual grading and gravel Resheet program are simple to identify. The benefits of having a smoother rather than rougher road are more problematic to quantify. The 'benefits', in essence, are the avoided costs associated with, for example:

- Roughness related accidents
- Increased vehicle operating costs and increased travel time related to roughness
- Dust nuisance associated with roughness
- Respiratory disease due to dust
- Costs associated with denial of access in extreme rainfall events ascribable to pavement maintenance policies.

This study only incorporated the first two benefits: reduced accident costs and reduced vehicle operating costs. Figure 7 illustrates the relationship between road roughness and accident rate, and road roughness and the vehicle operating costs of light trucks.

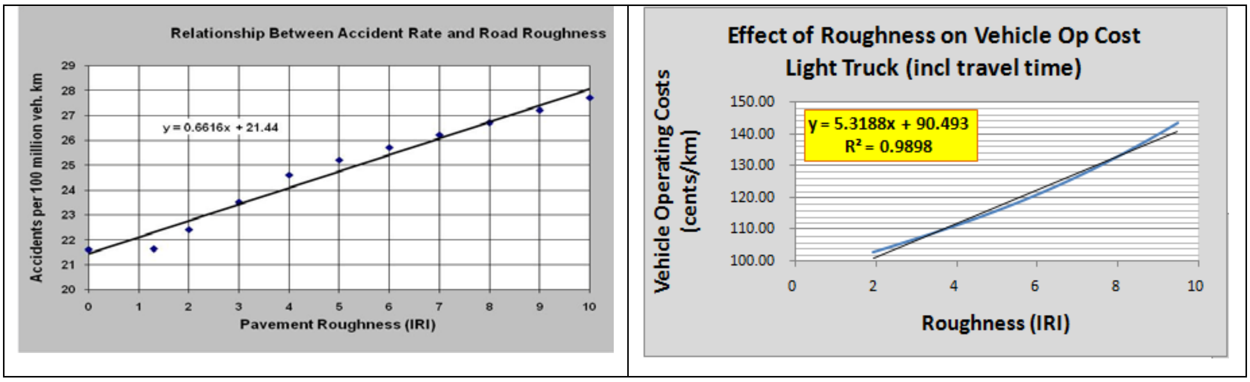


Figure 7: Relationship between Road Roughness and Various Social Costs

Figure 8 illustrates the Accident Rate Module, which computes the expected number of casualty accidents per year, based on the simulated roughness results. These are then compared with that expected were the roughness to be at an 'ideal level' of IRI = 5.

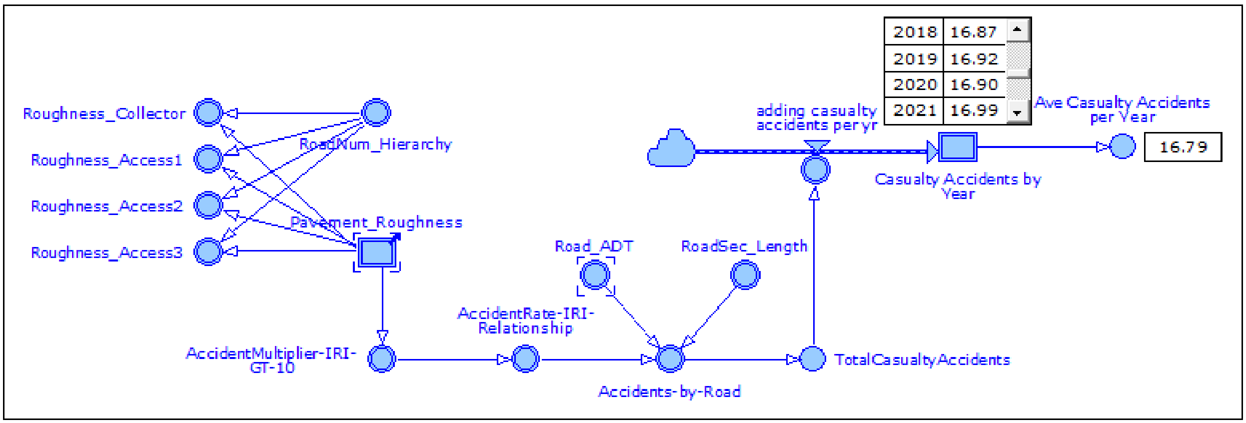


Figure 8: Casualty Accident Module - 'Forecast' increase based on simulated road roughness

Similarly, Figure 9 illustrates the Vehicle Operating Cost Module, which computes the expected increase in vehicle operating costs (including travel time costs) based on simulated roughness compared with that expected were the roughness to be at an 'ideal level' of IRI = 5.

