Road maintenance management

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The international study of highway development and management, soon to deliver HDM4 (a highway development and management model), provides this paper's perspective on road maintenance management in which many disciplines need to share resources. A primary requirement is an objective prediction of the consequences of road investment decisions, but it is also a requirement that the application of new techniques must integrate with current practices. This provides a clear indication that the way forward needs the flexibility of a modular approach. Common databases, shared between different professionals, will aid integration. The traffic module developed for HDM4 is described in sufficient detail to illustrate the themes.

HIGHWAY and traffic engineering, once combined as a single area of study, is now divided into a number of specialized areas. Clear distinctions have to be made between traffic planning, traffic management, highway engineering, highway management, etc., and whilst this leads to better understanding of details, it has its dangers. One danger is duplication of effort, another is lack of balance in attention and investment.

Examples of duplication of effort are easily found. The highway engineer establishes a database of information about the road network whilst the transport planner also establishes databases of information relevant to the particular activity and inadequate for both. The 26th International Symposium on Automotive Technology and Automation presented a session to which the present authors contributed[1], aimed at drawing attention to the variety of databases being established, each for a specific purpose.

Another aspect of transport is that it is a highly political activity. The research effort of the Highways Group in the University of Birmingham over the past two decades has been aimed, in a sense, at reducing the political element in highway maintenance budget allocation. Figure 1 has featured in a number of publications by group members[2], and seeks to illustrate the problem of the two views of the road network. The local district engineer, responsible for repair projects on one part of the network, is represented in the upper row of Figure 1. He sees the need for repair work and believes that if the money is not spent on the projects now, then satisfactory repairs will be more costly in the future. Generally, the budget falls short so some projects are left undone. This is the project view of road maintenance.

On the other hand, the overall cost of provision and maintenance of roads has traditionally fallen upon the government, possibly supported by aid agencies. The lower row of Figure 1 represents the budget driven, network view of road maintenance in which economics and politics, rather than engineering, are the instruments which will determine the overall budget and the specific allocation to the local district engineer. If the consequences of both project decisions and network decisions were better understood, then those decisions may serve the nation better.

The introduction of private finance initiatives introduces another layer of demand for predictive methodologies. Investors require financial forecasts that inspire confidence and these will be based on appropriate engineering techniques and methodologies.

The perspective offered by this paper is that it is rational road investment appraisal that is needed. A common concern to cater for traffic provides a unifying theme between the various specialized areas involved in road transport. Hence the provision of a single traffic database, relevant to all professionals concerned with road traffic, is an important component of a more integrated approach. An attempt to develop such a database is described in some detail.

Road investment appraisal

The World Bank coordinated the research leading to the Highway Design and Maintenance Standards Model because of the need to compare road investment projects in different countries on a common basis. HDM-III, described by Watanatada *et al.*[3,4], is the most widely-used version, and the aim is to predict the costs directly associated with roads. The construction costs for a new road are easily calculated once the design standard is known, and these may be supplied to the model. However, the design standard will depend upon the predicted traffic and both design standard and predicted traffic will influence the rate of deterioration and hence the maintenance costs. It will also be appreciated that as a road deteriorates, the roughness increases leading to increases in journey times, fuel costs and vehicle maintenance costs. These costs incurred by road users over the life of a road are now known to be the largest proportion

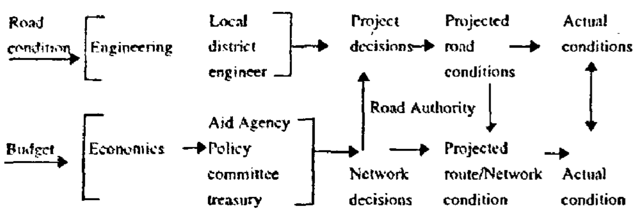

Figure 1. The project and network views of road maintenance.

of the costs to be included in the appraisal. HDM-III models the interactions between road, pavement and traffic to provide annual predictions of deterioration and vehicle operating costs for a given construction standard of a road maintained according to a given regime.

