UNIVERSITY OF BIRMINGHAM

University of Birmingham
Research at Birmingham

The benefits of sustainable road management: a case study

Burrow, Michael; Evdorides, Haralampos; Wehbi, Mohamed; Savva, Melissa

DOI:
10.1680/tran.11.00075

License:
None: All rights reserved

Document Version
Peer reviewed version

Citation for published version (Harvard):
Burrow, M, Evdorides, H, Wehbi, M & Savva, M 2013, 'The benefits of sustainable road management: a case study', *Institution of Civil Engineers. Proceedings. Transport*, vol. 166, no. 4, pp. 222-232. https://doi.org/10.1680/tran.11.00075

Link to publication on Research at Birmingham portal

Publisher Rights Statement:
Checked 12/09/2016

General rights
Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

•Users may freely distribute the URL that is used to identify this publication.
•Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
•User may use extracts from the document in line with the concept of ‘fair dealing’ under the Copyright, Designs and Patents Act 1988 (?)
•Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy
While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

Download date: 24. Apr. 2024

The benefits of sustainable road management: a case study

M Burrow, H Evdorides, M Wehbi and M Savva

Word count: 4935

Number of Tables: 4

Number of Figures: 7

Author's names: **Michael Burrow**, MA PhD, Lecturer

University of Birmingham, School of Civil Engineering, Edgbaston,

Birmingham B15 2TT, United Kingdom,

T: +44-121-414 5079, F: +44-121-414 3675, E: M.P.Burrow@bham.ac.uk

(corresponding author)

Harry Evdorides, CEng PhD EurIng MCIHT, Lecturer

University of Birmingham, School of Civil Engineering, Edgbaston,

Birmingham B15 2TT, United Kingdom,

T: +44-121-414 3071, F: +44-121-414 3675, E: H.Evdorides@bham.ac.uk

Mohammed Wehbi, BEng, MSc

University of Birmingham, School of Civil Engineering, Edgbaston,

Birmingham B15 2TT, United Kingdom. mxw012@bham.ac.uk

Melissa Savva, BEng, MSc

University of Birmingham, School of Civil Engineering, Edgbaston,

Birmingham B15 2TT, United Kingdom. mxs096@bham.ac.uk

Abstract

The road transport sector must continuously seek to sustain effectiveness and responsiveness to changing demands of users and stakeholders. Sustainability may be considered in terms of interdependent aspects associated with economics and finance, engineering, environment, ecology and society. This paper concerns the economic sustainability of appropriately maintained road networks and by means of a case study demonstrates how it can be achieved through a number of measures aimed at utilising fully the resources available for road management. First it describes and discusses the concept of sustainability in relation to road management. Then it presents how a highway management system was introduced and has subsequently been operated for 25 years in a sustainable manner by examining aspects associated with its main technical components, namely: data collection, standards, treatment selection, and prioritisation. Further to these it identifies the factors associated with the successful adoption and use of the system by the road authorities concerned. As a means of demonstrating the success of the sustainable performance of the system, valuations of the road asset and measures of its condition over time are given. The results confirm the preservation of the asset value, as effected by the implementation of appropriate maintenance management, which in turn show that a road authority can achieve its operational objectives if it is committed to a systematic implementation of robust engineering and management principles.

Keywords: Sustainability, Transport Management, Roads & Highways

1 Introduction

The value of road networks and the transport they enable together with the economic growth they encourage has long been recognised. Originally road professionals were concerned mainly with the development of new networks and extending existing ones. Their concern focused on design and construction. However with the greater use of roads problems with deteriorating network conditions led to the emphasis being placed on road network management and maintenance (Robinson, 2008). Maintenance was seen as a technical issue addressed by engineers who were concerned with selecting the most appropriate maintenance regime based on an engineering approach. Subsequently economists developed models based on road condition which could allow optimal maintenance standards to be defined so that the total transport cost could be minimised. The models were also deployed to define maintenance strategies, budget requirements, prioritise road works programmes and appropriate treatments. However, influential work by the World Bank (1981) identified the multi-dimensional nature of the road maintenance problem in terms of attitudes, finance, staffing, management and institutional arrangements, in addition to technical issues. This change in the understanding of road management required a fundamental reconsideration in the approach taken which ultimately led to the introduction of the concept of sustainability in road management. However, it could be argued that to date there is a need to demonstrate how sustainability is achieved in practice. To this end, this paper (a) discusses the requirements for achieving a sustainable road management system through a definition of factors associated with sustainability and (b) demonstrates its benefits by means of a case study of a management system which has been sustained successfully since its introduction 25 years ago.

2 Sustainable Road Management

2.1 Sustainability

A classic definition of sustainability is given in the Brundtland Report (WCED 1987) by the World Commission on Environment and Development (WCED); it is defined as *'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'*. It is common to represent sustainability by a three-pillar model, where the pillars stand for the economy, the environment, and society (Kastenhofer and Rammel, 2005). Using this approach, sustainability is achieved only when there is a balance between economic development, growing and changing human needs, conserving natural resources and the capacity of the environment to absorb the consequences of human activities (Hay and Mimura, 2006). It may be seen therefore that sustainability is a term associated with various meanings because it includes a variety of objectives, connected with environmental, social, and human factors, as well as wider goals such as equilibrium, growth or reduction. Another definition of sustainability considers the provision, or development, of an activity from spatial and temporal perspectives. Consequently, sustainability goals may vary because people and organisations have different objectives in different time periods (Kajikawa, 2008). Furthermore, sometimes there appears to be a better understanding of what is unsustainable rather than what is sustainable in terms of environmental degradation, impacts of human population, affluence and technology on global ecological limits (Fricker, 1998).

2.2 Sustainability and highways

In the area of highways (Savva, 2011), sustainability may be considered in terms of equity, economy and ecology and recognises that highways projects and procedures (such as maintenance) are associated with complex systems with various scale and context (University of Washington, 2011).