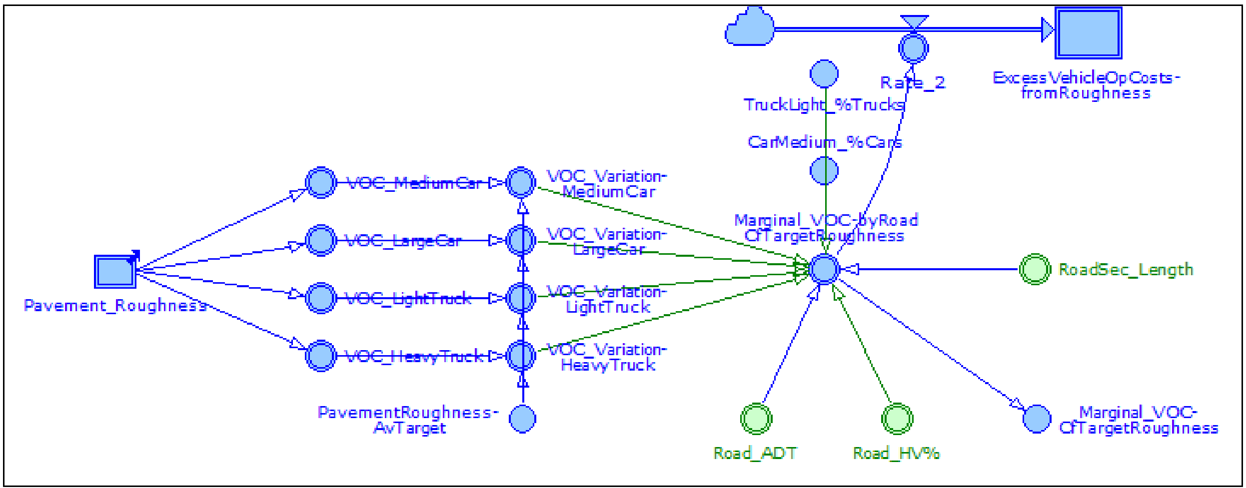


Figure 9: Vehicle Operating Cost Module – 'Forecast' based on simulated road roughness

Use of simulator to communicate basic 'science' of road deterioration & rehabilitation

The simulator can be used as a decision support tool. However, its primary value is in communicating the underlying 'science' of road deterioration and rehabilitation. What factors affect roughness progression? How does wet weather, or drought, affect roughness progression? How much impact does grading have on roughness?

It also has significant value in identifying exactly who (which taxpayers) will be disadvantaged because, for the first time, the decision makers can see which roads and which households will be affected by deteriorating roads.

<u>Effect of grading on roughness</u>

Road roughness is typically measured using the International Roughness Index (IRI), which is a mathematically defined summary statistic of the longitudinal profile of the road surface. IRI is a scale of roughness which is zero for a completely smooth surface, 2 for paved roads in good condition, 6 for moderately rough paved roads, 12 for a extremely rough gravel roads, and up to about 20 for extremely rough unpaved 4-wheel-drive tracks.

Figure 10 provides several qualitative 'word pictures' to enable the reader to understand the implications of the subsequent discussion of gravel road roughness in the Shire.

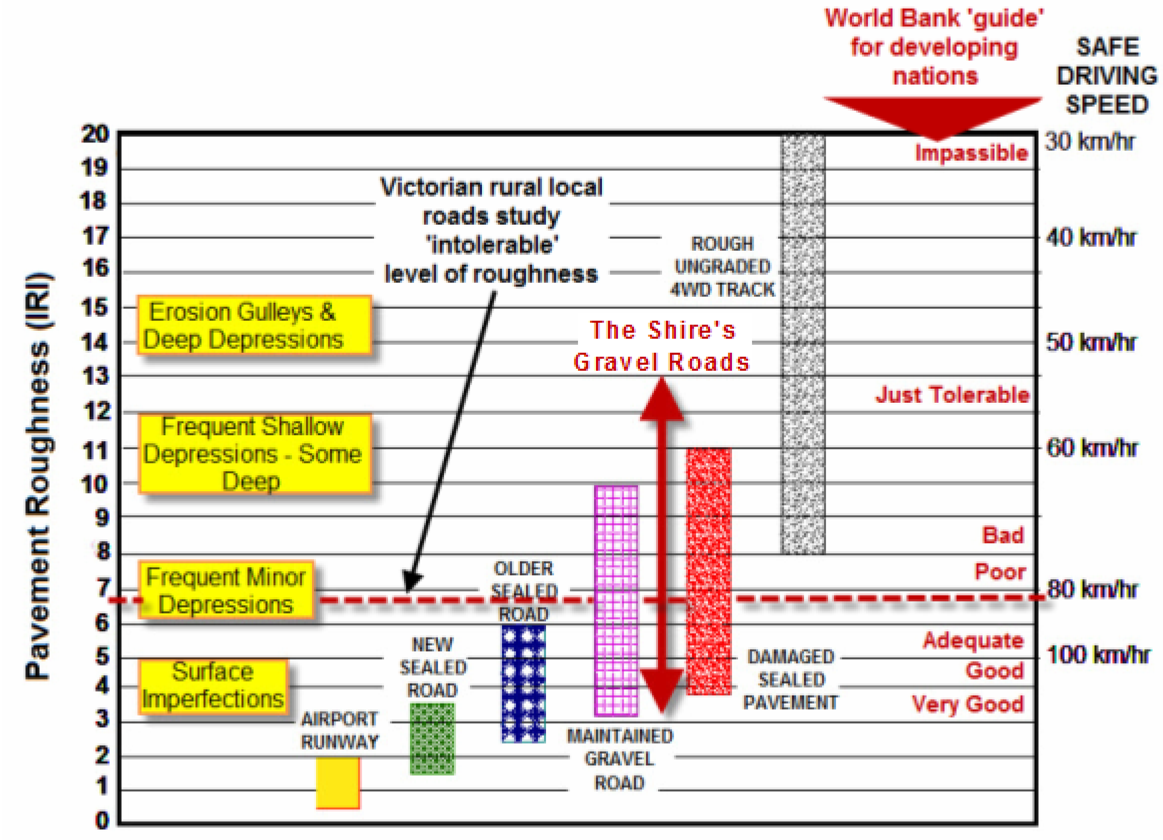


Figure 10: Word Pictures Explaining the International Roughness Index (IRI) Measures[2]

Gravel roads require regular maintenance grading to ensure adequate ride quality and safety. Periodic heavy grading is also required to re-instate the cross-section of the road, reshaping the crown to ensure that surface water does not pond. Heavy grading is also required to remove deep corrugations and significant potholes. For major or extensive defects, ripping, reworking watering and compaction may be necessary.

