International Journal of Scientific & Engineering Research, Volume 4, Issue 9, September-2013 1464
ISSN 2229-5518

Calibrating Road User Cost Model in HDM-4 for Conditions Prevailing in India – A Case Study

Aswathy Das A, Dr. Bino I Koshy, Jeena Pradeep

Abstract—Engineering economic analysis applies economic concepts and methods to engineering problems to support decisions on a best course of action. Economic analysis provides a way of comparing the economic gains expected from an investment with the cost of that investment; providing an objective understanding of value to be expected for cost incurred. The Highway Development and Management Model (HDM-4) system is seen as the international standard decision support tool for road management. This article focuses on the Road User Cost Modelling in HDM-4 and validation of the model using Road User Costs Knowledge System (RUCKS).

Index Terms— Road User Costs, Vehicle Operating Cost, Travel Time Cost, HDM-4, RUCKS.

1 General

THE economic analysis is a critical component of a comprehensive project or program evaluation methodology that considers all key quantitative and qualitative impacts of highway investments. It allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over a multiyear timeframe. With this information, highway agencies are better able to target scarce resources to their best uses in terms of maximizing benefits to the public and to account for their decisions.

2 Economic Evaluation For Road Improvement

The objective of the cost benefit analysis is to identify and quantify the benefits and costs associated with the project. This analysis will help in identification of the optimum solution along with the economic viability in terms of its likely investment return potential.

2.1 Cost Components in Transportation System

In broad terms, the society costs pertaining to the highway development, to be considered in this analysis includes:
Agency costs: Capital cost, Recurrent cost for maintenance (annual & periodical), Residual value at the end of analysis period
Road user costs: Vehicle operating cost, Travel time cost, Accident cost

2.2 Benefit Component in Transportation System

The objective of a good transportation system is to provide an efficient, quick and safe transportation to its users. And this is counted as the benefit of transportation. The various possible forms of benefits can be summarized as follows **(IRC: SP-30, 1993):**
Road user benefits: This type of benefit includes, saving in VOC, saving of travel time, saving in terms of accident cost, saving in the cost of maintenance etc.
Social benefits: This type of benefit includes, benefit due to improvement in administration, health, education, agriculture, industry, trade, environmental standards etc.

3 Methodology

Selecting the optimal alternative in transportation projects can be a very complex affair. Thus with new developments in technology, computer models and programs were used for the economic analysis so that the complex task of analysis becomes much easier. There are a number of softwares available for the economic analysis of road projects including Micro-BENCOST, Cal B/C, Redbook Wizard, RED, HDM-III, HDM-4 etc. HDM-4 is one among the best software's available for economic analysis being developed by World Bank and accepted worldwide. Primary and secondary data needed as inputs to these softwares are huge.

3.1 HDM-III

The Highway Design and Maintenance Standards Model (HDM-III) is a computer program for analyzing the total transport costs of alternative road improvement and maintenance strategies through life-cycle economic evaluation. The program provides detailed modeling of pavement deterioration and maintenance effects, and calculates the annual costs of road construction, maintenance, vehicle operation, and travel time needed to perform the economic evaluation of the alternatives being considered.

3.2 HDM-4

The Highway Development and Management Model (HDM-4) Version 1.3 was released in January 2002 which is the recommended software for evaluating highway investment options. HDM-4 is the result of the International Study of Highway

- *Aswathy Das A is currently pursuing Masters degree in Transportation Engineering from Rajiv Gandhi Institute of Technology, Kottayam, Kerala E-mail: aswathydasa@yahoo.in / achudas89@gmail.com*
- *Dr Bino I Koshy is currently working as Professor, Department of Civil Engineering, Rajiv Gandhi Institute of Technology, Kottayam, Kerala*
- *Jeena Pradeep is currently working as General Manager(Transport Planning), CDM Smith India Pvt. Ltd., Bangalore*

ISSN 2229-5518

Development and Management (ISOHDM) that was carried out to extend the scope of the World Bank's HDM-III model. The system has become the de-facto standard for road investment analysis for many road authorities and financing agencies.