As different designs and maintenance standards may be modelled, it is possible to use the model as a tool to explore alternative construction standards and maintenance regimes. In this way an optimum may be found, and it seems reasonable to suggest that the optimum over the whole life of a road is that which minimizes the sum of the construction, maintenance and vehicle operating costs. The Overseas Development Administration, the Asian Development Bank, the Swedish National Road Administration and the World Bank are co-sponsors of an international study to develop HDM4, but the initials now stand for Highway Development and Management.

Pavement management systems

The definition of a pavement management system (PMS) as *the process of coordinating and controlling activities required to maintain pavements so as to make the best possible use of resources available... and maximise benefits to society*[1] is quoted from a textbook by Haas and Hudson[5] and whilst their book[6] moves to more precise definitions of pavement management, a pavement management system and total pavement management systems, the economy of the earlier definition best serves the current purpose.

Many computerized decision support systems are regarded as types of PMS. Some systems are primarily designed for pavement maintenance management, others for storing highway information. A common feature is that any prioritization of maintenance projects is concerned only with the forthcoming financial year and is based upon budget allocation arising from the network view. Historical practice is more likely to determine the outcome than a realistic appraisal of future needs.

Road management system (RMS) is a description that includes the function of planning and design that were omitted from the earlier definitions of a PMS. In addition, maintenance, monitoring and audit functions necessary for evaluation of a road network are included in a RMS, in order to demonstrate that the best possible use of resources has been achieved. It is necessary to define the objective and role of each component of a RMS, taking a systems approach in which the interactions between people, resources, activities, information and outcomes are considered.

It should not be assumed at this stage that the functions of many of the components would be achieved by computer software. The final methodology must be compatible with the structure of the organization and the available resources. It is important to concentrate on the information flow, what data is collected and the uses to which it is put, a process that should also highlight the deficiencies.

The road management process

It has to be recognized that the process is applied to an existing road network. New construction is generally a small part of the whole, but it does need to be considered within the broader context. The objective is to apply sound knowledge about the road network and its users in order to *make the best possible use of resources available and maximise benefits to society.* The main factors may be summarized as follows.

Inventory. The purpose of the inventory data is to establish what there is to be managed and where it is located.

Condition. The condition of a road needs to be measured or assessed with sufficient precision to enable the need for repair or replacement to be established within a framework of priorities.

Traffic. The purpose of the road network is to carry traffic. The amount of traffic on a particular road is an important factor for establishing priorities for repair or replacement. The amount of traffic also contributes to deterioration.

Deterioration. All roads deteriorate. It is the rate at which deterioration will take place that needs to be understood as an essential element of a long-term road maintenance strategy.

Costs and benefits. These are the basis of prioritization within a road management system that aim to *maximise benefits to society* rather than respond to political pressures.

Resources. We define these to be the physical constraints including people and their abilities together with the equipment and materials.

Budget. This provides the financial constraint that limits repairs and replacements. The overall budget is likely to be subdivided into allocations for specific subnetworks such as main roads and secondary roads. The RMS should aim to advise on overall budget and allocations within that budget in order to achieve long-term goals.

Standards and policies. These reflect the long-term plans and will be developed by predicting the future network condition in response to different budgets, different traffic predictions and different standards and policies.

Management information. Effective decision-making and subsequent audit depend upon the quality of information. All the information involved in the various components of the system must be readily available and in appropriate form for each of the management functions.

A modular approach

There are compelling arguments for developing separate modules to provide for each function of a RMS. Different road authorities have different administrative structures and a modular RMS can be decentralized to correspond with the administrative division of responsibility. Furthermore, a modular structure will enable individual components to be implemented in a phased programme. It is argued that the required integration can be achieved through a common data source which then needs very careful consideration in order to address all the needs.

Existing PMS provide a number of the required modules, but they are incorporated into a single system in a particular way so there is a loss of flexibility. Operation of the PMS may become a separate function, divorced from the people who perform the various activities involved in each of the components, a situation that is unlikely to be beneficial. A PMS developed for a western country may be inadequate for a country with very different traffic characteristics and administrative structure.

A traffic module

The principles that this paper seeks to promote are perhaps best illustrated by discussing the specification of a module to handle the traffic knowledge required by a RMS. The results of economic analyses are quite sensitive to traffic data, as most benefits that justify road improvements arise from savings in road user costs. Traffic characteristics of roads therefore need to be represented with appropriate accuracy and detail in order to cater for economic analyses.