Regular grading has a disadvantage of loosening up the wearing coarse of the unsealed road and as a result may increase the rate of material loss. Good grading practice, such as grading after rain when the wearing coarse has higher moisture content, is advisable.

Routine Grading in the dry season is of limited effectiveness as the absence of moisture can prevent the reshaped material from 'bedding down' (unless watered at additional cost). More damage can be caused by dry grading than not doing the grading at all.

Figures 11 and 12 illustrate the impact of different traffic volumes on roughness and also the effect of grading.

Figure 11 depicts a maintenance strategy of grading every 6 months, together with periodic resheeting (every 10 to 12 years). We see a typical 'saw-tooth' pattern, where the roughness on the low trafficked road varies from International Roughness Index (IRI) of 5 to IRI of 8, and on the heavier trafficked road from IRI of 6.5 to IRI of 11.

2 William Paterson, *Road Deterioration and Maintenance Effects - Models for Planning and Management.* The Highway Design and Maintenance. Baltimore: Johns Hopkins University Press, 1987.

Figure 11: Effect on Roughness (IRI) of Grading every 6 months

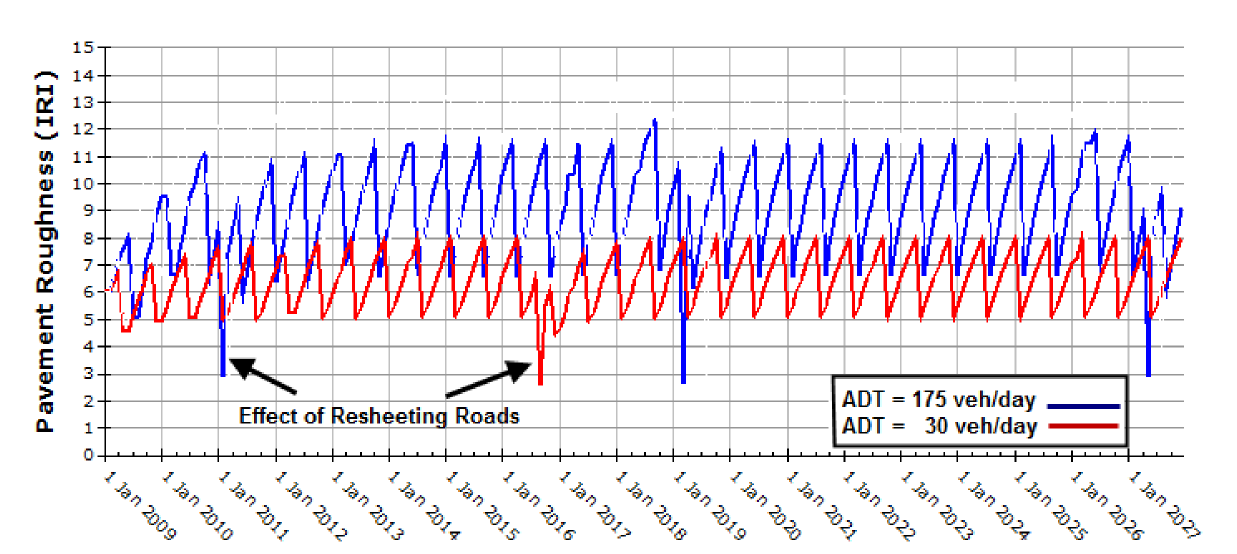
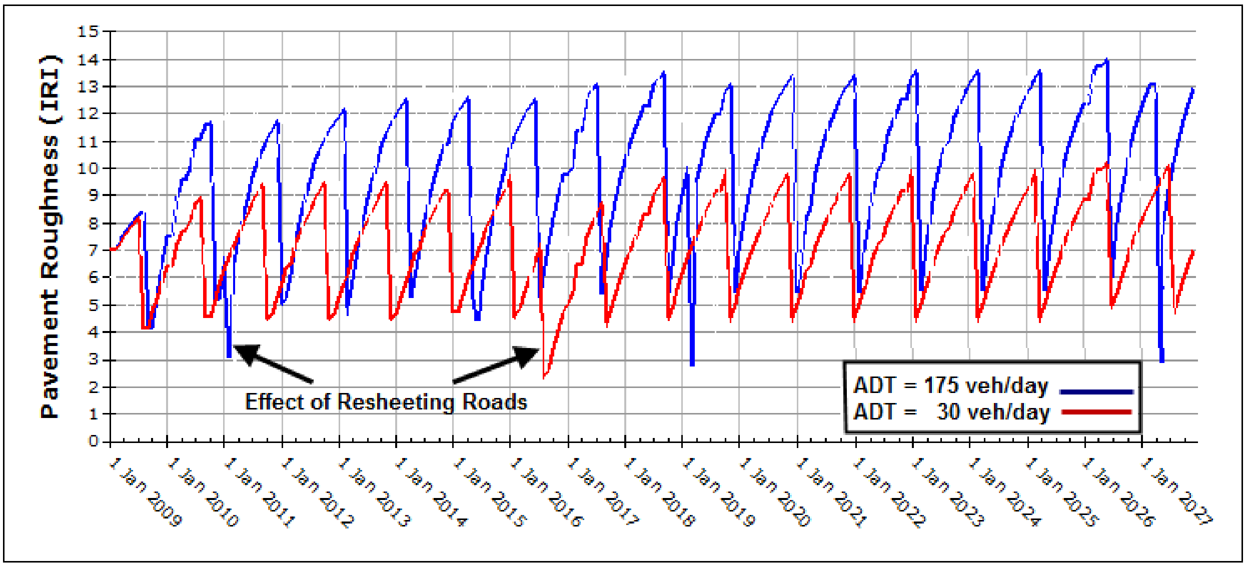