4 Need For Calibration

As part of the International Study of Highway Development and Management Tools (ISOHDM), a compendium was compiled of the countries where HDM had been applied. HDM or its relationships has been applied in over 100 developed and developing countries having markedly different technological, climatic and economic environments. Since the model simulates future changes to the road system from current conditions, the reliability of the results is dependent upon two primary considerations:

- How well the data provided to the model represent the reality of current conditions and influencing factors, in the terms understood by the model; and,
- How well the predictions of the model fit the real behaviour and the interactions between various factors for the variety of conditions to which it is applied.

Thus before analysis, the system will have to be calibrated to the existing conditions or the prevailing conditions of the study area or country [2].

5 Data Collection

The project stretch being selected for the present study is a part of an important State Highway of Kerala. The project stretch has a length of about 47km and average carriage way width of 7.5 m. A huge number of inputs are needed for analysis in software. Data collection includes primary data and secondary data.

5.1 Primary data

Primary data includes the classified volume count survey, road side interview survey, and pavement condition survey was collected for the project stretch.

5.2 Secondary data

The inputs needed in HDM-4 are enormous and for each representative vehicle the basic data like the following were collected from secondary sources and calculations:

Basic characteristics

- Physical: Passenger car space equivalent, number of wheels, number of axles
- Tyres: Tyre type, base number of recaps, retread cost
- Utilization: Annual km, working hrs, average life, private use, passengers, work-related trips
- Loading: Equivalent Single Axle Load Factor(per vehicle), operating weight

Economic unit costs

- Vehicle resources: new vehicle, replacement tyre, fuel, lubricating oil, maintenance labour, crew wages, annual overhead, annual interest
- Time value: passenger working time, passenger non-working time, cargo.

Table 1represents the calculation of time value from NSDP (Net State Domestic Product).

TABLE 1

Time Value For Bus (Work Time Value And Non- Work Time Value)

Parameter	Notation	Unit	2013
Input			
Net State Domestic Product (NSDP)	A	Rs million	1,869,976
Population	B	million	32.00
Working population: main	C	%	25.38
Working population: marginal	D	%	6.09
Working population: FTE*	E=C+(D/2)	%	28.42
Computed			
Assumed NSDP (70%) to households	F=Ax0.70	Rs million	1,308,983
Average income per FTE worker	G=(F/B)/E	Rs/year	143,950
Average income per FTE worker**	H=G/2400	Rs/hour	59.98
Work time value, with 33% overheads	I=Hx1.33	Rs/hour	79.77
Non-work time value at 30%	J=Hx0.30	Rs/hour	23.93

*Full-time equivalent workers, assuming marginal workers are employed half-time
**Assuming 2,400 worked hours per year

From the time value of bus passenger the time value of mini bus, two wheelers, car and autorickshaw was calculated. Table 2 gives the values arrived at for the other vehicle types.

TABLE 2

Time Value Of Other Vehicle Types

Vehicle Type	Time value (Rs / Hour)	
	Work	**Non work**
Bus	79.77	23.93
Mini Bus (= Bus*1.20)	95.73	28.72
Two Wheeler (= Bus *1.40)	111.68	33.50
Car (= Bus *1.75)	167.55	50.27
Auto Rickshaw (= Car*0.70)	117.29	35.19

5.3 Analysis of primary data

Table 3 gives an idea of the results that are obtained from the analysis of survey data using Microsoft Excel applications.

TABLE 3

VALUES OBTAINED FROM ANALYSIS

Sl. No	Survey	Results from analysis of survey data
1	Classified Volume Counts (3 days-24 hrs)	1. Average Daily Traffic (ADT) 2. Daily variation of traffic 3. Peak Hour Traffic 4. Directional Distribution/split 5. Annual Average Daily Traffic (AADT)
2	Origin Destination & Commodity Survey (1 day- 24hrs)	1. Zone wise influence 2. Trip Distribution 3. Trip frequency distribution 4. Commodity Distribution 5. Trip Purpose Distribution 6. Trip length distribution
3	Axle load surveys (1 day- 24hrs)	1. Equivalent Single Axle Load (ESAL) 2. Vehicle Damage Factor
4	Pavement Condition Survey	1. Distresses (in %) 2. Pavement Condition 3. Shoulder Condition 4. Road Side Drain 5. Right of way(m) 6. Carriage Way

6 STEPS FOR CALIBRATION OF HDM-4

It is important that prior of using HDM-4 for the first time in any country, the system should be configured and calibrated for local use. Since HDM-4 has designed to be used in a wide range of environments, calibration of HDM-4 provides the facility to customize system operation to reflect the norms that are customary in the environment under study (Bennett et al).