The new HDM4 will offer tools in separate modules for project analysis, programme analysis and strategy analysis. Project analysis requires a detailed representation of traffic characteristics on the road being analysed. For each road section, the data should include items describing the changing traffic composition and volumes, axle loadings, capacity and speed-flow relationships, hourly traffic flows, traffic induced by road improvements, and demand shifts. These sets of traffic data may need to be specified separately for each lane of the carriageway.

The required traffic data for programme analysis are similar to those for project analysis, with the exception that the data are at a more aggregated level. For example, traffic volumes may be specified by vehicle class and several road sections with similar characteristics may use the same data group.

Strategy analysis requires the specification of an aggregate set of traffic data, representative of a group of road sections in the analysis. Traffic levels should be expressed in terms of daily flows, and may be described as low, medium or high. The composition of traffic may be expressed as a percentage of daily flow for each vehicle class/type.

For the purposes of representing traffic characteristics both for project and network level analyses in HDM4, road links within a network must be categorized according to the following.

Road type (single lane, four lane, motorway, etc.) This is used to determine the parameters for capacity, speed-flow relationship shape, width effects and passenger car space equivalents for each road type.

Predominant road use (commuter, recreational, inter-city, etc.). This is necessary for describing the patterns of traffic flow along each road category; commuter routes tend to have weekday peaks but low weekend traffic whereas recreational routes have a more peaked distribution.

Road-side friction. This is a measure of the effect of road-side activity on traffic speeds. It includes the effect of pedestrians, land use, road-side stalls, bus stops, parking, etc.

The vehicles that use the road network also need to be systematically categorized as motorized transport and non-motorized transport. Each category will comprise vehicle classes (cars, trucks, buses, etc.) and each class will comprise types (light trucks, medium trucks, articulated trucks, etc.).

Data types

The traffic data types, required in HDM4, may be considered under the following headings.

Traffic categories. Traffic falls into three separate categories, normal traffic, diverted traffic and generated traffic. It is important to assess the economic benefits of each category separately, as the benefits associated with each category may need to be handled differently. Normal traffic is that traffic which would pass along the road in the absence of investment. Diverted traffic is the traffic that changes from another route or another mode of transport to the project road. Forecasting diverted

Comparison of road and vehicle fleet sizes

Country	Inter-urban express-ways (km)	Estd% toll roads	National highways ways (km)	Number of vehicles	Length of express ways (km per 1000 vehicles)	Length of highways (km per 1000 vehicles)	Total area (000 sq km)	Density of expressways (km per 000 sq km)	Density of highways (km per 000 sq km)
USA	83,964	7%	737,702	184,397	0.46	4	9,373	8.96	78.71
Japan	4,407	90%	51,212	55,097	0.08	1.26	378	11.66	135.48
West Germany	8,721	0%	39,829	31.588	0.28	1.28	249	35.02	159.96
France	6,950	81%	35.450	27,598	0.25	1.94	551	12.61	64.34
Italy	6,083	90%	51,862	26,801	0.23	0.71	301	20.21	172.3
United Kingdom	2,993	0%	15,574	22,031	0.14	6.92	230	13.01	67.71
Brazil	–	n/a	115,970	16,606	–	5.45	8,512	–	13.51
Argentina	1,231	n/a	36,928	8,324	0.15	7.06	1,969	0.63	23.04
Mexico	378	n/a	43,379	5,233	0.07	7.62	2,792	0.14	13.23
India	93	0%	33,689	4,423	0.02	5.99	3.290	0.03	13.24
Indonesia	198	–	13,140	2,193	0.09	7.76	1,919	0.1	6.85
Thailand	88	–	16,902	2,179	0.04	6.78	514	0.17	32.88
Korea	1,550	–	13,805	2,035	0.76	13.28	99	15.66	139.44
Egypt	–	–	18,300	1,378	–	–	1,000	–	18.3
Kenya	–	–	14,288	–	–	–	583	–	24.51

Source: *The India Infrastructure Report*, Ministry of Finance, Government of India, 1996.

traffic can be difficult and estimates should be based on external traffic demand models developed by transport planners. Generated traffic is defined as additional traffic that occurs in response to the road investment. It is also difficult to forecast as the main effects may be well into the future, following other developments resulting from the initial investment in the road.