Figure 12 illustrates a maintenance strategy of grading once per year. The consequence is a much greater roughness range for both traffic volume situations, with IRI varying from 4.5 to 9 for the lower trafficked road and from 5.5 to 13 for the higher trafficked road.

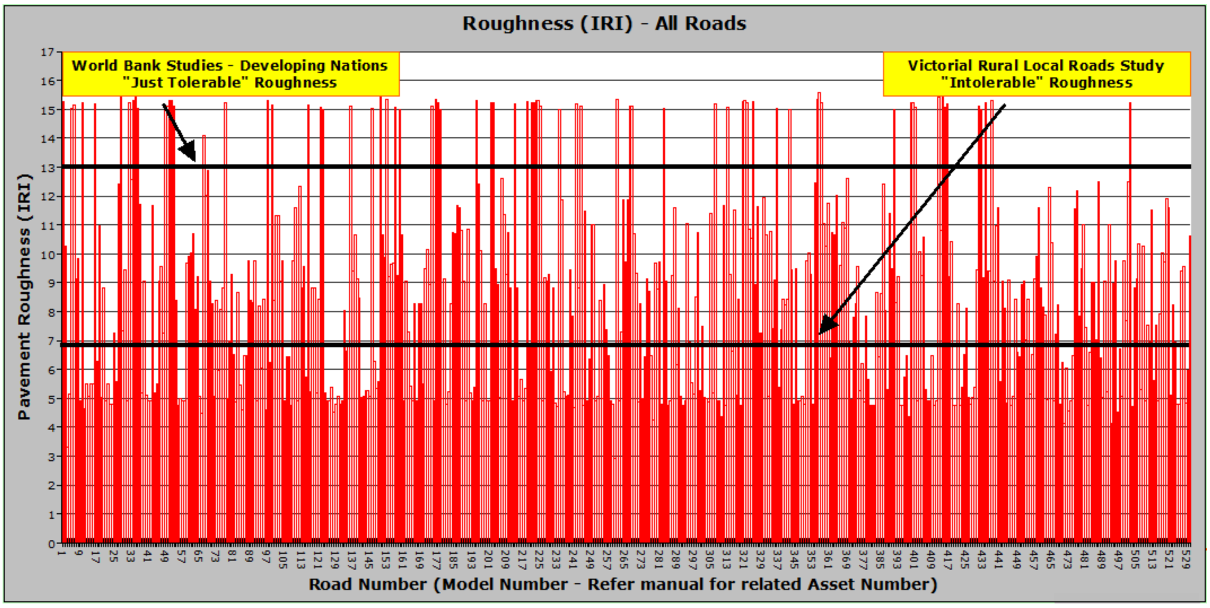
Figure 12: Effect on Roughness (IRI) of Grading every 12 months



These figures also illustrate the fact that grading does not return a gravel road to a smooth status. Typically, grading eliminates about 50% of the difference between the roughness prior to grading and the theoretical minimum roughness achievable from grading (around IRI = 2.5)

Figure 13, overleaf, shows the resulting roughness at the end of the 20 year simulation period based on continuation of current budget allocations. It shows that close on 50% of unsealed roads in the Shire will have roughness levels categorised as "intolerable". In fact, this pattern is fairly representative of every year in the simulation. The current annual budget for grading would have to be increased by 60% to keep the majority of roads below an IRI of 7.

Figure 13: Pavement roughness of 530 unsealed roads – Year 20 based on current budget levels