Calibration of the HDM model focuses on the two primary components which determine the physical quantities, costs and benefits predicted for the analysis, namely:

- Road User Effects (RUE) ; and
- Road Deterioration and Maintenance Effects (RDME)

The degree of local calibration appropriate for HDM is a choice that depends very much on the type of application and on the resources available to the user. For example, in planning applications the absolute magnitude of the RUE and road construction costs need to match local costs closely because alternative capital projects with different traffic capacities or route lengths are evaluated on the comparison of the total road transport costs. In road maintenance programming, on the other hand, the sensitivity of RUE to road conditions, particularly roughness, and all the road deterioration and maintenance predictions are the most important aspects [2].

6.1 Levels of Calibration

There are three levels of calibration for HDM, which involve **low**, **moderate** and **major** levels of effort and resources, as follows:

Level 1 - Basic Application

This level determines the values of required basic input parameters, adopts many default values, and calibrates the most sensitive parameters with best estimates, desk studies or minimal field surveys.

Level 2 - Calibration

This level requires measurement of additional input parameters and moderate field surveys to calibrate key predictive relationships to local conditions. This level may entail slight modification of the model source code.

Level 3 - Adaptation

This level undertakes major field surveys and controlled experiments to enhance the existing predictive relationships or to develop new and locally specific relationships for substitution in the source code of the model.

6.2 Road User Effects (RUE)

Road user effects (RUE) comprise of vehicle operating costs (VOC), travel time, accident costs, vehicle emissions (noxious gases and noise), and developmental effects. The use of appropriate calibration factors in HDM-4 pavement deterioration models will facilitate more reliable and rational prediction of pavement deterioration for the road network under considerations [2].

6.3 Road Deterioration and Maintenance Effects (RDME)

Road Deterioration and Maintenance Effects (RDME) are comprised of the deterioration of the pavement and the impact of maintenance activities on pavement condition and the future rate of pavement deterioration [2].

In this study focus is on Road User Effects (RUE) calibration rather than the Road Deterioration and Maintenance Effects (RDME). Hence the calibration factors of HDM-4 pavement deterioration models derived for Indian conditions by Aggarwal et al (2005) are being used.

7 VALIDATION OF HDM-4

After the calibration of HDM-4 to the local conditions, the model will have to be validated. For this purpose, Road User Costs Knowledge System (RUCKS) released by World Bank on February 18, 2010 is being used.

As mentioned earlier Vehicle Operating Cost (VOC) is an important component of the Road User Cost (RUC) and also it consists of more number of variables like economic costs of fuel, lubricants, tyre, maintenance parts, maintenance labor, crew time, depreciation, interest, overhead etc rather than travel time cost and accident cost components in Road User Cost. So for the process of validation, Vehicle Operating Cost values from both the applications are compared.

For the purpose of running the analysis in HDM-4 at least two alternatives including the base case should be considered. Thus two scenarios are considered including the present condition for the study:

- Base option or 'do-nothing' which is the present condition of the project stretch i.e., in 2013

ISSN 2229-5518

- Four laning of the existing two lane road or 'do-something' which is the expected condition of the project stretch in 2017 after the four laning works are completed and the facility is open to public

Ten vehicle types were used for the validation of the calibrated RUC model of HDM-4 using RUCKS. The result of VOC obtained is as represented in Table 4.