First, sustainability of road networks may be associated with the equity in providing satisfactory and safe road transport to all communities. It may also be linked with the objectives to preserve or enhance the historic, scenic and aesthetic context of highway projects, to integrate highway projects with community needs whilst preserving and enhancing community life, and to encourage community involvement in the transportation process (I –LAST, 2010).

Secondly, with regard to economy, sustainability may be linked to the options and practices offered for the management of financial, natural, manufactured and human capital resources. For example, this may be achieved by considering the constraints and limits of a project, the quality of the maintenance processes and improved worker productivity. In addition, it may examine the availability of technical expertise, innovation and knowledge that is critical in the decision-making processes. Furthermore sustainability may be associated with the requirement for continuous education and awareness programmes for the key road transport stakeholders.

Thirdly, considering ecology, sustainability seeks to minimise impacts on environmental resources and reduce consumption of energy and materials. Highway maintenance and new construction projects consume large quantities of construction materials and generate large quantities of waste. The extraction, processing and transporting of these materials is a significant source of greenhouse gas emissions, particularly in the production of cement and asphalt. The use of primary aggregates, in preference to recycled or secondary aggregates, may result in the depletion of irreplaceable natural resources and damage to the environment where the aggregates are located. In addition, incorrect use of materials can result in pollution of the environment (Reid, et al., 2008). Rigorous resource management is therefore a necessary part of sustainable development.

It is evident therefore, that the aims of sustainability are many and general and for the practising road manager there is a need to express them in more specific terms. It has been stated (Robinson 2008) that the failure to provide adequate road maintenance is the main reason for a lack of sustainability of road transport networks in many countries. For sustainable road asset management a set of specific criteria can be identified that seek to ensure the continuous use of such a system over time (McPherson and Bennett, 2005). To this end, this paper focuses on the implementation of a sustainable management system in the Republic of Cyprus is presented and seeks to find out its success factors from a practising road manager's view point.

3 Case study

The case study concerns the sustainable management of the maintenance of the Cyprus road network by the Ministry of Public Works Department (PWD) in the Republic of Cyprus since its introduction in 1987 (Snaith, 1998). The size of the network and that of its managing authority are comparable to those of a number of large local authorities in the UK and other countries and therefore representative of wider conditions.

3.1 Cyprus Road network

The main paved road network in Cyprus is approximately 2,700 lane km according to the system database (see Table 1). Half of the road network is classified as secondary roads, one third is classified as motorways and the rest of the network is classified as primary and tertiary roads.

Table 1: Paved Road description in Cyprus in 2011

Road class	Road type	Length (lane km)
Class A	Motorways	537
Class B	Primary	403
Class E	Secondary	1,366
Class F	Tertiary	383
		2,689

3.2 System implementation

In 1987 the Wold Bank funded a project to implement an objective programme of highway maintenance in the Republic of Cyprus to ensure an equitable and transparent allocation of maintenance funds so that the condition of the entire road network would be optimised to the benefit of the economy as a whole. From a technical point of view the implemented road maintenance management system (RMMS) consisted of the main components shown in Figure 1.

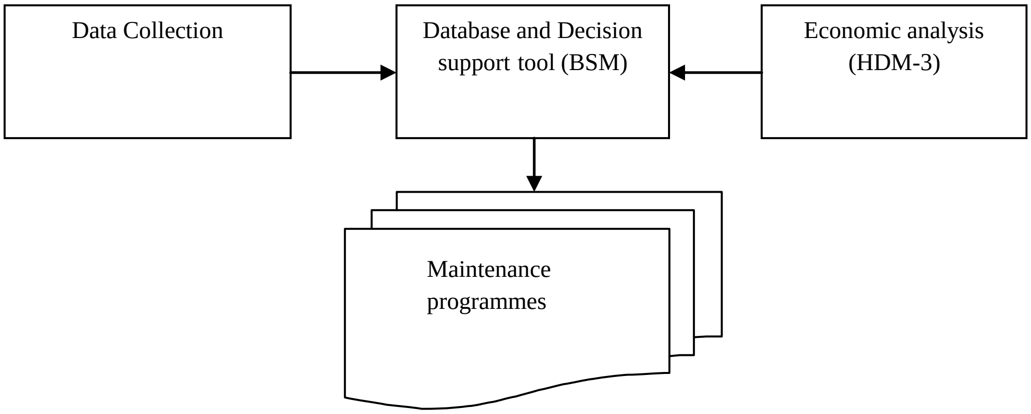


Figure 1 Structure of the Cyprus RMMS

The initial implementation consisted of determining appropriate maintenance standards and the associated periodic maintenance expenditure required (Kerali et al., 1990). The resulting standards were used in a computerised maintenance management system known as BSM, together with road condition data collected on a recurring basis to produce an annual list of defective sections of the road network, recommended remedial treatments and the priority order in which these treatments should be applied. During 2001, BSM was replaced with an updated Windows™ based version, HMS-2.

