Integrating HDM-4 to Prioritize Pavement Maintenance in Highway Infrastructures Projects Using Sustainability Matrix

Yashika Yadav
Assistant Professor
Department of Civil Engineering
Faculty of Engineering & Technology Agra College, Agra, Uttar Pradesh., India

Siddharth Gupta
Consultant
Confiance Engineers & Infratech, Agra Uttar Pradesh, India

Abstract

Highway plays a vital role for economic development of any country by providing basic infrastructure for systematic and timely movement of raw materials and industrial products from one point of a country to other point so as to maintain the flow of economy from one zone to the other. It is important for Highway to contribute, in economic development to well recognized, a country not progress economically unless it has a good system of Highway which links its different parts together and also different parts of the world. The need and importance of Highway in national economy can been determined by evaluating the economic and social impacts of that project on the people of the Nation. Economic growth of any nation is dependent on growth of Highway, including India. According to census 2011, 31% of population of India is considered to an urban population while the rest 69% is considered as rural and not suited for smooth transit. With increasing urbanization, urban areas will be covering near about 40% of India's population and contribute 75% of India's GDP by 2030. So it is hereby needed to have a connecting mapping of rural and urban Development. Therefore comprehensive development will be needed in physical, institutional, social and economic infrastructure.

Keywords: Highway Development Maintenance and Management (HDM-4), Pavement Management System (PMS), Pavement Management Information System (PMIS), Social Analysis, Economic Analysis, Social Cost Benefit Ratio

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I. Introduction

The continued extension and improvement of the road network does however create new and growing challenges in terms of an increasing maintenance burden. In order to sustain the benefits of the investments made in improving roads, there is a need to boost capacity in terms of providing adequate maintenance. After all, the expected benefits in terms of social and economic development will only materialize if the good transport infrastructure is maintained over time. When road networks mature as a result of reaching the desired coverage of the rural population, more emphasis needs to be placed on the maintenance of already existing infrastructure assets. This implies that a growing portion of funding and technical and managerial capacity need to be allocated to protecting the investments made earlier in building

The road network. In order to sustain the quality of the all-weather roads built to service rural areas, there is a need to mobilize political support for this change process to take place. Secondly, it involves significant changes within government institutions in charge of the road networks. A growing portion of total funding needs to be allocated to maintenance of existing roads together with the technical staff required to attend to road maintenance. With increase in population and vehicular density in urban and Rural areas, the roads are having traffic above the capacity for with they are designed, which lead to wear and tear in road conditions. Roads are of vital importance in order to make a nation grow and developed.

II. Motivation

Road maintenance policies should include key functional requirements that secures the quality of the existing rural road network from deteriorating, while new connectivity and up- gradation works continue. Hence, there is a need to alter and refine the requirements at operational level, ensuring that economic and financial aspects as well as appropriate management arrangements are secured in order to actually carry out the necessary maintenance. This attempts to describe the functional requirements at operational level necessary for securing adequate maintenance of the road network. Roads are rapidly to become insurmountable to traffic until a point when they are no longer trafficable. The pace of deterioration is largely depends on the quality of initial construction of the pavement and surface materials, and drainage measures, levels of traffic and weather conditions. Gravel roads are to deteriorate more quickly than other bitumen surfaced roads and hence their value can often be assumed to be negligible after five years without any form of the maintenance. So bitumen surfaces may have a marginally longer life without any maintenance

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but are more expensive to rebuild. Hence they should also be noted that for rural roads where traffic is more limited, the critical maintenance interventions are often related to maintenance. So the use of quantitative- based index for the identification of high priority areas can also be improved the decision making process and can promote sustainable planning.

III. Objectives

Primary objective of this research is to develop a project basis prioritization matrix for the evaluation of social and economic aspects for the road maintenance policies using the HDM-4 as a tool to evaluate a financial model. Secondary object is to identify and analyze pavement conditions. And third objective is to rank type of pavement maintenance as per Indian scenario.

