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A FRAMEWORK FOR ECONOMIC EVALUATION OF HIGHWAY DEVELOPMENT PROJECTS BASED ON NETWORK-LEVEL LIFE CYCLE COST ANALYSIS

ABSTRACT

For economic evaluation of a highway development project, multiple criteria must be considered on a timeframe longer than the project implementation interval and a geographical area larger than the project zone. In this study, a framework is proposed based on the Network-Level Life Cycle Cost Analysis (NL-LCCA) to assess the effect of highway development projects on mobility, safety, economy, environment and other monetizable criteria. In this approach, project impacts are estimated within physical boundaries of highway network over the network life cycle. This framework can be used as a decision-making support for evaluation and ranking of pre-defined development projects, proposing new cost-effective development projects, assessment of cost efficiency of existing highway network and budget allocation optimization.

KEY WORDS

life cycle cost; network-level; project-level; economic evaluation;

1. INTRODUCTION

The process of decision-making for selecting a set of highway development projects among a group of project proposals is not a straightforward process for highway administration agencies. A number of criteria must be considered and compromises must be made in order to find suitable investment options. These criteria are different or differently weighted across various highway agencies and include improving safety, optimizing mobility and access, project cost-effectiveness, preserving the existing structure, economic vitality and environmental impact. Some of the above mentioned criteria are conflicting (safety vs. mobility or environmental impact vs. mobility) and trade-offs are essential for decision-making.

In this study, a framework is developed for economic evaluation of projects based on highway network Life Cycle Cost (LCC). Life Cycle Cost is the sum of all costs incurred to a system during its lifetime. In highway transportation, LCC of a project includes all the costs of various phases of planning, design, construction, maintenance and operation. These costs must be accumulated to calculate LCC of a project. These costs are not covered by one stakeholder or payer, but by various individuals, organizations, communities or even the whole society. Where criteria of the decision-making process can be converted into monetary terms, Life Cycle Cost Analysis (LCCA) can be used as a tool for management accounting and decision-making support.

Due to the fact that implementing a development project is not limited to the project site, LCCA within project's scope does not reflect project's total costs and benefits. Thus, the concept of Network-Level Life Cycle Cost Analysis (NL-LCCA) is introduced and highway projects are assessed by the reduction they cause on the Network LCC (NLCC). In NL-LCCA the question changes from "which alternative is the best choice for a project" to "which highway development project is economically most suitable for a highway network". Where PL-LCCA is used for comparing costs of alternatives of a single project, NL-LCCA is a means for comparing various projects and budget allocation schemes for the entire network. The NL-LCCA approach can have the following applications:

- Evaluation of existing highway network sites (road segments and intersections) in terms of LCC and economic effectiveness;
- Evaluation of the highway development projects (construction, operation and maintenance projects) in terms of LCC and economic effectiveness;
- Proposal of cost-effective highway development projects with Economic Impact Analysis (EIA) of projects;
- Compare/ prioritize projects based on NLCC savings;
- Budget allocation optimization by changing budget share of each cost module or site according to the cost it imposes on the network;
- Evaluation of highway network policies and strategies by developing "what if" scenarios.

1.1 LCCA Approaches

There are four generally accepted life cycle costing methods: Analogy model, Parametric Cost Estimate (PCE), engineering cost models and cost accounting models, [1-2].