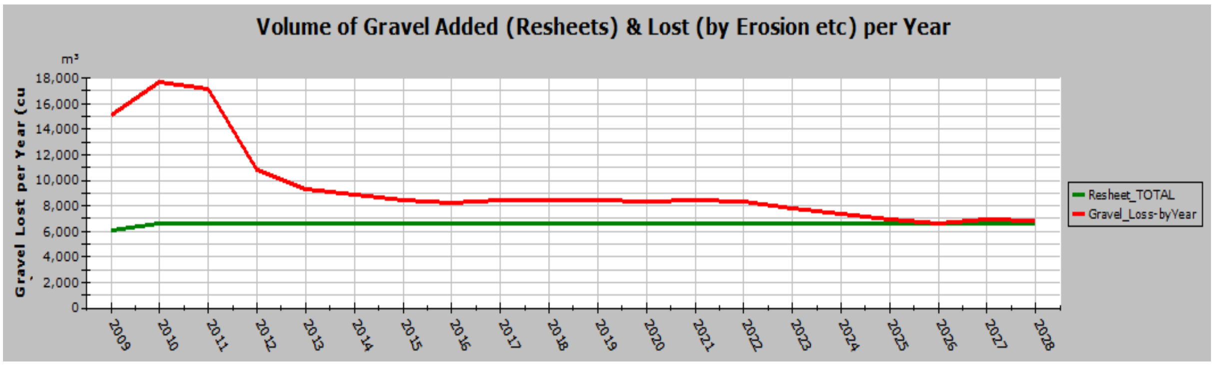
Gravel loss and gravel resheeting

Gravel loss is mainly due to erosion of fine particles in the road base gravel – either as dust in dry conditions or washed off in wet conditions. Larger particles break down under traffic, weathering and grading. The key factors affecting the amount of gravel lost are traffic volumes, rainfall and the gravel characteristics. Gravel loss is higher on steep grades and curves.

As the gravel wearing course reduces in thickness, other developments such as the formation of wheel ruts will generate greater impact on subgrades through moisture penetration, further increasing the loss of gravel. Similarly, loss of shape leads to ponding of water and pot holing, again further increasing the loss of gravel. Ideally, gravel roads should be resheeted when the remaining thickness is between 50mm and 75mm before these additional factors become significant..

Based on continuation of the current levels of funding, the model shows that the volume of gravel placed each year is significantly less than that required for replacement, as illustrated in Figure 14. (In fact, the diagram understates the extent of the gravel loss because, as discussed below, many roads have lost all their gravel. There is no more to lose by erosion.)

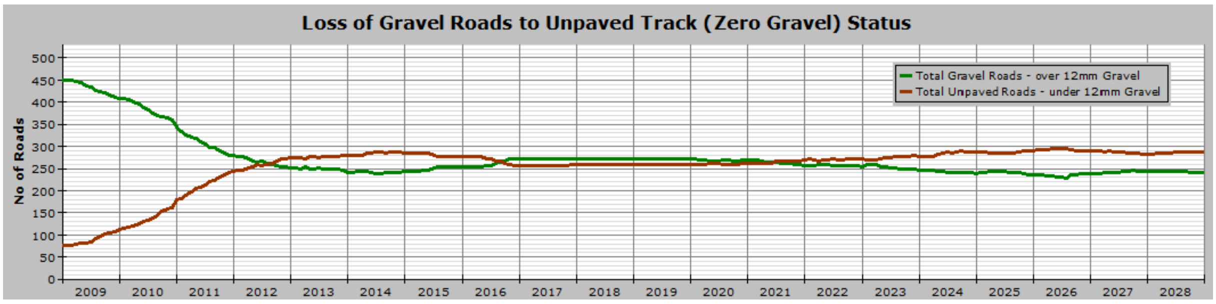
Figure 14: Gravel Added Compared With Gravel Loss per Year- $500K annual Resheet budget



The consequence of this shortfall is dramatically evident in Figure 15, where the number of roads without any gravel left (i.e., that are down to the clay sub-grade) rises from around the current 80 roads to over 260 roads, or 49% of the network within 6 to 10 years.

In fact, the situation is even worse, because a further 100 roads will have only 10mm to 30mm of gravel remaining. Noting that gravel loss tends to be much higher as pavement depth decreases, most of these roads would be down to the clay sub-base within a year.

Figure 15: Transformation of gravel roads to unpaved track status - $500K annual Resheet budget



The real implication of the loss of gravel will not be felt until there is sustained heavy rain. The Shire has been suffering prolonged drought, which at least has the beneficial side effect that a clay track can carry heavy vehicles. Once wet, however, the clay surface quickly collapses, as illustrated in Figure 16, with two such roads in the Shire after the last heavy rains.

Figure 16: Rain and unpaved (clay) roads do not go together

Use of simulator to communicate the social and political implications of resourcing levels

Analysis of resident complaints show that they are strongly correlated with the prevailing weather conditions. In months where there is no rain, dust becomes a major problem, especially where the gravel layer is very thin. On the other hand in wet weather, complaints from households served by roads that are down to the clay sub-grade sky-rocket. Such roads can become virtually impassable overnight, as illustrated in the above photoes.

To capture this characteristic, and to communicate this effect to the decision makers, the model incorporates the stochastic variations in monthly weather patterns into the Client Feedback reports, Figure 19. (Of course the 'prediction' of a flood event next year after 10 years of drought might raise some questions. The model is meant illustrate the impact of weather on client complaints, NOT predict it.)