IV. Methodology

To develop a project based sustainability factors we will apply selected factors to a real world transit network, for which the following research methodology is followed:

1) Literature review: Review background and vulnerability related to highway infrastructure, performance metrics, index methodologies, and Decision analysis tools.
2) Factor selection: Identify relevant HDM-4-based sustainability metrics for highway infrastructure project selection.
3) Survey method: Develop and distribute a pairwise comparison survey based on AHP using the factors
4) Data analysis: Synthesize the results of the pairwise comparison survey using Expert Choice (2012), an AHP-based soft- ware program, to determine factor weights.
5) Index development: Construct PLPI based on the factor AHP weights.
6) Case study: Apply selected factors (one from each category) to NH-15 Jaisalmer to Bikaner.

V. Sustainability matrix

The concept of sustainability is defined in the Brundtland Report as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [World Commission on Environment and Development (WCED) 1987]. Although there are numerous ways to define the term, the three dimensions of the triple bottom line (environmental, economic, and social) are becoming widely accepted, specifically within the transportation field (Jeon and Amekudzi 2005). The triple bottom line suggests that agencies should equally balance the economic, environmental, and social benefits/costs of the project. A growing number of transit agencies have incorporated sustainability into their mission statements such as the Southeastern Pennsylvania Transportation Authority (SEPTA) Sustainability Program Plan, which aims to apply the triple bottom line principles through a three-pronged approach (SEPTA 2012). Although significant effort has been placed on identifying vulnerabilities associated with sea level rise within the last few years, impact on the environment is just one of many aspects that influence the decision to pursue a transportation project. Therefore, exploring all possible environmental, economic, and social factors with regards to future development is necessary. Previous studies such as Jeon and Amekudzi (2005), Oswald and McNeil (2010), Black (1995), and Bossel (1999) have explored the process of developing metrics that allow for a more performance-based approach to sustainable development. In addition, agencies such as the Wilmington Area Planning Council

VI. Analytical hierarchy process

The analytic hierarchy process (AHP) developed by Saaty (1982) is a multi-criteria decision-making model that allows for a hierarchal analysis of qualitative factors. This model is composed of three main principles: (1) hierarchal construction (dividing the problem into individual elements), (2) priority analysis (ranking the elements in order of importance), and (3) logical consistency (grouping the elements together and reviewing consistency).

Order to quantify the importance of each toward the overall goal, which is reported through weights (on a normalized scale of 0 to 1.0). Ultimately, this process aids in the decision-making process when comparing qualitative measures. Recently, an integrated AHP approach with the use of GIS has emerged for site selection through methods such as weighted suitability, thematic mapping, and mathematical

Factors are prioritized using pairwise comparisons in Programming (Ho 2008; Malczewski 2006; Young et al. 2009; Anagnostopoulos and Vavatsikos 2012). Previous studies such as Goodchild (1993), Farkas (2009), Tresidder (2005), Armstrong and Khan (2004), and Chen et al. (2009) use this synergistic approach where geographical data (the input) is assimilated into a decision (the output). Integrated AHP and GIS has been applied in the transportation

VII. Factor selection

In order to develop a transit project prioritization index focused on sustainability, specific factors (metrics), as discussed previously, are selected as they pertain to the overall goal of the index as well as the opportunity for HDM-4 application. Table 1 displays the factors selected including the focus (project-based), description, and source. The 6 factors selected reflect a broad range of components that influence highway infrastructure planning and serve as a basis for revision and expansion over time. As the term sustainability is refined and priorities change, this list can evolve and become more comprehensive. Another challenge of measuring sustainability is the interdependency of systems. Therefore, the factors selected are not mutually exclusive from one another and can pertain to more than one dimension of sustainability. In addition, the vulnerability of social and economic impacts to a more sustainable location (mixed land use, high population, etc.) may be higher than an undeveloped region. The interconnectedness of the factors is accounted for in the pairwise comparison survey, discussed in detail below. For each factor, the following characteristics are determined based on their application to pavement maintenance planning:

Category	*F ac*	*Focus*	*Definition and units*	*Source*
Economy	*Mixed land use*	*Location*	*Combination of zoning in an area, including commercial, residential, and industrial units, promoting walkable communities and use of public transportation (land mix index)*	*Frank et al. (2004)*
	Connectivity of network	*Project*	*Redundancy of links and level of service through a transportation network that connects a set of nodes (link to node ratio)*	*Tresidder (2005)*
	Value of infrastructure	*Project*	*The monetary value of a transit agency's individual assets, including structures such as bus stops and rail stations (dollars)*	*Colgan and Merrill (2008)*
	Jobs and wages of transportation	*Project*	*Average salary ranges for transit agency employees that work in a particular service area (dollars)*	*Black (1995)*
	Peak hour travel time	*Project*	*Travel time from an origin to a destination during typical high traffic periods (h)*	*Noland and Small (1995)*
	Employment density	*Location*	*Current concentration of employment within a specified area (people/sq. mile)*	*U.S. Census Bureau (2010)*
	Future employment density	*Location*	*Projected concentration of employment Within a specified area (people/sq. mile)*	*U.S. Census Bureau (2010)*
Society	*Intermodal transfer facilities*	*Project*	*Number of transportation facilities/services that provide passengers the ability to switch between modes of travel (count)*	*Horowitz and Thompson (1994)*
	Affordability of transportation	*Project*	*Ability to purchase transportation services, measured by the percentage of a household budget dedicated to the costs of using transportation (average percent)*	*Lipman (2006)*
	Ridership	*Project*	*Number of passengers using the transportation network (passenger miles)*	*Black (1995)*
	Population density	*Location*	*Number of people residing within a specified area (people/square mile)*	*U.S. Census Bureau (2010)*
	Future population density	*Location*	*Projected concentration of population within a specified area (people/square mile)*	*U.S. Census Bureau (2010)*
	Access to public facilities	*Location*	*Proximity and connectivity from a transportation node to a public use facility, including hospitals, schools, grocery stores, etc. (count)*	*Manaugh and El-Geneidy (2012)*

VIII. PAVEMENT MAINTENANCE

Unfortunately in India, we construct and forget our infrastructural assets. This truth is also applicable to our roads. We build roads and remember them only when they reach in extremely bad condition. The pavement management system and the systematic approach contained in this is not adequately implemented for repairs and rehabilitation. Noncompliance result into heavy losses, discomfort, Mechanical damages in vehicles and loss of man hours. In many cases the high speed corridor pavements have failed prematurely in the absence of adequate maintenance during the design life itself. Today's increasing budget constraints require that state and local agencies perform more work with less money. Historically, the emphasis of local highway departments has been on building new roads, but the new focus is on maintaining and preserving existing pavement surfaces. This shift has resulted in three types of pavement maintenance operations. (*Source IRC-099*)

A. Pavement Performance

Performance is a general term for how pavements change their condition or serve their intended function with accumulating use. Pavement performance can be measured in terms of:
1) Ride quality (International Roughness Index (IRI));
2) Rutting (depth of the rut);
3) Surface distress (cracking and default);
4) Skid resistance;
5) Structural capacity;
6) Frost susceptibility