1. *Analogy model*: is an estimation approach using historical data and a dominant cost driver. In highway construction, length of road is the dominant cost driver used for analogy and highway construction cost is often estimated using historical data on per kilometre cost. Although Analogy model is fast, well established and simple, its application is limited to instances when there is one dominant cost driver and the final products are almost identical. In addition, relatively extensive data is needed for a sound estimation.
2. *Parametric Cost Estimate*: this method is based on mathematical relationship between costs and a number of product- and/or process-related parameters. It can be stated that PCE is an upgrade to Analogy model because several parameters are taken into account instead of just one dominant cost driver. Furthermore, the relationship between LCC and parameters can be non-linear because these models are regression or response surface models in nature.
3. *Engineering cost models*: this model is based on breaking down the cost into a hierarchy of smaller cost objects and then estimating a particular cost element, item or component directly by examining the system component-by-component. This method uses Cost Estimating Relationships (CERs) to develop the accurate cost of each element and its relationship to other elements. Contrary to top-down philosophy of Analogy model and PCE, engineering cost models are bottom-up estimations because system cost is regarded as the sum of the costs of the components, from the lowest level of details upwards. This can be tricky for newly developed systems where full scale of subsystems are unknown or unclear. Hence, the engineering cost method is used where there is detailed and accurate capital and operational cost data for the system under study.
4. *Cost accounting models*: cost accounting is a process of tracking, allocating, analysing, summarizing and evaluating expenses and costs of a product or a service. The goal is to advise the management on the most appropriate course of action based on cost efficiency. Cost accounting is defined as the bridge between financial and management accounting, [3]. Financial accounting focuses on providing information for external parties such as investors and government agencies for investment and credit decisions. Management accounting, on the other hand, aims at providing information for internal parties such as managers for planning, controlling, decision-making, and evaluating performance. Cost accounting provides financial and management accounting with product or service cost information. It measures, analyses, and reports financial and non-financial information relating to the costs of acquiring or using resources in an organization, [4-5].

Where data deficiency or other time and budget constraints exist, these cost estimating models can be combined. In fact, because of the vast area covered by highway network LCC and diverse levels of data quality for different cost modules, the best way for estimating LCC is to use a combination of these estimation/ prediction models.

1.2 Economic appraisal methods

For economic performance evaluation of different highway development projects, methods for economic appraisal of investment choices must be applied. The concept of Time Value of Money (TVM) suggests the fact that the purchasing power of money changes constantly over time because of the interest and inflation rates, [6]. Life cycle of highway facilities is often a long duration of time and hence, considering the TVM concept in calculations it is of utmost importance. The discount rate is a variable which combines effects of interest and inflation rate on cash flows and it is widely used.

There are several methods for measuring the economic effectiveness of projects for capital budgeting and comparing alternatives, [6]. Net Present Value (NPV), Equivalent Annual Annuity (EAA), Net Savings (NS) and Saving to Investment Ratio (SIR) are approaches presented in this paper for measuring economic performance. However, there are several other measures used in different occasions such as Benefit to Cost Ratio (BCR), simple and discounted Payback, Profitability Index, Net terminal value, Internal Rate of Return, modified internal rate of return, sinking funds, total annual capital charge and real options.

Net Present Value is a method in which all costs and benefit cash flows during analysis period go through a discounting process to present value and then benefits are subtracted from costs. Thus, NPV takes the following mathematical form (Equation 1):

$$NPV = \sum PV(b) - \sum PV(C) \quad (1)$$

where:

$PV(b)$ = Present value of benefits

$PV(C)$ = Present value of costs

Equivalent Annual Annuity (EAA) approach calculates the constant annual cash flow generated by a project over its lifespan. EAA is calculated by dividing the NPV of a project by the present value of an annuity factor (Equation 2).

$$EAA = NPV/A_{t,r} \quad (2)$$

where:

$A_{t,r}$ = present value of an annuity factor

Net Savings method measures the benefits of a project in the form of cost reduction it brings about. For LCC, the NS of a project is calculated by subtracting LCC of the alternative project under consideration from the base scenario in the form of Equation 3:

$$NS = LCC_{base\ scenario} - LCC_{project} \quad (3)$$

In the equation above, positive NS value means that the candidate project is economically cost-effective relative to the base scenario because of the fact that lower LCC is anticipated from the project relative to the base scenario.

Saving to investment ratio (SIR) is another measure of economic performance that expresses the relationship between NS and investment cost (in present value). It is obvious that a project with the highest NS is not always the one with the highest SIR (Equation 4).

$$SIR = NS/I \quad (4)$$

where:

I = Project investment

It is helpful to mention that for projects with SIR values greater than 1.0, savings are greater than investment and the NS is greater than zero. This economic performance measure can be used for ranking a list of independent projects. If initial investment is used instead of total investment, the results will order projects based on savings to initial funding ratio.