4 System Sustainability

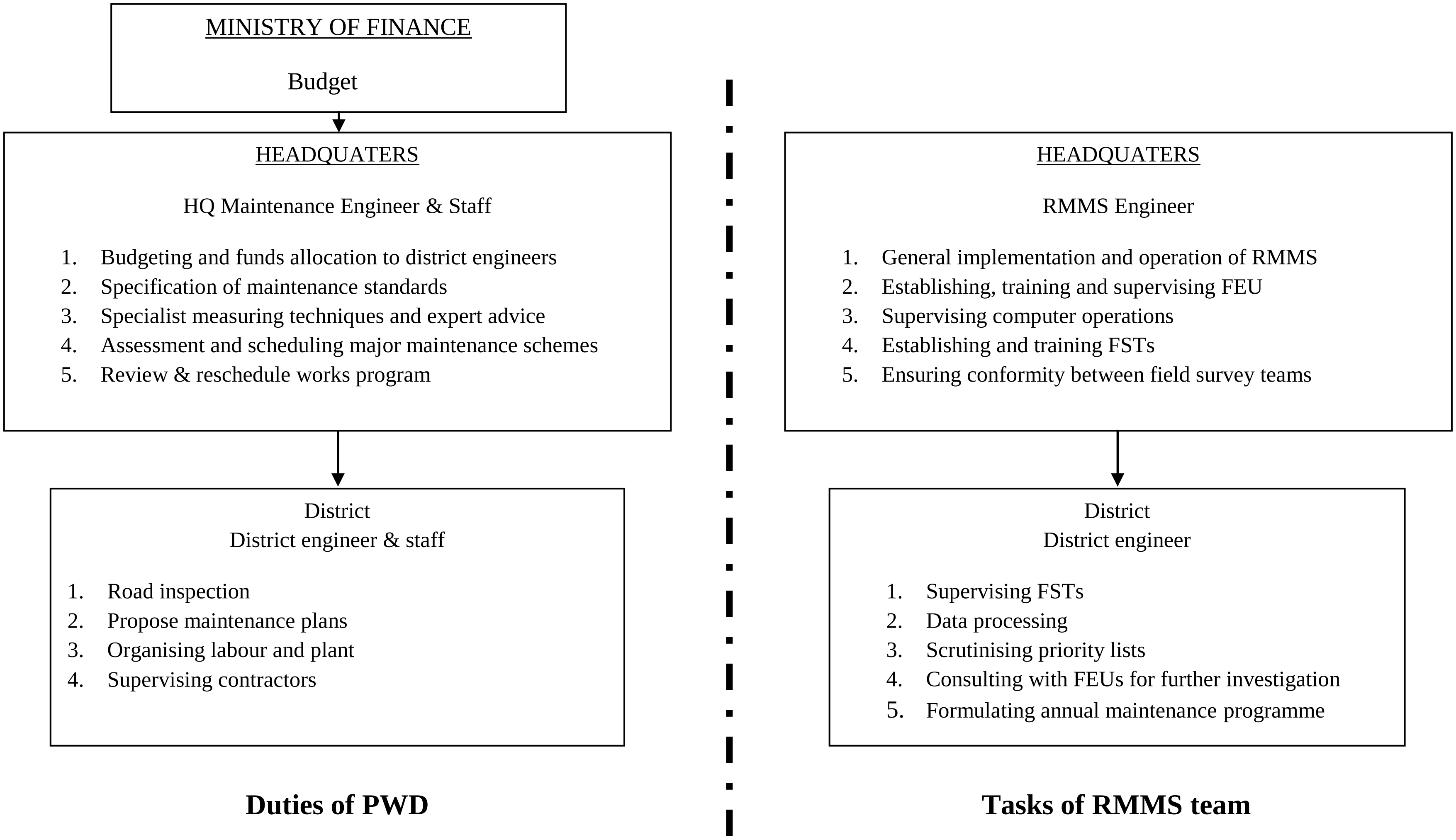
4.1 Institutional issues

The PWD maintenance organisation operated a two-tier system with a headquarters as the upper tier and the six administrative divisions, or districts, of Cyprus in the lower tier as shown in Figure 2. In the upper tier the members of staff are responsible to the headquarters maintenance engineer and their main tasks include maintenance standards specification, budgeting and other financial matters, assessment and priority selection of major maintenance or rehabilitation schemes proposed by the districts and the allocation of funds for routine and periodic maintenance. The lower tier (Figure 2) is made up of district maintenance units which are responsible for routine and periodic maintenance and who report to the district engineer. The tasks of the maintenance units include the organisation of the labour force and plant, execution of routine and periodic maintenance (in house or contracted out), highway inspection and the formulation of proposals for future maintenance schemes (RMMS, 1987).

The implementation process was based both on partnering and on local staff development. Its mobilization phase included discussion of the needs of the road network, construction, materials, available treatments, and prioritization routines. At institutional level it considered selection of the team and method of implementation as well as establishing local hardware and its servicing.

It was then followed by a pilot trial and training programme. During this phase all levels of maintenance staff from the headquarters maintenance engineer to district field survey teams were trained, according to their needs, in the use of the system from data collection to budget allocation by district and by activity. As part of the training process the RMMS was trialled on a small portion of a trial network (approximately 20 km) to facilitate customisation of the system with regard to data requirements, preferred treatments and rules for prioritization. Gradually the system’s implementation was expanded over the entire network and its operation was assessed with regard to its robustness and the PWD needs. Further training was offered on the concept of road maintenance management systems in addition to specific training on the use of BMS. It was observed that the success of the first stage of the implementation was based on the involvement of senior staff (who were conversant with the need for a PMS) in the pilot trial phase and the support of the engineers. In addition it should be attributed to the cooperation between the central administration, the local engineers and the system's providers and consultants.

To facilitate the buy in and uptake by members of staff working in the PWD and its ongoing sustainability, the RMMS was designed to operate on a two-tier basis comparable to those of the PWD described above (see Figure 2). The headquarters maintenance engineer was placed in overall charge of the RMMS, but delegates its daily running to a specially chosen and trained engineer. The engineer's responsibilities include the overall implementation and running of the RMMS, establishing and training the specialist field evaluation unit (FEU) who are responsible for detailed data collection, supervising computer operations, training and ensuring conformity between the local field survey teams (FST) (who are responsible for coarse data collection). In the second tier the district engineers are responsible for the data acquisition process, including verifying the accuracy of the collected data. To effect this, maintenance technicians were appointed to be in charge of the district field survey teams who carry out the recurring condition assessments of the paved roads within each district.