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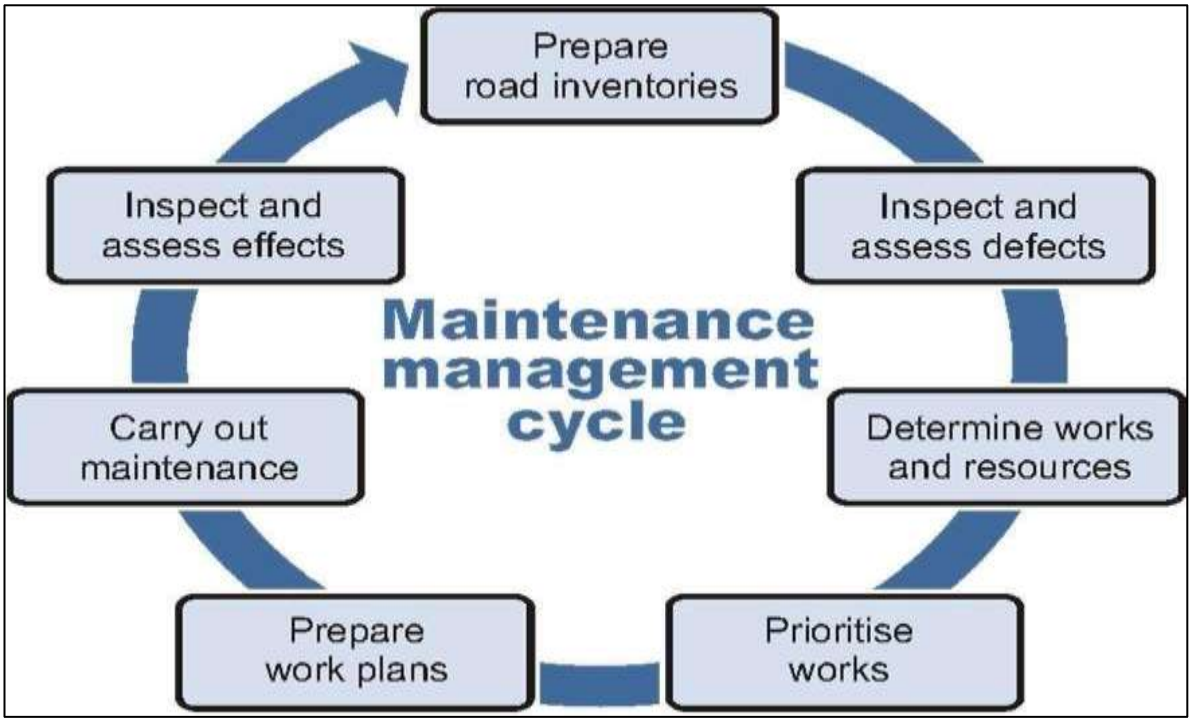

Fig. 3: Maintenance Management Cycle (Source Indian Rural Road Manual)

IX. HIGHWAY DEVELOPMENT MAINTENANCE MANAGEMENT (HDM-4)

The Highway Development and Management System (HDM-4), originally developed by the World Bank for international use, is a software tool for systematically addressing pavement maintenance and rehabilitation issues. HDM-4 can provide road performance prediction, road treatment programming, funding estimates, budget allocation, project appraisal, policy impact studies, and a wide range of special applications. However, its effectiveness is dependent on its ability to accurately model and predict pavement performance, which is affected by numerous factors including structural design, materials, construction variability, and traffic, vehicle operating costs, environmental considerations, as well as maintenance and rehabilitation practices. Therefore, in order to effectively use HDM- 4, its predictive models must be calibrated to local conditions. While Tonga, Thailand, India, Canada and several other counties have calibrated some HDM-4 models to their local conditions, there is no evidence that this calibration is valid for Washington State. To date, there has been no thorough documented calibration and application of HDM-4 in the U.S. (Kerali et al., 2000b).

The Highway Design and Maintenance Standards Model (HDM-III), developed by the World Bank (Harral et al, 1987; Watanatada et al, 1988), has been used for over two decades to combine technical and economic appraisals of road investment projects, and to analyses strategies and standards. An international study has been carried out to extend the scope of the HDM- III model, and to provide a harmonised systems approach to road management, with

Adaptable and user-friendly software tools. This has resulted in the development of the Highway Development and Management Tool (HDM-4) (Kerali 2000, Odoki and Kerali 2000). The scope of the HDM-4 tool has been broadened considerably beyond traditional project appraisals, to provide a powerful system for the analysis of road management and investment alternatives. Emphasis was placed on collating and applying existing knowledge, rather than undertaking major new empirical studies, although some limited data collection has been undertaken.

A. Functions and cycles

When considering the HDM-4 applications, it is convenient to view the highway management process in terms of the following functions (Robinson et al, 1988):

1) Planning

This involves an analysis of the road system as a whole, typically requiring the preparation of long term, or strategic, planning estimates of expenditure for road development and preservation under various budgetary and economic scenarios

2) Programming

This involves the preparation, under budget constraints, of multi-year road works and expenditure programmers in which those sections of the network likely to require maintenance, improvement, or new construction, are identified in a tactical planning exercise.

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3) Preparation

This is the short-term planning stage where road schemes are packaged for implementation. At this stage, designs are refined and prepared in more detail; bills of quantities and detailed costing are made, together with work instructions and contracts

4) Operations

These activities cover the on-going operation of a road agency. Decisions about the management of operations are made typically on a daily or weekly basis, including the scheduling of work.