2. LITERATURE REVIEW

The wide variety of LCCA applications makes it a well-established procedure for economic appraisal. Kirkham et al. proposed an integrated probabilistic LCC and performance model for building and civil infrastructures. In this work, a probabilistic approach called EUROLIFEFORM is described for predicting LCC. The method uses stochastic LCC model in addition to series of deterioration analysis algorithms and a decision support application for optimization of LCC design procedure, [7].

So far, LCC analysis applications are mostly limited to project-level LCC analysis where various alternatives of a single highway development project are stack up against each other to find the optimal form of project implementation. Chen et al. presented a fuzzy logic-based LCCA for agency costs of pavements and asset management. It is concluded that LCCA approaches based on soft computing techniques can demonstrate acceptable results because of the fact that available LCCA data are usually uncertain, ambiguous, subjective and incomplete, [8]. Li and Madanu introduced an uncertainty-based methodology for highway project-level LCC which can handle certainty, risk and uncertainty of input factors such as traffic growth rate and discount rate. A case study demonstrates the impacts of risk and uncertainty on estimating project benefits and costs and on network-level project selection, [9]. Amini et al. compared LCC of highways with conventional and perpetual pavements. Mechanistic-Empirical Pavement Design Guide (MEPDG) model is used for the prediction of pavement performance and HDM-4 model is used for the selection of optimum M&R practices, [10]. Goedecke et al. carried out a study on the effect of alternative fuels and vehicles on LCCA of a highway facility. A web-based model has been developed to calculate social cost, the consumer LCC and the tax for various vehicle technologies, [11].

Jawad and Ozbay investigated the effect of discount rate in LCCA of transportation projects. Using look-back analysis, it is suggested that probabilistic approaches should be applied based on distributions estimated using historical data, [12]. They also proposed a probabilistic project-level LCC optimization model for pavement management with the objective of finding strategies that can bring about an optimum gain to society. The model uses Genetic Algorithm (GA) for arriving at the optima with Monte Carlo simulation as a risk analysis technique, [13].

To trigger uncertainty bounds of discounted cost calculations, Noortwijk proposed explicit formulas for the variance of LCC over an unbounded horizon. The formulas are based on Monte Carlo simulations to estimate regenerative cycle characteristics such as cycle length and renewal cycle cost, [14].

Performance prediction of infrastructure is crucial for sound LCC practice. Sanchez-Silva et al. investigated the LCC of structures subjected to multiple deterioration mechanism including progressive degradation (e.g. corrosion and fatigue) and sudden events (e.g. earthquakes). The structural condition of facility at a given time is measured in terms of the system's remaining life, expressed by an appropriate performance indicator. A stochastic model was developed which describes the system's performance in terms of its capacity, resistance or safety availability. In that model, damage is a consequence of successive shocks and progressive deterioration. The model can provide for defining preventive maintenance strategies, [15]. Frangopol et al. reviewed various probabilistic models for LCC performance of deteriorating structures under various maintenance scenarios. Models studies include Random-variable models (failure rate, reliability index and time dependent reliability index) and stochastic-process models (Markov decision processes and renewal models), [16]. Frangopol et al. developed a conceptual framework for minimizing the expected LCC while maintaining allowable lifetime reliability for the structure. The overall cost to be minimized includes initial cost, costs of preventive maintenance, inspection, repair and failure, [17]. Noortwijk and Frangopol also presented two probabilistic LCC models for deteriorating civil infrastructures to insure an adequate level of reliability at minimal LCC. These models can be used for justification and optimization of maintenance measures, [18]. Optimization of pavement and bridge M&R practices has been subject of various researches, [19 - 20].

On application of LCC for capital budgeting and optimization, Haas et al, [21] suggested that a generic protocol for LCCA should be applicable to various infrastructure areas, incorporating consistency, rationality, practicality and understandability. It is proposed that three levels of applicability must be considered: (1) Strategic, where the desired Level of Service (LOS) for the system or network are defined and the minimum costs to achieve are determined, (2) Network, in which an optimum program for given budget(s) or funding is determined, and finally (3) Project, where LCCA can be used to identify the most economically effective alternative within a project/section/link/area. This generic protocol starts from network/system wide level towards the project or site-specific level. Based on that proposal, Daniel et al. prepared a report for the Ministry of transportation of Ontario in an attempt to develop a generic protocol for LCCA, [22]. According to Haas et al, [23] there exists a clear distinction between financial planning and LCCA. First, Financial Planning is fundamentally concerned with estimating revenues over some forecasting period and programming cost outlays through that period, whereas LCCA is used to compare the alternative uses of funds or expenditures. Financial planning is an activity to determine the financial requirements to achieve a pre-defined economic goal, while LCCA is a tool for comparing alternatives or optimizations for budget spending to satisfy a non-financial need. Financial planning and LCCA can be applied concurrently for better decision making.