TABLE 4
VOC VALUES AND ITS VARIATION FOR 'DO-NOTHING' SCENARIO – 2013

Vehicle Type	HDM-4	RUCKS	Percentage variation of HDM-4 values from RUCKS
3-axle trucks	35.56	35.42	0.39%
Auto Rickshaws	4.09	4.36	6.24%
Bus	20.99	35.85	41.46%
LCV+Mini LCV	10.79	14.17	23.85%
Mini Bus	9.25	9.61	3.78%
Multi-axle	44.07	42.81	2.95%
New Tech Car	5.41	5.42	0.16%
Old Tech Car	11.47	11.49	0.14%
Tempo or Mini Lorry(2-axle)	22.24	22.73	2.20%
Two Wheeler	1.47	1.68	12.47%

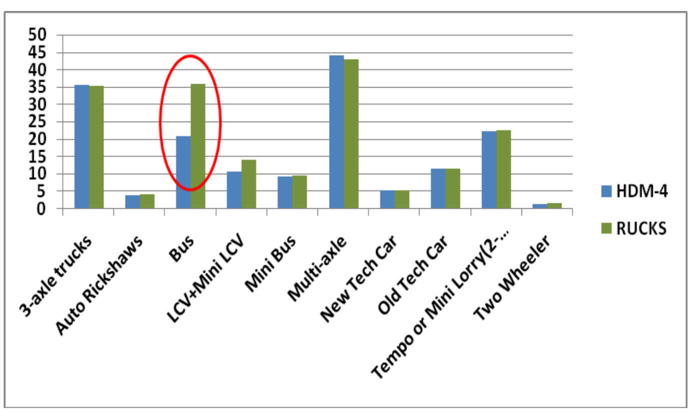

FIG 1 VOC VALUES FROM HDM-4 AND RUCKS

From Table 4 and Figure 1 it is clear that a remarkable difference in VOC is obtained in case of Bus and Mini LCV while other values are acceptable. A variation upto 15% is considered to be acceptable. However the variation in value of 2 vehicle types may be because of the difference in vehicle feature in HDM-4 and RUCKS.

Hence it was necessary to check which component shows the variation. For this purpose the percentage of Vehicle Operating Cost and Travel Time Cost which comprises Road User Cost was found. As a thumb rule the percentage of Travel Time Cost (TTC) should be more for passenger vehicles i.e.; in the range of 70% or more and Vehicle Operating Cost (VOC) around 30% or below. While for commercial vehicles this TTC component should be below 5% and VOC should be above 95%. Table 5 shows the percentage for each vehicle type.

TABLE 5
COMPONENT PERCENTAGE OF RUC

Vehicle Type	HDM-4		RUCKS	
	VOC	TTC	VOC	TTC
3-axle trucks	97%	3%	97%	3%
Auto Rickshaws	40%	60%	42%	58%
Bus	30%	70%	42%	58%
LCV+Mini LCV	97%	3%	98%	2%
Mini Bus	29%	71%	30%	70%
Multi-axle	97%	3%	97%	3%
New Tech Car	29%	71%	29%	71%
Old Tech Car	46%	54%	46%	54%
Tempo or Mini Lorry(2-axle)	98%	2%	98%	2%
Two Wheeler	23%	77%	26%	74%

From the table above its clear that the percentage of VOC and TTC for bus is not matching with the thumb rule in case of values form RUCKS. But the percentage matches in case of HDM-4 showing a correction needed only for RUCKS. As this project uses HDM-4 there is no need for correction. Thus, the software is being calibrated and can be used for economic analysis

8 CONCLUSION

While validating the values obtained in HDM-4 using RUCKS, 8 vehicle types were found to have only very minor variation in values while 2 vehicle types (Bus, Mini LCV) especially Bus, was found to have remarkable variation. A variation of value up to 15% was considered acceptable for the validation. However the percentage of RUC that goes into VOC for bus is acceptable in case of HDM-4. Thus the calibration of Road User Cost in HDM-4 was found to be acceptable. As an extension to the work, economic analysis of the road improvement scheme can also be carried out in future.