X. ECONOMY

1) Connectivity of Network: Connectivity can be defined as the number of links that join together each node within the transportation network and "as connectivity increases, travel distances decrease and route options increase" (Victoria Transport Policy Institute 2012). The link-node ratio is a measure where the number of links is divided by the number of nodes within a study area, and higher values are indicative of higher connectivity (Tresidder 2005; Dill 2004).
2) Value of Infrastructure: Asset management is crucial for transportation agencies because infrastructure such as bridges, tunnels, bus stops, and rail stations are prone to failure and inadequate performance (Gharaibeh et al. 2006). High value investments must be protected to promote cost-effective decisions and improve infra- structure integrity (Colgan and Merrill 2008).
3) Jobs and Wages of Transportation: Infrastructure projects that have the opportunity to promote job growth are beneficial not only to those employed but to the local economy (Black 1995). Therefore, transit projects that lead to job creation are of high priority in order to promote employment and enhance economic development.
4) Peak Hour Travel Time & Commute Time: Network reliability is essential for continued customer satisfaction because it ensures that commuters arrive to their destination on time (Noland and Small 1995). Reducing congestion and delays is essential in order to promote system efficiency (Downs 2004).
5) Commute Cost: Out-of-pocket costs can influence travel decision; therefore, adjusting the dollar amount to promote ridership while still balancing operating and maintenance costs is beneficial (Tse and Chan 2003).
6) Employment Density and Future Employment Density: Patterns in commuter

Travel show that employment density and transit usage have a positive correlation (Schimek 1996; Cervero 1996). Thus, transit planning prioritization should reflect the usage of these travel patterns to and from commercial areas and central business districts

XI. SOCIAL IMPACTS

1) Affordability of Transportation: Housing and transportation costs are typically the largest expenses for most households (Lipman 2006).
2) Households without access to private transportation are limited in their mobility options. Therefore, promoting affordable transportation is important for enhancing quality of life for low income as well as non-driving populations.
3) Ridership: Transit routes with high ridership indicate high facility demand (Black 1995). Therefore, projects that improve facilities with high ridership can ultimately benefit more people as well as address potential congestion and travel delays.
4) Population Density & Future Population Density: Travel demand increases with an increase in population (McFadden 1974). Thus, transit planning prioritization should reflect the use of transportation to and from residential areas.
5) Access to Public Facilities: Efficient transportation networks provide access to public uses such as jobs, schools, grocery stores, and hospitals, regardless of car ownership (Manaugh and El-Geneidy 2012). Therefore, priority should be placed on projects that provide the most access to public facilities.
6) Walkability: The use of a facility is inversely related to one's distance from the facility, primarily with regards to pedestrian access (Hansen 1959). Therefore, promotion of walkable and accessible facilities encourages public transportation usage.

XII. PAVEMENT MAINTENANCE

1) Routine maintenance

Critical elements of the drainage system, such as culverts and drains, need particular attention. Priority is therefore given to the removal of obstacles, debris and silt blocking water from exiting the road in a controlled manner. Erosion channels should be repaired before the next rains deepen and widen them. All these tasks require regular inspection

2) Periodic maintenance

Priorities are also important when carrying out periodic maintenance. Again, activities relating to the drainage system should be given particular attention. The table below lists some common periodic maintenance work according to their importance.

3) Emergency maintenance

Urgent maintenance work requires immediate action. Priority should be given to such activities that ensure that the road remains (even partially) passable. For example, a broken culvert may disrupt the passage of traffic and needs to be attended to immediately. While a landslide only covers part of the carriageway, allowing the traffic to pass the affected section, remedial action is still required to clear the full width of the road and remove all debris from the drainage system.

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4) Preventive Maintenance:

Performed to improve or extend the functional life of a pavement. It is a strategy of surface treatments and operations intended to retard progressive failures and reduce the need for routine maintenance and service activities

XIII. CASE STUDY APPLICATION

In order to apply this process as well as determine the applicability of the factors to a real-world network, a case study application is used. The case study area selected is the National Highway network in India County, under the jurisdiction of the NHAI. NHAI, representing the Indian case study, and is participating the case study region of India County is located Distance between Bikaner and Jaisalmer.