Highway Development and Management Model (HDM-4) is a software package published by The World Road Association (PIARC) and the World Bank for PL-LCC estimation, prioritization of pavement projects or resource allocation for pavement networks. Three levels of analysis are possible with HDM-4; Project analysis for selection of best pavement project, Program analysis for prioritization of candidate road projects in a one-year or multi-year program under the defined budget constraints and strategy analysis for prediction of performance, funding requirements and optimal allocation of funds for pavement networks, [24].

In a study by Tsunokawa and Hiep, a unified procedure for optimizing the allocation of a network-wide budget is presented. The objective of the model is to maximize the total NPV of the entire asset system, under a system-wide budget constraint. Moreover, the model assumes that there is a procedure available for each asset subsystem called Asset Subsystem Optimizer (ASSO) to find optimal management programs, [25]. To address probabilistic nature of budgeting, Li and Puyan (2006) introduced a stochastic optimization model for project selection that considers budget uncertainty. The model was formulated as the stochastic multi-choice multidimensional Knapsack problem with Ω-stage budget recourses. Multi-choice corresponds to multiple budget levels for different asset management programs, while multi-dimension refers to multiple years of analysis. The objective was to select a subset of candidate projects to achieve maximized system benefits under budget and other constraints, [26]. Li and Sinha proposed a multi-criteria decision-making methodology for trade-off analyses between candidate projects and project selection and programming in highway asset management under certainty, risk, and uncertainty, [27]. An analytic network process (ANP) model was developed by Dikmen et al. for project appraisal and selection in a highway network. They showed that the ranking of project alternatives may significantly change when the ANP model is used instead of the classical Cost-Benefit Analysis (CBA) approach, [28]. The work by Bjornsson et al. presents a simulation model based on system dynamics methodology that can be used as a decision support system to effectively allocate road maintenance funds, [29].

In his Ph.D. dissertation, Ofosu formulated M&R investment over a multiyear programming period as a large-scale multi-objective integer non-linear optimization problem. The multi-objective approach enables trade-offs to be analysed with network parameters including present value of life-cycle benefits, asset value, and asset service index. The network optimization problem incorporates the project-level methodologies developed in the study for various highway assets such as pavements, bridges and culverts and a genetic algorithm is developed to solve the multi-objective integer non-linear program, [30].

3. DISCUSSION OF THE METHOD

The method developed in this study is illustrated in *Figure 1*. It consists of four major phases and fourteen steps including two decision-making points. It must be mentioned that the term "site" used frequently in this study refers to road segments and intersections. Road segments are a length of road between two successive intersections in which road function and geometric parameters such as road width remain approximately identical. In addition, the term *highway* refers to all public roads. For the sake of simplicity, it is assumed that project candidates have no interactions, meaning that their costs and effects are not affected by the implementation of other projects. Considering, these interactions are out of the scope of this study. The process of the NL-LCCA is described below.

I. Network identification

In this phase the highway network is determined, identified and categorized for LCCA. This phase consists of the following steps:

1. *Network Selection*: the very first step in carrying out NL-LCCA is to select the highway network for the analysis. If a highway network of a district, city or a country is selected for the analysis, the attention must be focused on the highway sites located near the boundary of the network. In addition, it must be determined what functional types of highway sites are included in the analysis. For example, it must be stated whether the intersections or collector roads are included in the analysis or not.
2. *Analysis life cycle*: An appropriate life cycle period must be considered for the analysis. For this, the highway network is regarded as a whole and a universal life cycle is selected for this "one project". Here the question changes from "cradle-to-grave" analysis of a project to a wider definition of "network life cycles". In conventional LCC, the life cycle usually begins with the planning phase of a project or facility (like a vehicle, a dam or a pavement overlay) and ends when it is no longer operable. However, when networks are considered for the process, life cycles are the timeframe in which a decision-making system and their inherent general strategy/policy or a set of technologies appear valid. For instance, a breakthrough in electric battery may alter the electric vehicle market share so drastically that fuel consumption costs which account for a fairly large proportion of highway user costs would be no longer valid. There are many other examples on how other emerging technologies such as autonomous vehicles or even external parameters such as Internet access (especially in developing countries) may mark an end to network life cycle and start a new life cycle with different cost models. Though these changes are unpredictable, selecting a proper network life cycle based on the analyser's experience may help in avoiding wrong capital budgeting decisions. In addition, changing policies and strategies may lead to the expiration of a network life cycle. For example, when the network strategy changes from "minimum delay for the whole network" to "safety without compromise" (like implementation of "Vision Zero policy" in some European countries to achieve a highway system with no fatalities or serious injuries in road traffic), then it is possible that authorities change the speed limit for a number of highways with high accident records. As a result the parameters such as fatality frequency and attributed cost, average speed and average delay of the network may change. So, vehicle operation costs, passenger and cargo time-related costs and accident costs may alter and previous LCC estimations will be no longer valid.

   Generally, an analysis period of 20 years is chosen for traffic forecasts, 20 to 40 years for pavements and 75 years or more for infrastructures such as bridges and buildings, [10, 21]. For a highway network, a life cycle of 10 - 50 years can be selected based on highway agency needs and visions.
3. *Dividing the network into zones/regions*: The highway network must be broken down into zones/regions based on budgeting organization. For example, a metropolitan area may have a number of districts among which the city budget is distributed and a part of budgeting decisions are made at the district level. Therefore, each district must be considered as a zone and analysed separately. This step is crucial for the subsequent budget allocation process. For larger projects that contain entire network or multiple zones, separate zoning process is required. In any case, zones are defined in such a way that they represent the decision maker's territory for budget allocation.
4. *Categorization of sites*: The zones can be further divided into classes of comparable sites. Although this step is not obligatory, it can help in proposing new highway development projects because each site would be compared within its own class. The classification system can be based on site type (intersection vs. highway segments) and function (e.g. non-signalized vs. signalized intersections or freeway vs. arterial). Nonetheless, road class, cross sections, number of lanes and topography can be used for classification purpose.

II. Network-level Life Cycle Costing

This phase is related to cost estimation of the selected highway network. There are key decisions that must be made in this phase regarding which cost