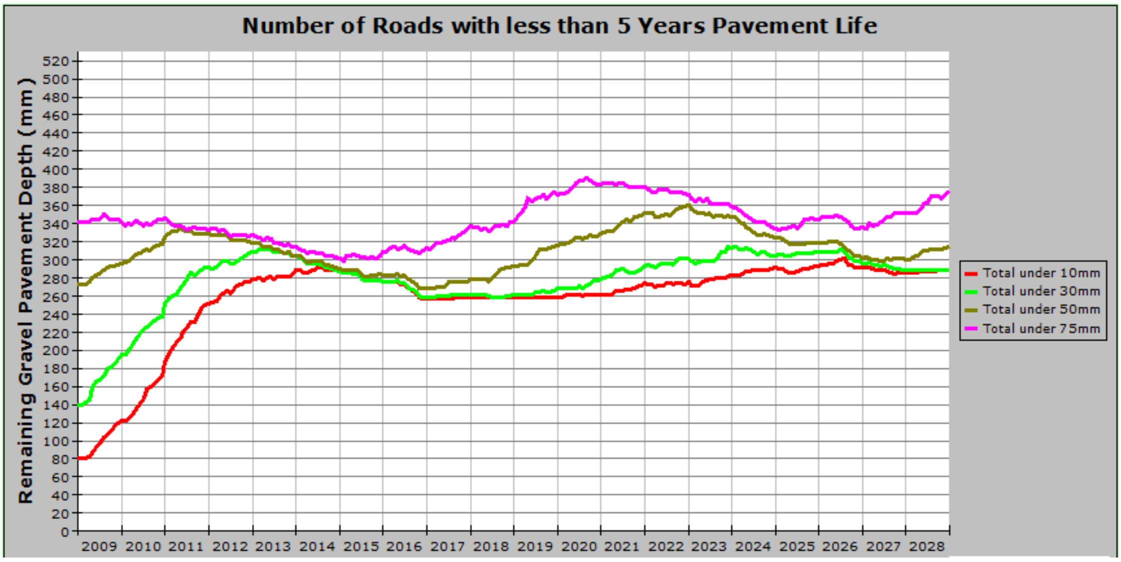
The model permits simulation of alternative budget scenarios, varying either or both the annual budget allocation to maintenance grading (addressing roughness) and resheeting (addressing pavement thickness, and hence strength). For each scenario there are a variety of outputs geared especially to the political decision makers.

System Wide Presentation of Consequences

The outputs are in two categories. Average system –wide outputs which serve to illustrate how the Shire's assets overall are faring. This is a useful basis for comparison with other Shires to compare how well the community's resources are being managed. Figures 17, 18 and 19 are typical system wide outputs to assist decision makers understand the implications of their decisions.

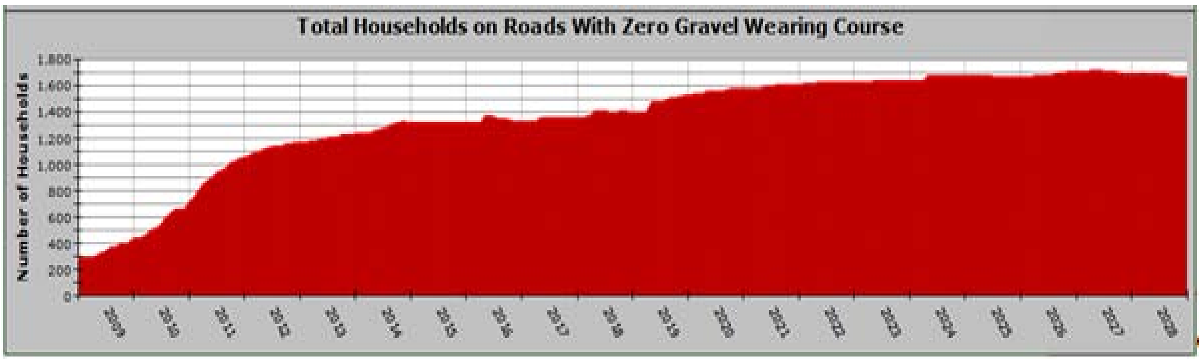
Figure 17 suggest that within 6 to 10 years, at current budget levels, the number of roads with effectively zero gravel will increase from 80 (15% of the network) to 260 (49% of the network). Because of the stock of roads with very low pavement thickness, this shortfall is not eliminated over time. At $500K annual Resheet budget, the equilibrium level of clay roads will be between 260 and 280 out of 530 roads.

Figure 17: Roads with minimal remaining gravel depth – Annual budget $500K p.a.



This, of course, translates into affected households (and affected voters). Figure 18 indicates the approximate number of households which will be affected by the loss of all gravel, i.e., by roads that are down to the clay sub-base. .

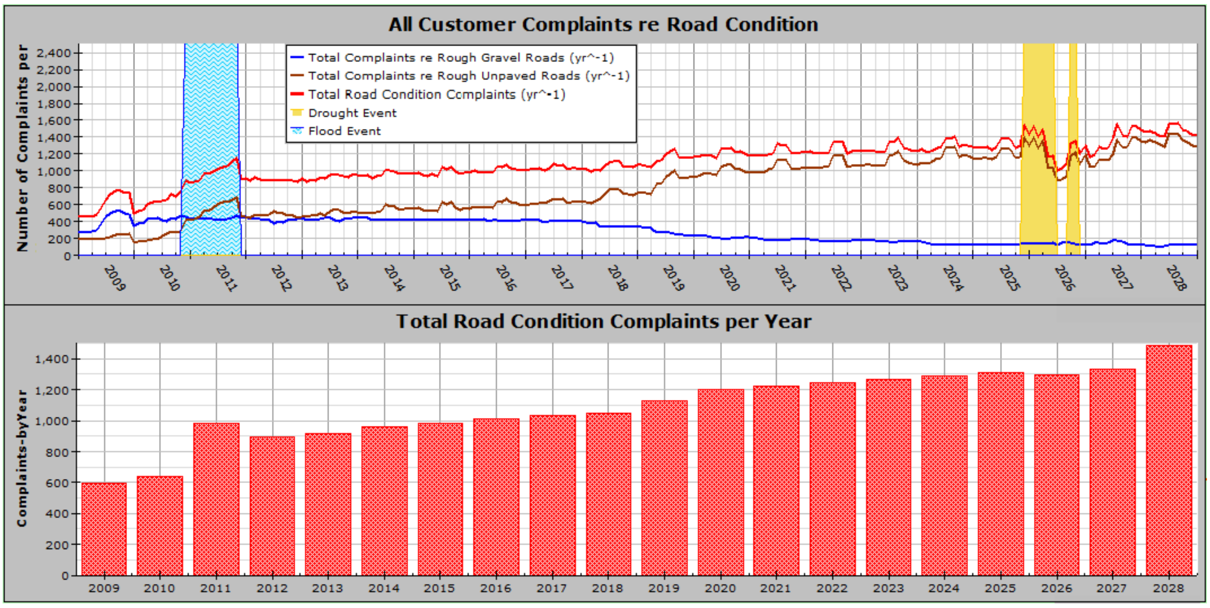
Figure 18: Effect on Households of Loss of Gravel Wearing Course – Annual budget $500K p.a.



