ROAD USER EFFECTS MODEL CALIBRATION IN HDM-4 – A CASE STUDY

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ABSTRACT

This article reports the results of study done on calibration of Highway Development and Management Model (HDM-4) for conducting economic analysis. HDM-4 developed by the World Bank is considered as the best management tool for managing pavements worldwide. However the calibration of the model is inevitable to represent the existing situation as the results of analysis will be based on the calibration accuracy and as well as on how well the model represents the realistic condition. This paper focuses on the Road User Effects Modelling in HDM-4 and validation of the model using Road User Cost Knowledge System (RUCKS).

NOMENCLATURE

RUC   Road User Cost

RUE   Road User Effects

RUCKS   Road User Cost Knowledge System
TTC   Travel Time Cost

VOC   Vehicle Operating Cost

1. INTRODUCTION

Economic evaluation is a rational approach of quantifying the future benefits and costs of proposed highway improvements. Economic evaluation makes it possible to choose the best of the various alternatives. The objective of the cost benefit economic analysis is to identify and quantify the benefits and costs associated with the project.

1.1 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.

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.

2. METHODS OF ECONOMIC EVALUATION

The following are the various methods of economic evaluation of highway projects:
- Rate of return methods Benefit Cost (B/C) ratio method o First Year Rate of Return method
- Discounted Cash Flow (DCF) methods o Net Present Value (NPV) method o Internal Rate of Return (IRR) method

IRR method seems to be the most preferred economic analysis tool. Investments in Road infrastructure development may not be evaluated using only traditional appraisal methods such as the Net Present Value (NPV), Internal Rate of Return (IRR), Annual Rate of Return (ARR), Payback Method etc. This is due to the fact that road infrastructure comes with other social and economic benefits that are difficult to quantify in monetary terms [2].

Selecting the optimal alternative in transportation projects can be a very complex affair. The analysts must consider numerous options and take into consideration the baseline data and projections of traffic flows with and without the project; the project‟s impact on generated demand and the project‟s impact on existing services. Even in relatively straightforward projects, such as roads, there are a wide range of options to consider, including the design of the road (whether or not to pave, how thick the pavement, how wide and how straight the road, etc.), limitations on vehicle size and weights, on access, and so on. 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.

3. ECONOMIC ANALYSIS USING SOFTWARES

There are a number of softwares available for the economic analysis of road projects including MicroBENCOST, Cal B/C, Redbook, RED, HDM-III, HDM-4, RUCKS etc.

The HDM-4 now provides a set of tools which can be integrated either individually or as a set within road management systems used by road agencies. The modular system design adopted for HDM-4 should

facilitate the adoption of HDM-4 as the standard tool for project analysis, work programming and long term strategic analysis of road network requirements. The technical modules permit extensive calibration of the models used in HDM-4 in order to cover the range of environment experienced world-wide. In addition, the HDM-4 software modules can be replaced, if necessary to customize their use within existing road agency management information systems [3-4].

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.

4. NEED FOR CALIBRATING HDM-4

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 other 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 [5].

5. DATA COLLECTION

A huge number of inputs are needed for analysis in software. Data collection includes primary data and secondary data.

Primary data
Primary data includes the classified volume count survey, road side interview survey, and pavement condition survey was collected for the project stretch of State Highway-1 of Kerala.

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.

Basic characteristics: This includes
- Physical: Passenger car space equivalent, number of wheels, number of axles
- Tyres: Tyre type, base number of recaps(retread), 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: This includes
- 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.

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 [5].

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 [6].

6.1 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 [6].

Hence for calibration of Road User Effects, travel time of different vehicles need to be obtained.

TABLE 1. VALUE OF TRAVEL TIME FOR BUS (WORK TIME VALUE AND NON- WORK TIME VALUE)

Parameter		Unit	2013
Net State Domestic Product (NSDP) as per State Economic review, Govt. of Kerala, 2011-12	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
Assumed NSDP (70%) to households	F=A×0.70	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=H×1.33	Rs/hour	79.77
Non-work time value at 30%	J=H×0.30	Rs/hour	23.93

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

TABLE 2. VALUE OF TRAVEL TIME 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

Govt. of Kerala, 2011-12

Table 1 represents the calculation of Value of Travel Time from Net State Domestic Product (NSDP) for Bus. From the time value of bus passenger the time value of mini bus, two wheelers, car and auto rickshaw was calculated. Table 2 represents Value of Travel Time for other types of vehicles.

6.2 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 [6].

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 Jain et al (2005) [7] are being used and is as represented in Table 3.

TABLE 3. CALIBRATION FACTORS OF HDM-4 PAVEMENT DETERIORATION MODELS

Sl. no	Model Description	Calibration Factors
1	Cracking Initiation	$K_{cia} = 0.43$
2	Cracking Progression	$K_{cpa} = 1.25$
3	Ravelling Initiation	$K_{vi} = 0.37$
4	Ravelling Progression	$K_{vp} = 0.52$
5	Potholing Initiation	$K_{pi} = 0.45$
6	Potholing Progression	$K_{pp} = 0.95$
7	Roughness Progression	$K_{gp} = 0.85$

VALIDATION OF HDM-4
After any calibration it is indeed necessary to validate the calibrated model for the purpose of accuracy. For the validation of RUC model being calibrated in HDM-4, RUCKS is used. RUCKS is an excel format software available which uses the „Macros‟ application in Microsoft Excel. For calibrating RUC in HDM-4 separate software is currently being released by World Bank. However for the present study HDM-4 Version 1.3 only is used.