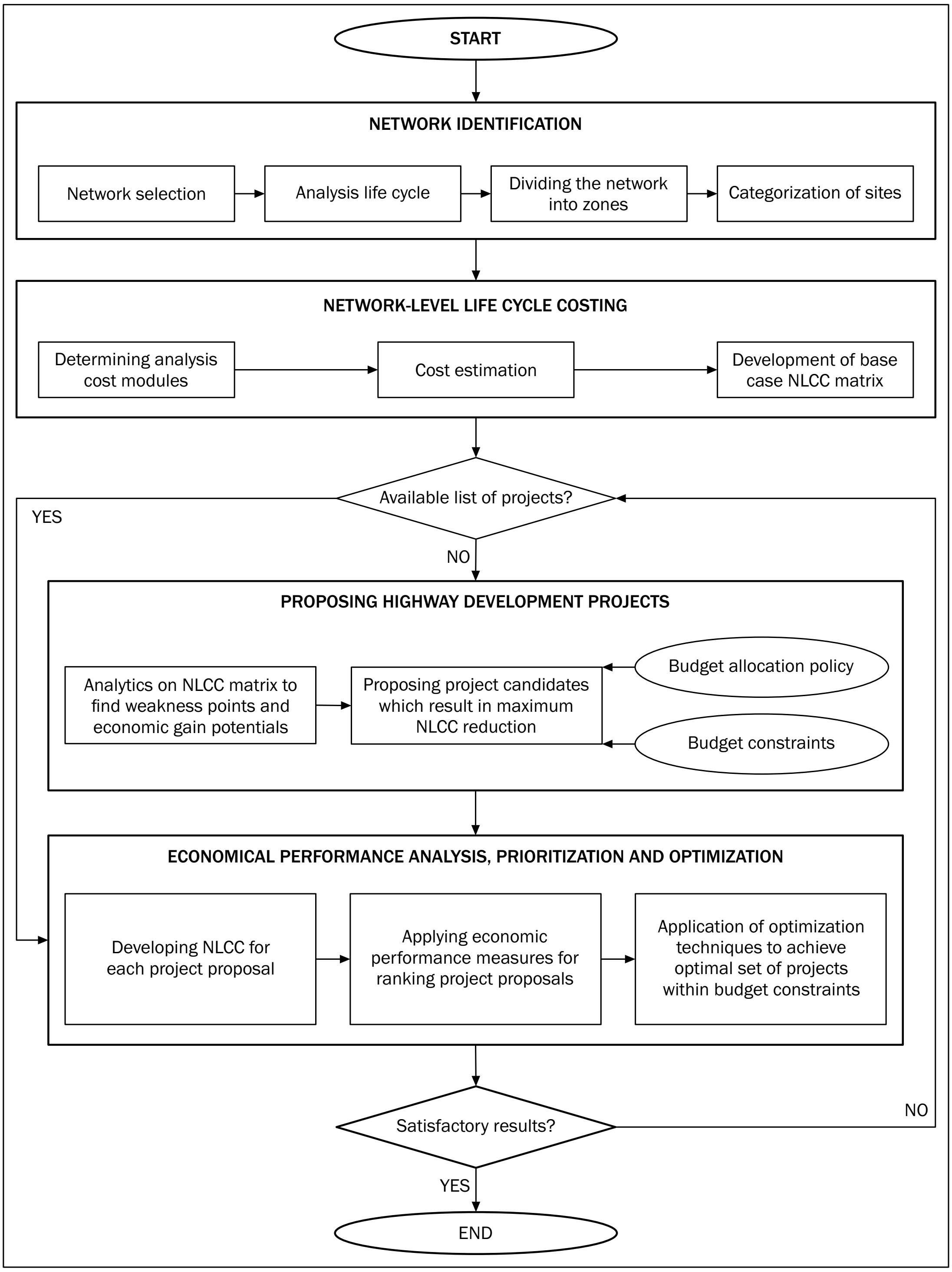

Figure 1 - Network level life cycle cost analysis framework

modules are considered in LCC from all possible cost modules (e.g. environmental costs, accident costs or work zone related delays) and which level of details are needed to achieve acceptable results. Through this phase, Cost estimation models are used for each individual cost module to develop Network LCC (NLCC) matrix. The aim of this phase is to know the LCC of highway network in the base scenario (i.e. "do nothing scenario").

5. *Determining analysis cost modules*: Five generally accepted phases of a highway facility life are highway planning, design, construction, operation and maintenance. These costs are incurred to various stakeholders including highway agencies, road users and the whole society. Cost modules of highway LCC are presented in *Table 1*.
6. *Cost estimation*: Cost estimation for each module is a major step in NL-LCCA process. Availability of

cost estimation models is limited due to the difficulty of acquiring reliable data and extensiveness of the LCC estimation process in addition to the related uncertainties. In common practice, a combination of Analogy, PCE, engineering cost and cost accounting models is used for LCC estimation. Historic cost data can be used in cost estimation process. Cost estimation in this step is for the base scenario. It means no major projects are incorporated in LCC and only routine maintenance work and operation costs are included in the estimates.

7. *Development of base scenario NLCC matrix*: In this step, NLCC matrix is developed for each zone as shown in *Table 2*. Highway sites and cost modules constitute rows and columns of the matrix, respectively. As can be seen, each highway project development phase is further subdivided into various cost modules/submodules. The sum of all the elements in a row result in total site cost and the summation of all column elements leads to total module/submodule cost in that particular zone. It must be noted that for the existing sites during the specified life cycle, some phases like planning, design or construction may not occur. In this situation, the respective costs are set to zero. On the other hand, if new highway sites are considered for the highway network expansion, the costs incurred to stakeholders in all phases must be taken into account, i.e. costs of sites are only included in this matrix if they occur during previously determined network life cycle (step 2).
8. After step 7, if a set of project proposals is already prepared for the highway agency and there is no need to submit new project proposals, phase III can be skipped. This occurs when economic assessment and ranking of pre-defined projects is the purpose of NL-LCCA instead of finding solutions to minimize highway NLCC. If proposing projects is intended as a part of the program, phase III must also be carried out.