The loss of gravel, and the resulting increasing road roughness and dust, in dry weather, and boggy conditions in wet weather will be reflected in the level of customer requests for remedial action. Two wet weather 'events' in Dec 2004 and Feb 2005 generated almost 150 customer requests, compared with the average annual total of 600. With almost 3 times the number of roads down to the clay sub-grade, compared with 2005, a dramatic escalation in complaints is expected. Similarly, the general level of complaints will rise as the gravel wearing course on many roads disappears, and grading has little lasting effect on roughness.

This is illustrated in the charts in Figure 19 which suggest the expected pattern of taxpayer complaints as the roads deteriorate over time if current budget levels continue. The simulation suggests a steady increase in resident complaints, with complaints more than doubling over the 20 year time horizon.

Figure 19: Customer feedback on road conditions – Annual budget $500K p.a.

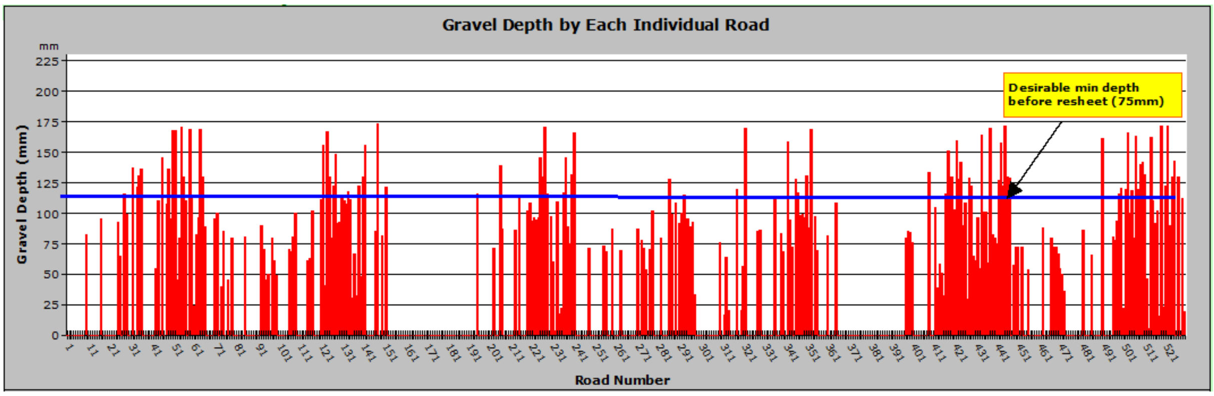


<u>'Personalised' Presentation of Outputs – Naming the Affected Roads</u>

The model produces as an output not only 'anonymous' average results, but the likely outcome for individual roads (based on the adopted prioritisation criteria). The elected politicians are thus confronted with the pattern of outcomes in their particular Ward (electorate). This is produced in graphical and tabular form and also, through linkage of Powersim to MapInfo, in map form.

Thus, Figure 20 shows the expected situation after 6 years, where almost 50% of the roads are down to the clay base. The difference in the information content, however, compared with Figure 17 is that the affected roads can be identified.

Figure 20: Scenario 1 - Gravel depth by Individual Road after 6 years – Annual budget $500K p.a.



In the chart above, one needs a key to link the road number to the road name. However, the model exports a table to Excel spreadsheet tabulating roads by township by electorate. Figure 21 shows how the data is presented to Councillors so that they know precisely which roads in their electorate are likely to be affected by different annual budget levels.