MINISTRY OF FINANCE

Budget

HEADQUATERS

HQ Maintenance Engineer & Staff

1. Budgeting and funds allocation to district engineers
2. Specification of maintenance standards
3. Specialist measuring techniques and expert advice
4. Assessment and scheduling major maintenance schemes
5. Review & reschedule works program

District
District engineer & staff

1. Road inspection
2. Propose maintenance plans
3. Organising labour and plant
4. Supervising contractors

Duties of PWD

HEADQUATERS

RMMS Engineer

1. General implementation and operation of RMMS
2. Establishing, training and supervising FEU
3. Supervising computer operations
4. Establishing and training FSTs
5. Ensuring conformity between field survey teams

District
District engineer

1. Supervising FSTs
2. Data processing
3. Scrutinising priority lists
4. Consulting with FEUs for further investigation
5. Formulating annual maintenance programme

Tasks of RMMS team

Figure 2: Institutional structure of road maintenance sector in Cyprus

4.2 Data Collection

Clearly the decisions of any management system should only be founded on sound data and it was appreciated that data collection was a costly process. Therefore to ensure the sustainability of the data collection process, careful consideration was given to establishing a referencing system and the process of data collection. Accordingly, the road network within each district was divided into sections of 1 km in length of which the references were based on the existing road classification system. The sections were divided into sub-sections, nominally 200 m in length. The sub-sections are the fundamental elements of the referencing system according to which data are recorded, entered and stored, and subsequently treatments are determined and priorities assessed on a sub-section basis. The collection of data is done on an annual cycle using manual and automated means. It was defined early in the development of the RMMS that data would be collected in stages, an approach similar to that of Information Quality levels (IQL) introduced by the World Bank (Robinson, 2008) and shown schematically in Figure 3. In the first stage objective measures of road deterioration are collected by the district FSTs in what could be regarded as a low-cost but high output screening. The condition data collected in this manner includes surface deterioration, roughness, and skid resistance. This is followed, where deemed necessary by the system, by a more detailed structural assessment that could lead thereafter, where significant remedial work is likely, to a detailed analysis involving possibly laboratory testing. The detailed investigation is carried out by the headquarters based field evaluation unit using its specialist knowledge and equipment to ensure uniformity of assessment and accuracy.

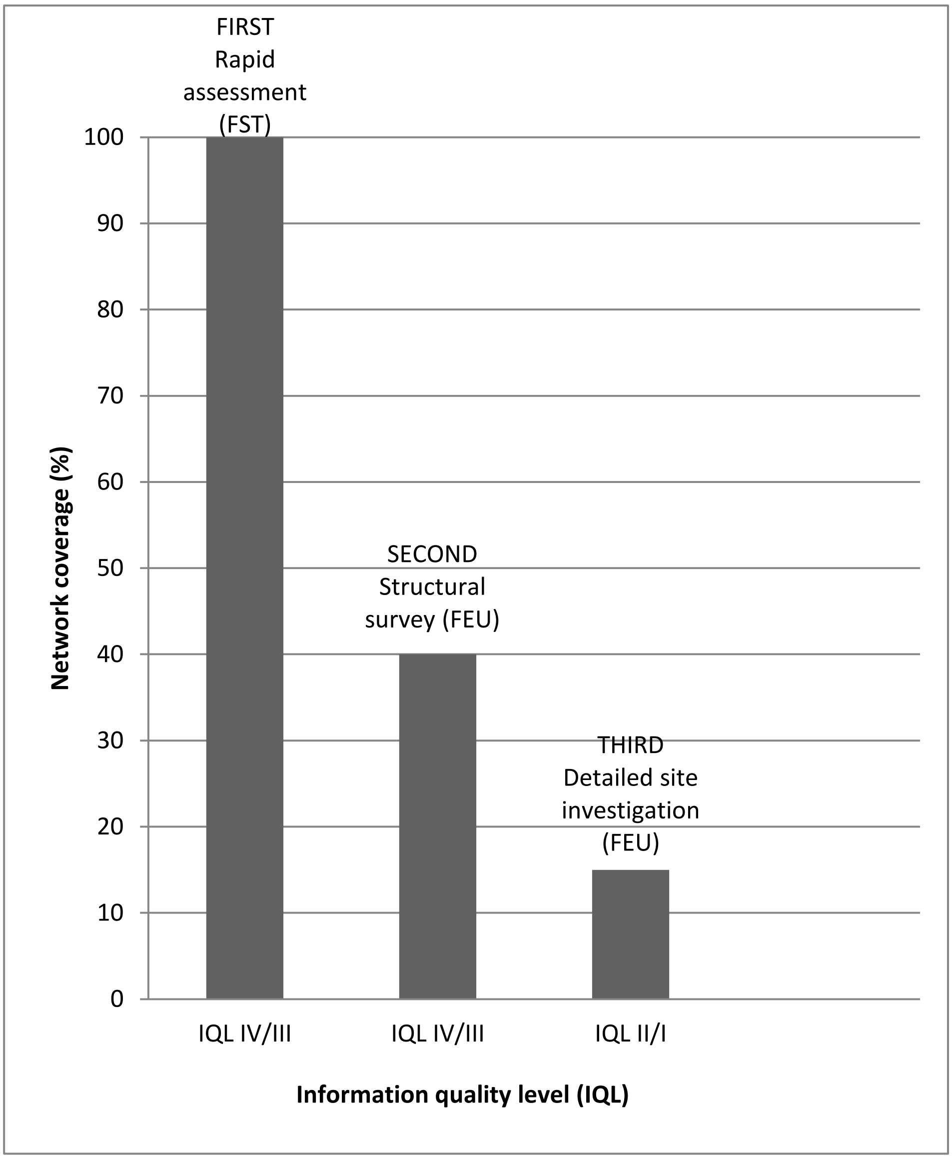


Figure 3: Data collection strategies

4.3 Standards and Strategies

Before the introduction of the RMMS there was a clear imbalance of maintenance funds based on an historical perception of need. It was therefore necessary to establish maintenance standards for the different class of roads in the network on a more rigorous basis than before and from that determine the periodic maintenance expenditure requirements for each district (Snaith, 1998). The maintenance standards, associated with optimum maintenance strategies at the network level were defined in terms of road roughness using the World Bank model HDM-3 (Kerali et al., 1990), calibrated to the prevailing local conditions and taking into account available treatments and budgets. These were then further developed using a combination of appropriately calibrated behavioural models for `typical' Cypriot roads and local engineering knowledge to define a set of overlay thickness standards as a function of surface deterioration, roughness, structural capacity and skid resistance. The associated intervention levels were determined as a function of the district, road class and construction. The standards so determined are given in Table 2, together with the intervention levels for A class roads.