In order to provide an example of how to apply the HDM-4-based factors in the sustainability matrix to a real-world network, selected factors (one factor from each category) are applied to India County. In order to fully implement the prioritization matrix to highway infrastructure for all 15 factors should be applied, and it is recommended that each be developed spatially on separate layers. However, as mentioned for this case study, one factor from each category is selected to illustrate the repeated process of developing each layer. Because the factors are spatially represented, most of the location-based data is publicly available and accessible from agency websites and data clearinghouses such as the Indian. Census Bureau.

Once the data are collected for all three factors, of India County region. For each factor, the distribution range of values is displayed, respective of the factor units. Because natural breaks occurred in the data, the Jenks (1963) method is used to classify data into categories of high, medium, and low. This statistical procedure minimizes within-class variance, maximizes between-class variance, and is a common classification scheme used in cartography (Jenks 1963).

A similar process should be followed for all 15 factors included in the index. Each reclassified layer is then added together in order to sum the total points for all factors. A completed application includes 15 factor points assigned to specific projects or network locations.

XIV. CONCLUSION

As interest in sustainable development continues, identifying opportunities for improved decision making through the use of sustainable metrics reflecting Maintenance, economic, and social factors that influence project priority is needed. Highway infrastructure is vital to promoting mobility and access; however, issues such as accidents that cause fatal death and injuries.

Table – 1
Ranking of Social Factor

No	*Social Factor*	*Weights*	*Rank*
1	*Affordability Of Transportation*	*62.00766*	*1*
2	*Ridership*	*14.49089*	*2*
3	*Population Density*	*6.935344*	*4*
4	*Future Population Density*	*12.62316*	*3*
5	*Access To Public Facility*	*3.942946*	*5*

Table – 2
Ranking of Pavement Maintenance Factor

No	*Type of Pavement Maintenance*	*Weights*	*Rank*
1	*Routine*	*9.935028*	*4*
2	*Periodic*	*53.7228*	*1*
3	*Emergency*	*3.257448*	*5*
4	*Preventive*	*23.10274*	*2*
5	*Corrective*	*9.981989*	*3*

Table – 3
Ranking of Economic Factor

No	Type of Pavement Maintenance	Weights	Rank
1	CONNECTIVITY TO NETWORK	37.76699	1
2	VALUE OF INFRASTRUCTURE	35.29786	2
3	JOBS AND WAGES	15.99269	3
4	PEAK HOUR TRAVEL TIME	2.973472	5
5	EMPLOYMENT DENSITY	7.968994	4

This research focuses on the development of a project to prioritize a sustainable growth of an infrastructure as per the Indian standards and needs. The methodology used to develop the gap between

The use of, sustainability metrics, and the use of AHP, for infrastructure planning. The index can be applied to transportation planning agencies in order to identify project priorities based on vulnerability and sustainability, which is the first step in adaptation planning. Through the application of the index, at- risk projects/networks are identified and then appropriate adaptation design techniques can be implemented.

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Although there are implications including the rigorous spatial data needs, the comprehensiveness and evolving nature of the factors included, and the relative point values assigned to the factors, the index provides a foundation for beginning to quantify sustainable factors and prioritize projects to promote adaptation.

In addition, the index is based on weights from experts within the Mid-Atlantic region, reflecting the climate change impacts of that region. Future work can include applying the same survey method to experts in other regions throughout the country as well as updating the list of factors that influence project prioritization as metrics adapt and change over time. Overall, this index serves as a foundation for a more quantitative method to applying sustainability and adaptation methods to Infrastructure planning.