Figure 21: Putting names to the consequences – Tabulating the 'failed' roads

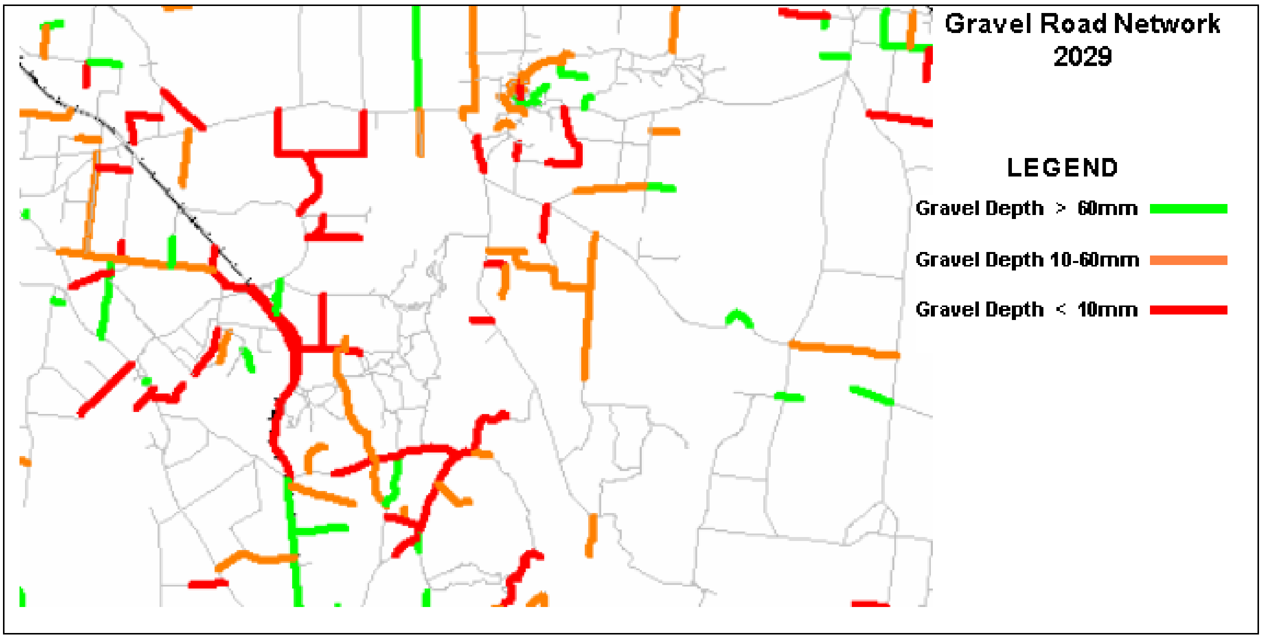
Scenario 1: Current Funding Levels ($500K per year)

Xxxxxx Ward (88 roads With Zero Gravel (I.e., down to clay surface) by 2027)

Road	Township	Road	Township	Road	Township	Road	Township
Ανδρεωσ	Βαλλαν	Βλαξκσ	Βερεμβοκε	Ωαρδσ	Ελαινε	Ηαστινγσ	Μουντ Εγερτον
Βαλλανεε	Βαλλαν	Ξουροψ	Βερεμβοκε	Λεννοχσ	Φισκcιλλε	Λιλλισ	Μουντ Εγερτον
Βραδσηαω	Βαλλαν	Γοςερνμεντ	Βερεμβοκε	Γιλλετσ	Ινγλιστον	Λιττλε Φορεστ	Μουντ Εγερτον
				Ingliston			Mount

Finally, the model is set up to export both roughness data and data on remaining pavement depth to Excel spreadsheet. The spreadsheet is linked to a MAPINFO table, permitting the graphical display of the simulation outputs. This is illustrated in Figure 22 where the red lines indicate roads that have lost all gravel, orange lines indicate roads that will be down to the clay sub-base within 2 to 3 years, and green lines indicate roads with gravel depth greater than 60 mm. This may be even more meaningful to elected representatives than collections of tables and graphs.

Figure 22: Simulation Roughness Results Linked to GIS



Using the model – Findings from 'what if' budget scenarios

The model shows that the Shire faces a very dramatic resourcing problem. Continuation of current budget policies will reduce half the gravel road network to clay track status within 6 to 10 years, with disastrous consequences for access to many properties when heavy rains return.

Just to keep the road network in its current condition over the next 20 years requires an annual lift in budget resourcing to 225% of the current budget ($1,125,000 p.a. compared with $500,000 p.a.).

In order to eliminate the backlog which has resulted from years of underfunding will require an annual lift in resourcing to 300% of the current budget (1,500,000 p.a.).

The model has already been used to revalue the gravel road asset for accounting purposes and to identify the corresponding depreciation based on replacement cost. Hitherto, the Shire accounts used a simple straight line depreciation for gravel roads based on a 20 year life. The modelling suggested that actual depreciation (i.e., loss of gravel thickness) was proceeding at double the accountant's depreciation rate.

The model will be used in future budget negotiations to argue for significant increases in both maintenance grading and resheeting funding.

Model Limitations

This simulation model does not purport to predict the future, especially when the relationships are so dependent of climatic conditions. It does, however, provide a powerful basis for identifying trends in outcomes based on alternative policies with respect to resource inputs. The resourcing shortfalls in current budgets are so significant that the uncertainties in the modelling process pale into insignificance.

Conclusions

This paper has discussed the application of system dynamics modelling to the management of the road maintenance asset. From the work thus far the following advantages can be claimed for SDM over more traditional statistical correlation modelling:

- By focusing on key stocks (especially amount of gravel on the roads) the implications of years of underfunding become evident, and the lengthy time frames to redress the situation can be understood.
- The graphical interface makes apparent the relationships between key variables for the decision makers;
- "Soft" (qualitative) data, which is important in the decision making, can be readily incorporated into the model.
- The fundamental feedback relationships in this particular system are the technical advisors using the simulation model to provide advice, in politically and socially relevant format, to the elected policy makers, based on scenarios they identify.

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