To ensure the sustainability of the process a systematic approach is followed whereby yearly reports of sections requiring maintenance and the priority order in which they should be treated are produced using HMS-2 by comparing the standards with the assessments carried out by the district FSTs. Sections of road with a priority which are high enough for them to be treated within the available maintenance budget are reassessed by the headquarters FEU using available specialist equipment as necessary. In this way the implemented RMMS combines the specialist expertise and equipment of the headquarters field evaluation unit with the local experience of district engineers. This process is summarised in Figure 4.

Table 2: Road maintenance standards (with intervention levels for A class roads)

Defect	Condition	Intervention levels	Unit	Suggested treatment
Minor carriageway deterioration[1]	$\geq LTL \text{ and } < UTL$	13	%	Surface dressing
Minor carriageway deterioration[2]	$\geq UTL$	13	%	Thin overlay
Major carriageway deterioration	$\geq LTL \text{ and } < MTL$	3	%	Structural patch
Major carriageway deterioration	$\geq MTL \text{ and } < UTL$	3	%	Thin overlay
Major carriageway deterioration	$\geq UTL$	38	%	Structural overlay

Defect	Condition	Intervention levels	Unit	Suggested treatment
Left wheel track rutting	$\geq LTL\ and < UTL$	20	% > 25 mm	Structural patch in left wheel tracks
Left wheel track rutting	$\geq UTL$	40	% > 25 mm	Regulating overlay
Right wheel track rutting	$\geq LTL\ and < UTL$	20	% > 25 mm	Structural patch in right wheel tracks
Right wheel track rutting	$\geq UTL$	40	% > 25 mm	Regulating overlay
Deflection	$\geq LTL\ and < UTL$	20	mm/100	Thin overlay
Deflection	$\geq UTL$	40	mm/100	Structural overlay
Deflection AND Roughness	$\geq LTL$ $\geq UTL$	20 1.5	mm/100 IRI	Reconstruction
Deflection AND Left wheel track rutting	$\geq LTL$ $\geq UTL$	20 40	U % > 25 mm	Reconstruction
Deflection AND Right wheel track rutting	$\geq LTL$ $\geq UTL$	20 40	U % > 25 mm	Reconstruction
Deflection AND Major carriageway deterioration	$\geq LTL$ $\geq UTL$	40 38	U %	Reconstruction
Roughness	$\geq LTL$	1700	mm/100	Regulating overlay
SRV[3]	$\leq LTL$	45	SRV units (0 - 100)	Surface dressing
Left edge deterioration[4]	$\geq LTL$	20	%	Haunch left edge

Defect	Condition	Intervention levels	Unit	Suggested treatment
Right edge deterioration[4]	$\geq LTL$	20	%	Haunch right edge

Note: LTL = lover trigger level UTL = Upper trigger level

MTL = Middle trigger level

[1] Minor carriageway deterioration is defined as potholes, areas of interconnected cracking and gross deformation or extensive loss of aggregate.

[2] Major carriageway deterioration is single cracks, areas of non-interconnected cracking, bleeding, or fretting of the surface or any other defect which could be treated by surface dressing alone.