III. Proposing highway development projects

The goal of this phase is to find the weakness points of highway network where too much money is spent and to address this problem by proposing projects with the aim of cutting highway NLCC.

9. *Analytics to find weakness points and economic gain potentials*: After completing NLCC matrix, the sites with the highest costs are determined (e.g. intersections with a considerably higher LCC compared to all other non-signalized intersections). If step 4 of the procedure is carried out (Categorization of sites), the sites which show the highest LCC in their own class may have higher improvement potential. In addition, high module/submodule cost can be noticed (e.g. high environmental costs) and proposals can be made to lower costs of that module. Abnormally expensive cost module in a site is also of concern (e.g. a collector road segment with unusually high accident cost in comparison with similar collector road segments). On the whole, the matrix can be a base for data mining to find what can be done to reduce life cycle cost.
10. *Proposing candidate projects which result in maximum NLCC reduction*: In this step, highway development projects are proposed as LCC cutting remedies. Here, budget allocation policies and budget constraints must be acknowledged to avoid proposing inappropriate solutions, e.g., if maintenance budget is separate from safety, total budget cannot be spent for safety alone. Likewise, initial cost of projects cannot exceed available budget. These budget restrictions must be fully understood before proposing candidate projects. An interesting point to mention is that NLCC matrix can be a tool for fine-tuning budget allocation. The insight it gives in terms of the distribution of LCC among various cost modules or road classes can help decision makers adjust budget allocations. For example, if environmental pollutants impose higher than expected cost on society, the budget must be targeted to measures such as vehicle inspection to avoid further health-related costs. Moreover, when a large proportion of accidents occur at intersections, increasing intersection share of safety budget may seem a logical choice.

IV. Economic performance analysis, prioritization and optimization

11. *Developing NLCC matrix for each project proposal*: Developing NLCC matrix of step 7 is repeated here, but this time it is with the assumption that the candidate project is implemented. The resulting matrix would be the same as the base NLCC matrix except for the entities that are affected by the implementation of the candidate project. For example, widening an existing highway may cause an LOS improvement on both the segment itself and the adjacent parallel highways and therefore user cost reduction in all of them. In this respect, this procedure is capable of portraying the effect of highway development project on the network as a whole. This can be regarded as an Economic Impact Analysis (EIA) of a single project on the total highway network. To calculate NLCC matrix for each project, the effects of each measure (e.g. implementing lighting system for a road segment) or project (construction of a new highway) must be calculated, estimated or predicted. In some cases where data or prediction models are non-

Table 1 - Classification of Cost modules in various phases of highway life cycle (only major payers are indicated)

Phase	Cost modules
Planning	Pre-planning ^{a}, Feasibility Study ^{a}, Preliminary project studies ^{a}
Design	pre-design ^{a}, determine project scope ^{a}, analyse the existing road ^{a}, typical section design ^{a}, geometric design ^{a}, design of other geometric elements ^{a}, drainage design ^{a}, field inspection ^{a}, reports ^{a}, bridge design ^{a}, tunnel design ^{a}
Construction	pre-construction ^{a}, earthwork ^{a}, paving base courses ^{a}, bituminous pavements ^{a}, major structures ^{a}, misc. construction ^{a}, construction of tunnels ^{a}, construction of bridges ^{a}, traffic control devices ^{a}, deforestation ^{s}, contamination ^{s}, destroying wildlife inhabitant ^{s}, material consumption ^{s}, gas emission ^{s}, delay cause by road closure ^{u,s}, accidents caused by road closure ^{a,u,s}
Operation	management cost ^{a}, value of time ^{u}, vehicle operation cost ^{u}, accident costs ^{a,u,s}, environmental cost ^{s}
Maintenance	Preventive maintenance ^{a}, repair ^{a}, repave ^{a}, reconstruct ^{a}, rehabilitation ^{a}, reconstruction ^{a}, maintenance of traffic control devices ^{a}, bridge / tunnel Maintenance ^{a}, other Maintenance procedures ^{a}, traffic delay caused by work zone / Congestion ^{u,s}, accident cost ^{a,u,s}