REFERENCES

[1] Andres, C. and Collura, J. (1994), "Network-Level Prioritization of Local Pavement Improvements in Small and Medium-Sized Communities", Transportation Research Record 1455, Transportation Research Board, pp. 13- 21.
[2] Bandara, N. and Gunaratne, M. (2001), "Current and Future Pavement Maintenance Prioritization Based On Rapid Visual Condition Evaluation", Journal of Transportation Engineering, ASCE, vol. 127 (2), pp. 116-123.
[3] Butt, A., Shahin, M. , and Carnahan, J. (1994), "Application of Markov Process to Pavement Management Systems at Network Level", Proceedings of Third International Conference on Managing Pavements, Transportation Research Board, Texas, vol2, pp.159-172,.
[4] Cafiso, S., Graziano, A, Kerali, H. and Odoki, J. (2002), "Multicriteria Analysis Method for Pavement Maintenance Management", Transportation Research Record No.1816, Transportation Research Board, pp. 73-84.
[5] Chandran, S., Isaac, K. and Veeraragavan, A. (2007), "Prioritization of Low- Volume Pavement Sections for Maintenance By Using Fuzzy Logic", Transportation Research Record No.1989, Transportation Research Board, pp. 137-144.
[6] Cafiso S. and Di Graziano A, (1999). "A Model of Risk for the Definition of Priorities in the Maintenance of Road Pavements". PIARC XXI World Congress, Kuala Lumpur. pp. 71-78
[7] Cafiso S. and Di Graziano A., (2000). "Influence of Macro-texture, skid resistance and surface unevenness on driving safety". PIARC, IV International Symposium on Pavement Surface Characteristics of Roads and Airfields. Nantes, France. pp. 18-41
[8] Di Graziano A, (2000). Multi Criteria Decision Making in Pavement Management. Ph.D. Thesis, University of Catania, Catania, Italy
[9] EEC, (1988). Attuazione delle direttive 80/779, 82/884, 84/360, 85/203 (in Italian). D.P.R. 203/1988, Luxemburg: European Economic Commission. pp. 13-82
[10] European Commission, (1996). Evaluation Methods. APAS Road Transport Research Project. Luxemburg: European Commission.
[11] Farhan, J. and Fwa, T. (2009), "Pavement Maintenance Prioritization Using Analytic Hierarchy Process", Transportation Research Record No.2093, Transportation Research Board, pp. 12-24.
[12] Flintsch, G., Zaniewski, J., and Medina, A. (1998), "Development of a Knowledge-Based Formula to Prioritize Pavement Rehabilitation Projects", Transportation Research Record, No. 1643, pp. 54-61.
[13] Fwa, T. And Chan, W., "Priority Rating Highway Maintenance needs by Neural Networks, Journal of Transportation Engineering, ASCE, vol. 119 (3), pp. 419- 432, 1993 Karni R. et al, 1990. A comparative study of multi-attribute decision making methodologies. Theory and Decision, No. 29.
[14] Haas, R., Hudson, W and Zaniewski, J. (1994), "Modern Pavement Management", Krieger Publications, Malabar, Florida, pp. 85-87
[15] Jain, S.S. and Gupta, A.K. (1996), "Development of Maintenance & Rehabilitation strategy for Flexible pavements", Journal of Indian Roads Congress, vol.57 (2), pp. 367-418.
[16] Ortiz-Garcia J., (2000). Application of Multi Criteria Methods in Pavement Management. PhD Thesis, School of Civil Engineering, the University of Birmingham, UK. pp. 96-100
[17] Anani, S. (2008). "Revisiting the estimation of highway maintenance marginal cost." Ph.D. thesis, Univ. of California, Berkeley, Calif. pp. 78-102
[18] Berzelius, N. (2004). "Measuring the marginal cost of road use an international survey." Meddelande 963A, Swedish National Road and Transport Research Institute VTI, Linköping, Sweden. pp. 2-17
[19] Haraldsson, M. (2007a). "The marginal cost for pavement renewal—a duration analysis approach." Working Papers No. 2007:8, Swedish National Road and Transport Research Institute VTI, Linköping, Sweden. pp. 28-34
[20] Haraldsson, M. (2007b). "Marginal costs for road maintenance and operation—a cost function approach." Working Papers No. 2007:7, pp. 43-52
[21] Swedish National Road and Transport Research Institute VTI, Linköping, Sweden. Li, Y, and Madanat, S. (2002). "A steady-state solution for the optimal Pavement resurfacing problem." Transp. Res., Part A: Policy pp. 73-110

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