[3] SRV is the skid resistance value

[4] Edge deterioration is the excessive erosion of the edge of the carriageway

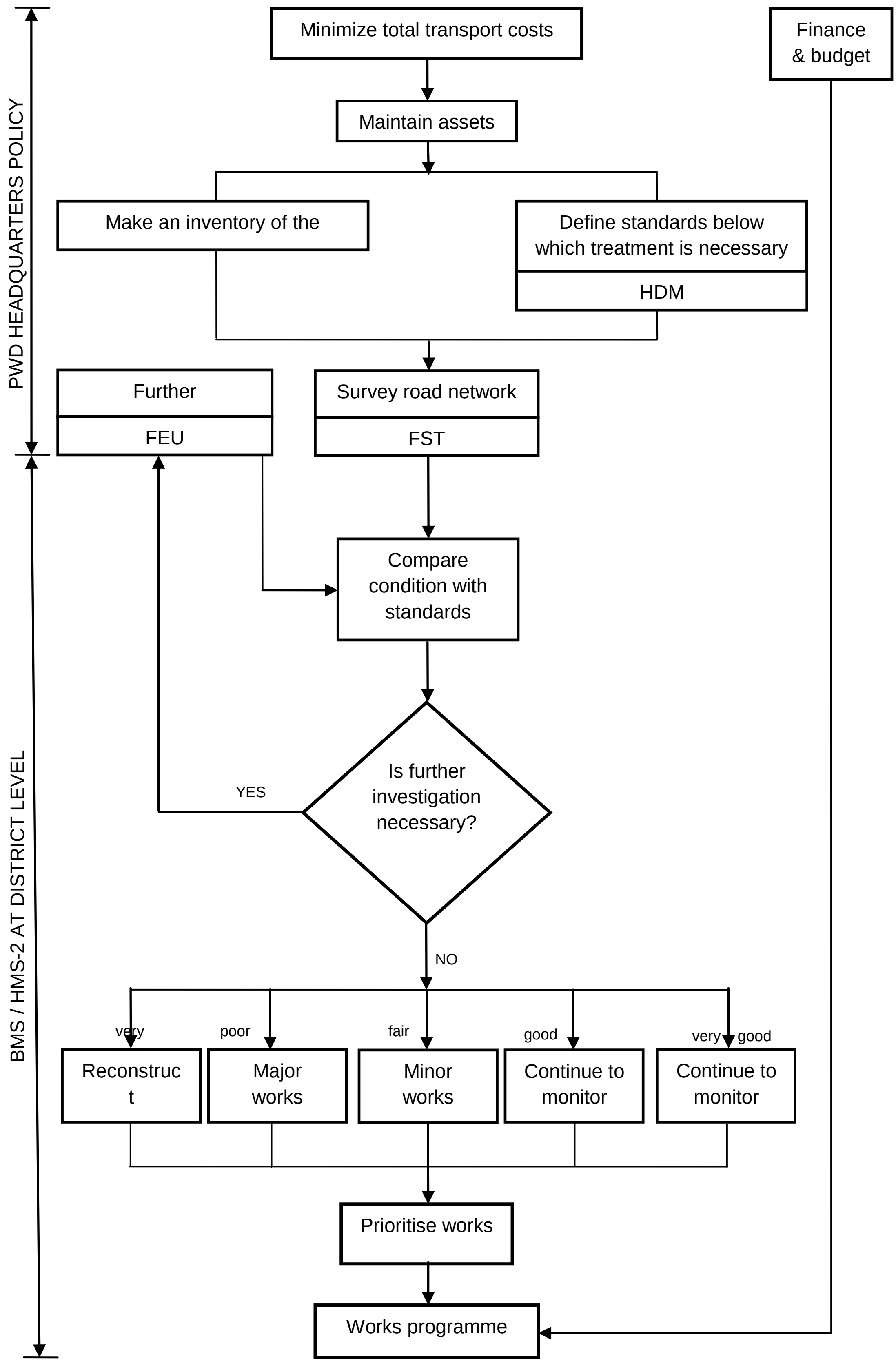


Figure 4: Mechanism to ensure the sustainability of the system of road maintenance management adopted in Cyprus

4.4 Condition achieved

The maintenance standards developed have been used consistently and as a result of the maintenance programmes derived from these, the condition of the road network achieved to date is very satisfactory, according to major deterioration, the predominant mode of deterioration of Cyprus' roads, as may be seen in Figure 5.

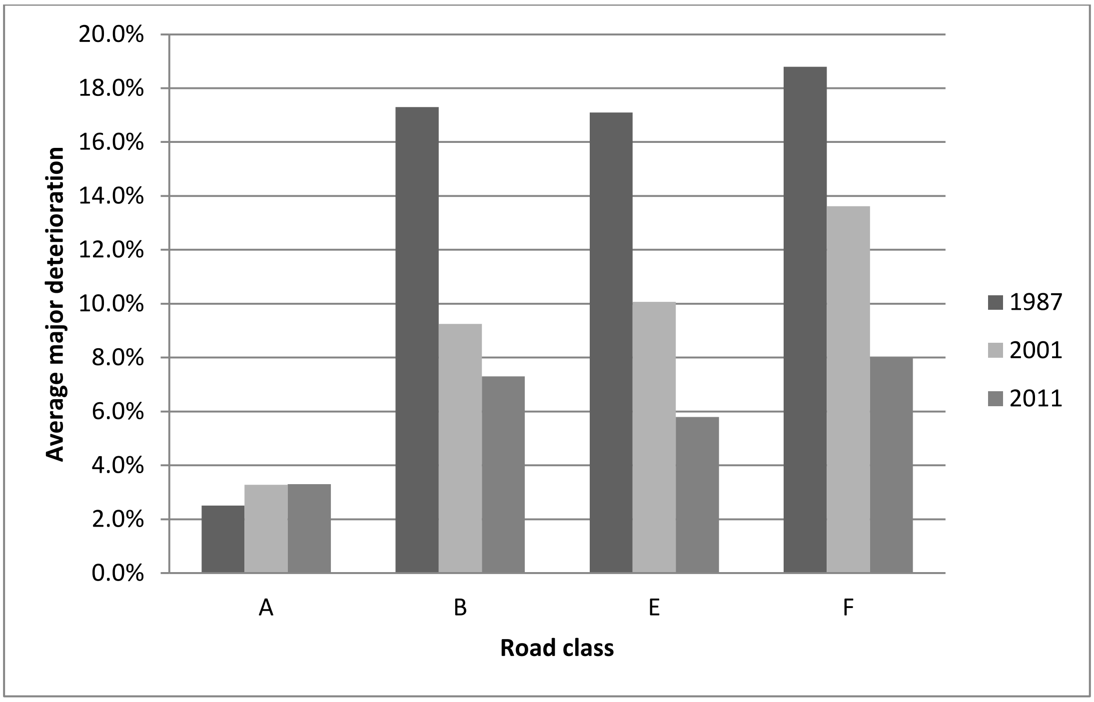


Figure 5: Average major deterioration by road class

Further to this, Figure 5 shows how the overall condition, in terms of major deterioration has progressed since the RMMS's initial implementation. It may be seen that for the B, E and F class roads the average amount of major deterioration has decreased. That for the A class roads however has increased slightly, from 2.5 to just above 3. This can be explained by considering the intervention levels determined for A class roads on an economic basis using HDM-3. The maintenance standards so determined for A class roads (Table 3) suggest that intervention need only to take place when the major deterioration exceeds 3%. Accordingly overtime the average condition of the A roads has increased to just over 3% (where it has remained steady over last 10 years).

5 Asset Valuation

To demonstrate the long-term sustainability of the road maintenance management system and the impacts of maintenance it was felt necessary to consider the value of the road network asset as its overall indicator. This was because if appropriate maintenance is not carried out and excessive deterioration prevails, and the asset value of the road network will reduce (Robinson, 2008). Generally, the basic principle used to calculate the asset value of the network is associated with the total cost of building a new network and then accounting for depreciation. Network depreciation may be represented by the expenditures required to maintain the network and bringing it to the original condition. The current asset value of a network is therefore the cost of building a new network minus the network's depreciation.

As the extent of the Cyprus road network has changed over time, the value of the network was represented by the ratio of the replacement cost of the asset to the total value of the road network in Cyprus. Determining this ratio sought to establish an approximation of the current condition of the road network and the sustainability of the current maintenance strategy in Cyprus. A number of asset valuation methods may be considered. But for the task in hand the simple method of the gross replacement cost was used (reference). The replacement cost of the asset is the current market price for supplies and installation of a similar new asset. The current asset value can then be calculated using a simple approach of subtracting the maintenance cost from replacement cost (see equation 1).