Inputs to RUCKS
The inputs needed for RUCKS are the same as HDM-4, but much lesser. In RUCKS, there are 12 vehicle types already assigned with default values. This does not include the non-motorised vehicle types and so the non-motorised traffic interaction effects are not included in RUCKS. Hence there is much lesser

accuracy for the values obtained from RUCKS than HDM-4. However a comparison can be done for the purpose of validation. For this purpose the base case or „do-minimum‟ scenario is considered.

Comparison of Results

Road User Costs is an important consideration in the justification of highway investments, comparison of alternative designs, projects and programs ordering within limited budget and analysis of policy and regulation. The determination of road user cost is a key element in evaluating the highway projects [8].
For the purpose of validation the road user costs obtained from both RUCKS and HDM-4 can be compared. Road User Cost is the combined value of Vehicle Operating Costs and Travel Time Costs. So comparing RUC is similar to comparing VOC or TTC. However for decreasing the chances of error in prediction, Vehicle Operating Costs can be compared as it includes much more variables than Travel Time Cost. Thus for the present study VOC of both the softwares are compared.

Vehicle Operating Cost Values from HDM-4 and RUCKS

The variation of VOC in HDM-4 over RUCKS is indicated in Table 4 and Figure 1.

TABLE 4. VOC VALUES AND VARIATION IN HDM-4 AND RUCKS

Vehicle Type	HDM-4	RUCKS	Variation in values
3-axle trucks	35.56	35.42	0.4%
Auto Rickshaws	4.09	4.36	-6.2%
Bus	20.99	35.84	-41.4%
LCV+ Mini LCV	10.79	14.17	-23.8%
Mini Bus	9.25	9.61	-3.8%
Multi-axle	44.07	42.81	2.9%
New Tech Car	5.41	5.42	-0.2%
Old Tech Car	11.47	11.49	-0.1%
Tempo or Mini Lorry (2-axle)	22.24	22.73	-2.2%
Two Wheeler	1.47	1.68	-12.5%
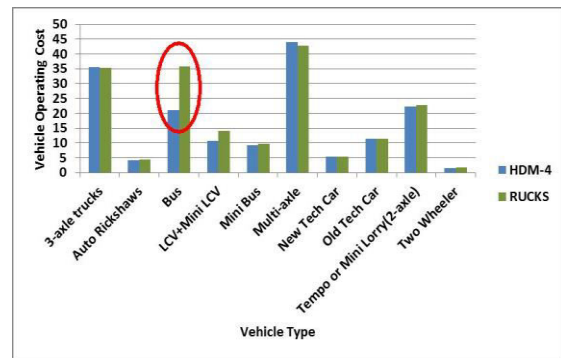
FIGURE 1. VOC VALUES FROM HDM-4 AND RUCKS

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%

TABLE 5. COMPONENT PERCENTAGE OF ROAD USER COST

Sl. No.	Observed (O)	Expected (E)	New Observed (O_i)	New Expected (E_i)	$(O_i-E_i)^2/E_i$
1	35.56	35.42	35.56	35.42	0.00055
2	4.09	4.36	4.09	4.36	0.01699
3	20.99	35.84	20.99	35.84	6.15262
4	10.79	14.17	20.04	23.78	0.58897
5	9.25	9.61			
6	44.07	42.81	44.07	42.81	0.03723
7	5.41	5.42	16.88	16.91	0.00004
8	11.47	11.49			
9	22.24	22.73	22.24	22.73	0.01098
10	1.47	1.68	1.47	1.68	0.02609
Average	16.53	18.35			

TABLE 6. CHI-SQUARED TEST

The percentage variation in VOC value upto 25% is considered acceptable. However the variation in value of bus was found to be on a higher scale. Thus it was necessary to check which component shows the variation. For this purpose the percentage of VOC and TTC which comprises RUC was found. As a thumb rule the percentage of TTC

should be more for passenger vehicles i.e., in the range of 70% or more and 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 of VOC and TTC for each vehicle type. 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.

Observed values more than the average value of observations need to be clubbed in case of Chi-Square test. Thus values 4 and 5 are clubbed as a single observation and 7 and 8 as another single observation as in Table 6.

$$\chi^2_{Observed} = \sum (O_i - E_i)^2 / E_i = 6.83346$$
Degrees of freedom= n-2 = 8-2 = 6
$$\chi^2_{critical} = 18.548 \text{ for 6 d.o.f}$$
Since, $\chi^2_{Observed} < \chi^2_{critical}$ therefore the observation is statistically proved to be acceptable.

6. CONCLUDING REMARKS

The study ended up in identification of a tool for conducting economic analysis of road improvement schemes. 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 25% 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.

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