Traffic composition, volumes and growth rates. The proportion of different types of vehicles which use the road is the traffic composition and this gives information about road deterioration, the estimation of vehicle operating costs, travel times, accident rates and the development of economic analyses and comparisons.

The existing traffic volumes on the road being analysed are specified in terms of vehicle type or class, depending upon the analysis being performed. The annual average daily traffic (AADT) is the single figure baseline flow for each type or class and will have been estimated from traffic counts.

Traffic growth will have a major effect on the predicted benefits for a scheme and changes in traffic composition over time can be effected by specifying different growth rates for each vehicle type/class. A negative growth rate may be used to phase out a particular vehicle class, and so change the composition. It should be noted that inaccuracies in predicting future growth rates will have a major influence on any analysis and it must therefore be recommended that the sensitivity of results to growth rates be explored.

Axle loading. The damage caused by the passage of an axle is approximately proportional to the fourth power of the axle load. The prediction of traffic impact on road deterioration therefore requires more than a single measure of axle load. HDM4 requires

– The number of 'vehicle axles' (YAX) defined as the total number of axles of all vehicles traversing a given link in a given year, and
– The number of 'equivalent standard axle loads' (ESAL) on each link for each year of the analysis period.

Road capacity and speed–flow relationships. The economic consequences of road capacity improvements may only be fully assessed if the effect of road capacity on speed is known. Speed–flow relationships may be determined in a wide range of conditions from three parameters. These are the capacity of the road, the free speed and the speed at capacity.

Passenger car space equivalents (PCSE), as discussed by Hoban *et al.*[7] are used in HDM4 in congestion modelling. These are based on the space occupied by a vehicle and not the delay which a vehicle causes to other traffic, as the speed-flow model in HDM-4 takes account explicitly of speed differences between the various vehicles in a traffic stream. PCSE factors vary with road type, narrow roads requiring higher PCSE values. Work on Indian mixed traffic, such as that of Ramanayya[8], suggests that separate computer models may be required to provide adequate precision in the analysis for Indian conditions.

Hourly flow-frequency distribution. Traffic congestion varies with the time during any given day and on different days in the weeks and year. This variation is modelled in HDM4 by defining the distribution of hourly flows over the 8760 hours in the year. The AADT data may then be converted to hourly flows and congestion analysis may be undertaken for a number of representative hourly traffic flow levels and the results aggregated to be representative of the year as a whole. Special care is needed with the highest hourly flow levels: provision has been made to model periods within the hour.

Demand shifts. Congestion and/or capacity changes, perhaps caused by changes in road surface quality, may lead to travel demand shifts. The three different types of demand shift are traffic diversion, traffic suppression and peak spreading. These are inter-related and difficult to deal with. Traffic diversion may be estimated, as stated previously, by using dedicated traffic assignment models. Traffic suppression occurs when there is no alternative route to accommodate diversion from a congested route. Peak spreading will occur when users reschedule journeys to avoid the worst of the congestion. The economic impacts of traffic suppression and peak spreading are difficult to estimate fully.

It may be useful to establish an interaction between traffic demand/planning models and road maintenance models, with demand models comparing alternative routes, modes and infrastructure capacity using speed and user cost information computed from the road maintenance models, based on the detailed traffic information provided by the demand models.

Discussion and conclusions

The paper proposes that there is a need for greater co-operation between the specialized areas involved in the provision of roads and road transport. It is not concerned with the even wider view implicit in any concept of an integrated transport policy. It is argued that well-established definitions of PMS neglect the planning and design that precede the construction of new roads and the whole-life approach to optimization.

If the ideas in the approach now put forward within the framework of a RMS are to be adopted, then they must first interface with and then extend existing practices. A modular approach is indicated in which the greater co-operation between the specialized areas may be achieved by the careful design of common databases.

The traffic module that has been developed for HDM4 is described in some detail to illustrate the theme. Traffic data must be available at different levels of aggregation within a common framework if a single database is to meet the requirements of engineers, planners and economists.

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