Current asset value = replacement cost of the asset – maintenance cost *(eq. 1)*

To calculate the replacement cost two main parameters are required: the total area of the road network and the unit cost of construction. The latter could be expected to vary with road type. However to simplify the calculations, an average unit cost was used to calculate the total replacement cost (see Table 2).

Table 3: Replacement cost for Cyprus road network (2011 figures)

Road class	Length (lane km)	Average width (m)	Unit cost of new construction (€ /m²)	Replacement cost (€)
Class A	537	7.38	135	535,013,100
Class B	403	7.01	135	381,379,050
Class E	1,366	6.49	135	1,196,820,900
Class F	383	5.08	135	262,661,400
	2,689			**2,375,874,450**

To examine the impact of maintenance on the value of the road assets of Cyprus, maintenance programmes were calculated for each year under scrutiny using HMS-2. The maintenance standards were as given in Table 2. The cost of maintenance and the resultant value of the assets are presented in Table 4.

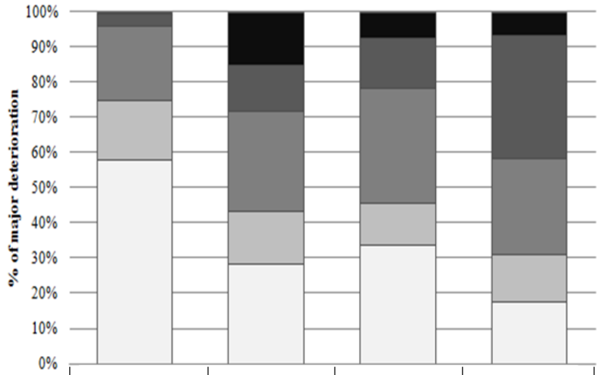
Table 4: Asset value of Cyprus's road network in 2011

Road class	Maintenance cost (€ million)	Maintenance budget	Replacement cost (€ million)	Asset value (€ million)	Ratio (2011)	Ratio (1987)
A	19.0	4.1	535	520	0.97	0.99
B	13.5	18.3	382	377	0.99	0.99
E	29.0	10.8	1,197	1,180	0.99	0.99
F	6.8	0.98	263	257	0.98	0.99
Total	48.3	34.2	2377	2333	0.98	0.99

The ratio of the current value of the network to the replacement cost to is 0.98, which indicates that the current value of the road network in Cyprus is almost equal to the value of a new road network (see Figure 5). Based on the asset valuation analysis, it may be concluded that the road network in Cyprus is in good condition. Although the accuracy of this figure is not ideal because of the assumptions used in the calculations, it is felt to be indicative of the sustainable success of the management system since its introduction. The continuous monitoring of both the standards and the implementation of the system made the standards achievable and sustainable.

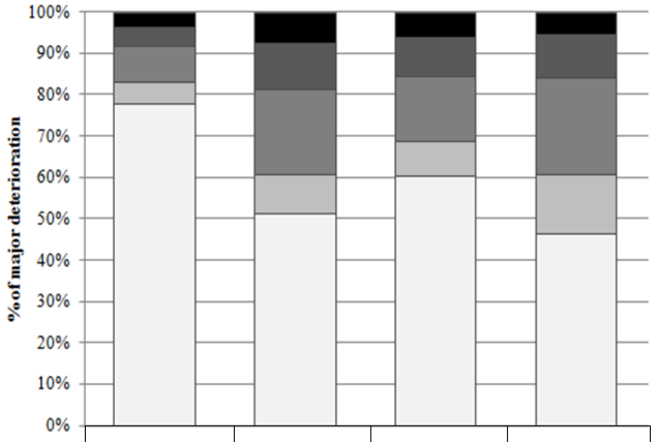
6 Concluding discussion

It has been suggested that the failure to provide adequate road maintenance is the main reason for a lack of sustainability of road transport networks in many countries. The RMMS in Cyprus has produced demonstrable results that provide the best evidence for its continuing capability to support an improved material standard of transport (Gwilliam et al., 1996).



	A	B	E	F
Very good (MDET >= 1%) ☐	57.8%	28.5%	33.9%	17.5%
Good (1% < MDET <= 3%) ░	17.2%	15.0%	11.6%	13.7%
Fair (3% < MDET <= 15%) ▒	20.8%	28.3%	32.6%	27.2%
Poor (15% < MDET <= 38%) ▓	3.6%	13.1%	14.5%	34.9%
Very poor (MDET >38%) ■	0.5%	15.0%	7.4%	6.8%

Figure 6: Average Road Deterioration by Road Class (1987)



	A	B	E	F
Very good (MDET >= 1%) □	77.7%	51.4%	60.4%	46.4%
Good (1% < MDET <= 3%) ░	5.3%	9.3%	8.4%	14.3%
Fair (3% < MDET <= 15%) ▒	8.8%	20.7%	15.8%	23.4%
Poor (15% < MDET <= 38%) ▓	4.4%	11.2%	9.5%	10.4%
Very poor (MDET >38%) ■	3.8%	7.4%	6.0%	5.6%

Figure 7: Average Road Deterioration by Road Class (2011

For example Figures 6 and 7 show the economic and technical sustainability of the road management process through the application of appropriate maintenance standards aimed at preserving the road infrastructure assets. It may be seen that the condition of all road classes has improved significantly. However the application of life-cycle analysis enabled maintenance funds to be allocated to all parts of the network, thus improving the condition across all road classes. Moreover the prioritization of the maintenance expenditure based on engineering driven criteria combined with cost-benefit analysis led to a sustainable maintenance programme which in turn ensured only a small reduction in the asset value of the network despite the budget constraints. It is important to note that this small reduction should be compared with savings associated with significant reductions in road user costs and improvements in the access to the areas covered by the road network.

More importantly, the methodical use of RMMS in Cyprus enables continuing improvements to the system itself. The PWD are now self-sufficient in updating or amending their maintenance standards to effect a different maintenance policy if needed. In addition, the systematic collection of data sustained over the years may facilitate further calibration of the HDM4 models which in turn will offer a more reliable prediction of the performance of the network and subsequently an improved calculation of the maintenance standards and strategies.