REFERENCES

[1] J Barry Standish. (2010) "An Economic Analysis of the Gauteng Freeway Improvement Scheme", Graduate School of Business, University of Cape Town, August 2010

[2] Christopher R. Bennett and William D. O. Paterson. (2000) "A Guide to Calibration and Adaptation", Volume-Five, HDM-4 User Guide

[3] Dinh Van Hiep. "HDM-4 Application For Management And Maintenance Of

Road Networks In Vietnam: Pitfalls & Future Directions", Lecture for Road Infrastructure Asset Management Course, Kyoto University & UTC Joint

[4] Eric Thompson, David Rosenbaum and Arthur Hall. (2008) "Evaluating Roads as Investments: A Primer on Benefit-Cost and Economic-Impact Analysis", Technical Report 08-0425, The Center for Applied Economics

[5] H R Kerali, R Robinson and W D O Paterson. (1998) "Role of the New HDM-4 in Highway Management", 4th International Conference on Managing Pavements

[6] H.R. Kerali, J.B. Odoki, D.C. Wightman and E.E. Stannard. (1998) "Structure of the new Highway Development and Management Tools (HDM-4)", 4th International Conference on Managing Pavements

[7] IRC: SP-30. (1993) "Economic Evaluation of Highway Projects in India", Indian Road Congress

[8] Ishtiaque Ahmed. (2009) "Project Appraisal-Cost-Benefit Analysis of Transport Projects", World Bank

[9] J Rolt, P Fouracre and A Davis. (2005) " A guide to road project appraisal", Overseas Road Note 5, UK Department for International Development, Published 2005, ISBN: 0-9543339-6-9

[10] James Adu. (2009) "Financing And Evaluation Of Investments In Road Infrastructure Development", A Thesis Submitted To The Institute Of Distance Learning, Kwame Nkrumah University Of Science And Technology

[11] L.R. Kadiyali, N.B. Lal and Rakesh Sati. (2006) "Cost-Benefit Analysis Of Rural Roads Incorporating Social Benefits", L.R. Kadiyali and Associates

[12] Michael Iacono and David Levinson. (2009) "The Economic Impact of Upgrading Roads: Draft Final Report", University of Minnesota, Department of Civil Engineering, 500 Pillsbury Drive SE, Minneapolis, USA

[13] Michael J. Markow. (2012) "Engineering Economic Analysis Practices for Highway Investment", A Synthesis of Highway Practice, Transportation Research Board Washington, D.C.

[14] Nantarat Tangvitoontham and Papusson Chaiwat. (2012) "Economic Feasibility Evaluation of Government Investment Project by Using Cost Benefit Analysis: A Case Study of Domestic Port (Port A), Laem-Chabang Port, Chonburi Province", Procedia Economics and Finance

[15] Ningning Zheng, Guoxin Liu and Yee-Chuang Jin. (2010) "Evaluation of Tools for Incorporating Road User Costs in Pavement Rehabilitation Decision Making on Rural Highways in Saskatchewan", Traffic and Transportation Studies, ASCE 2010

[16] Odoki J B and Henry G. R. Kerali. (2000) "Analytical framework and model descriptions", Volume-Four, HDM-4 User Guide

[17] P A Pienaar, A T Visser and L Dlamini. (2000) "A Comparison of the HDM-4 with the HDM-III on a case study in Swaziland", South African Transport Conference 'Action in Transport for the New Millennium'

[18] Pedro Belli, Jock Anderson, Howard Barnum, John Dixon and Jee-Peng Tan. (1998) "Handbook on economic analysis of investment operations, Chapter-11", Operational Core Services Network, Learning and leadership center

[19] Rodrigo Archondo-Callao. (2004) "The Roads Economic Decision Model (RED) for the Economic Evaluation of Low Volume Roads Software User Guide & Case Studies", Sub-Saharan Africa Transport Policy Program, SSATP Working Paper No. 78

[20] S. S. Jain, Sanjiv Aggarwal, and M. Parida. (2005) "HDM-4 Pavement Deterioration Models for Indian National Highway Network", Journal of Transportation Engineering, ASCE, August 2005

[21] Sanjiv Aggarwal, S.S. Jain and Dr. M. Parida. (2004) "Pavement Management System For A National Highway Network In India", 6th International Conference on Managing Pavements

[22] Yi Jiang, Guangyuan Zhao and Shuo Li. (2010) "Comparison of Software Packages for Life Cycle Cost and Benefit Analysis of Highway Projects", Sustainable Transportation Systems, ASCE, 2010