Further to the economic and technical sustainability aspects, the management of the road network described in this paper generated significant improvements in the general quality of road transport provision and this relates to the concept of environmental and ecological sustainability. The Cyprus RMMS has achieved in practice such concepts through good road conditions that generate less noise and emissions for ordinary traffic speeds. However, the two components of the RMMS, HDM4 and HMS2 used for network and project level management, can model environmental issues and therefore can be used as tools to define and maintain performance criteria for the environmental and ecological sustainability of the Cyprus road network. The introduction of such criteria not only will enhance the effectiveness and efficiency of the management process (Robinson, 2008), but will explicitly demonstrate the widening of the sustainability goals.

Finally, from a social sustainability viewpoint, the benefits that transport produce must be shared equitably by all parts of the community temporally and spatially. The RMMS in hand has been successful over the years in such aspects both directly and indirectly. As a direct result of the use of RMMS and the examination of all road sections recorded in the system in every cycle of management, good road condition has been provided to all districts of the country in an equitable manner throughout the years. Indirectly the RMMS and the improving road conditions achieved an element of social sustainability by ensuring an acceptable level of road safety as affected by the pavement condition and improving levels of road transport services to individuals. However it should be appreciated that the HDM model can also be used to calculate explicitly ecological and environmental sustainability indices. Furthermore the system presented herein may be coupled with an appropriate decision support system, such as those used for road safety management (i.e. i-RAP, 2012) to address social sustainability or indeed use the multi-criteria analysis of the HDM model to capture holistically any sustainability aspects in the road management process.

7 Conclusions and recommendations

The main conclusions that may be drawn from the sustainable implementation of the Cyprus RMMS are that sustainability of any road management system should be based on:

1. Institutional improvements achieved through
    a. An appropriate institutional structure with excellent communication between the system's headquarters and the field implementation units.
    b. Buy-in by the road agency
    c. Development of technical knowledge and provision of appropriate IT Training for staff operating the system to effect a self-sufficient road management implementation unit within the road administration
2. Adequate financing for maintenance
    a. Committed by the road administration concerned
    b. Justified through the calculation of maintenance budget driven by section priority.
3. Robust engineering approach by means of
    a. Routine use of computerised data management and decision support systems
    b. Pavement performance standards computed through life cycle analysis and monitored systematically

8 Acknowledgements

The authors would like to thank the Public Works Department of the Republic of Cyprus, in particular the Director for his agreement to publish information related to their RMMS and for the invaluable assistance provided over the years by his colleagues, Mr Socratis Zapitis and Ms. Maria Diakou. Thanks are also due to Mr Andreas Partaourides, 2011 MSc Road Management and Engineering graduate from the University of Birmingham, for his work in the area of road asset valuation that offered material presented in this paper.

9 References

1. ,i-RAP, http://www.irap.net/ accessed on 2 April 2012.
2. Fricker, A., (1998). Measuring up to sustainability. Futures, 30(4), pp.367-375
3. Gwilliam K and Shalizi Z. (1996). Sustainable Transport: Priorities for Policy Reform. Development in Practice Series, World Bank, Washington, DC.
4. Hay, J. and Mimura, N., (2006). Supporting climate change vulnerability and adaptation assessments in the Asia-Pacific region: an example of sustainability science. Sustainability Science 1(1): 23–35
5. Illinois Department of Transportation and Illinois Joint Sustainability Group, (2010). I – LAST: Illinois - Livable and Sustainable Transportation Rating System and Guide. [online]. Available at: <http://www.dot.il.gov/green/documents/I-LASTGuidebook.pdf>. [Accessed 15 May 2011].
6. Kajikawa, Y., (2008). Research core and framework of sustainability science. Sustainability Science, 3:215–239.
7. Kastenhofer, K. and Rammel, C., (2005). Obstacles to and potentials of the societal implementation of sustainable development: a comparative analysis of two case studies. Sustainability Science Practice Policy, 1(2): 5–13
8. Kerali, H. R., Snaith, M.S., and Boyce A.M. (1990). Implementation of investment appraisal techniques in road maintenance management systems. Journal of the Institution of Highways and Transportation, 37, No.2. London.
9. Maslow, A.H., (1943). A theory of human motivation. Psychological Review, 50 (4): 370-396.
10. McPherson, K. and Bennett, C. (2005). Success Factors for Road Management Systems. The World Bank. Washington. [online] Available at: http://www.dfid.gov.uk/r4d/SearchResearchDatabase.asp?OutPutId=181124 [Accessed 25 November 2011].
11. Reid, J.M., Chandler, J.W.E., Schiavi, I. and Hewitt, A.P., (2008). Sustainable Highways: A Short Guide, Department for Transport, London: TSO

12. RMMS (1987). Road Maintenance Management System, System Manual. John Burrow and Partners. Nicosia, Cyprus.
13. Robinson, R. (2008). Restructuring Road Institutions, Finance and Management. Volume 1. Concepts and Principles. The University of Birmingham. UK.
14. Savva Melissa, (2011), An investigation on how the concepts of sustainability are considered in the development of highways in Greece, MSc Construction Management Thesis, University of Birmingham.
15. Snaith, M.S. (1998). The development and implementation of pavement management systems: a case study over 15 years. Proceedings of the Institution of Civil Engineers, Transport, 129, pp 72 -79.
16. University of Washington, (2011). Greenroads: Abridged Manual. [online] Available at: <http://www.greenroads.us/312/register␣to␣review.html>[Accessed 31 May 2011].
17. WCED (1987). Our Common Future, Report of the World Commission on Environment and Development, World Commission on Environment and Development, 1987. Published as Annex to General Assembly document A/42/427, Development and International Co-operation: Environment.
18. World Bank, (1981) The Road maintenance problem and international assistance, Volume 1 World Bank. Transportation, Water, and Telecommunications Department, Washington DC