a: agency cost, s: social cost, and u: user cost

Table 2 - General NLCC matrix form for each zone

Sites \ Modules	Planning				Design				Construction				Operation				Maintenance				Total site cost
	S_1	S_2	...	S_N	S_1	S_2	...	S_N	S_1	S_2	...	S_N	S_1	S_2	...	S_N	S_1	S_2	...	S_N	
Site 1																					
Site 2																					
...																					
Site N																					
Module cost																					

S: cost module/submodule

existent, well-established engineering assumptions may be the last resort.

12. *Applying economic performance measures for ranking candidate projects*: Economic performance measures like EAC, NS, SIR and BCR are suitable for project rankings. The benefit of a proposed project is equal to the savings compared to the base scenario. Thus, it would be feasible to calculate net saving, benefit-to-cost ratio or saving-to-investment ratio. The selection of suitable economic performance measure is dependent on the policies and strategies of the analysing organization. For instance, if Performance measures EAC is used in calculations, the projects which lead to lower EAC for the entire zone will become favourable. In the case that initial capital is tightly restricted, SIR may be more informative for the reason that it takes initial funding requirements of the proposals into account.

    The NL-LCCA methodology is a single-criterion synthesis approach. In this method, a single objective function of LCC is considered and then the decision can be made implicitly by determining the project alternative with the highest value of NL-LCCA cost reduction. This method is applicable where the criteria are either monetary (e.g. cost of pavement maintenance) or can be translated into monetary terms (e.g. when it is logical, acceptable and ethical to consider economic value for safety or environmental pollution). But if non-monetizable criteria such as safety perception of the project to road users or the highway beauty must also be considered in the process of decision making or if ranking of projects based on Multi-Criteria Decision Making (MCDM) is intended, Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), or outranking methods such as ELECTRE or PROMETHEE must be used, [31, 32].

13. *Application of optimization techniques to achieve optimal set of projects within budget constraints*: After developing a list of projects and their respective benefits and cost, mathematical optimization techniques can be used for the purpose of selecting the optimal set of projects which fit into the available budget. Based on the deterministic or probabilistic nature of the calculated LCC costs and savings, linear programming, integer programming and stochastic programming can be applied for optimization. Integer Programming (IP) is a useful tool for prioritization in that it can take binary values 0 for rejection and 1 for acceptance of the project proposal. Optimal set of projects are defined in such a way that NLCC savings are maximized. Equation 5 is an example of this kind of optimization problem:

$$\text{Maximize } NS_{Total} = \sum_{i=1}^{m} NS_i$$
$$S.t. \sum_{i=1}^{m} Pcc_i(X_i) \leq \text{Available budget} \tag{5}$$

where:

X_i = 0 or 1

Pcc_i = construction cost of project i

NS_{Total} = total NS from all projects

The equation form can be modified according to the situation and the economic performance measure used. Other constraints such as allowable maintenance and operation costs may also be put to limit results. The final list is a set of projects which are suggested to reduce LCC of the network.

14. *Checking results*: The final list of projects must be investigated to check whether the results are satisfactory or otherwise, new proposals are to be developed. Since suggesting development projects is a subjective task, the whole framework is only able to deliver "good enough" solutions and rank them. So, the process must be repeated from step 8 if new project alternatives are to be developed.

Although it is difficult to obtain high quality data for the entire network, acceptability of lower accuracy degrees for NL-LCCA compared to PL-LCCA facilitates the process. This is due to the fact that decisions which are to be made by this framework are of a large scale. NL-LCCA compares a wide variety of project proposals over highway network whereas project-level LCC is applied to compare multiple alternatives of a single project. So, cost estimation based on Analogy models or PCE should be sufficient for many cost modules in NL-LCCA. The selected projects can go through PL-LCCA for more precise cost estimation.

4. CONCLUSION

In this study, a methodology is presented for the economic evaluation of highway projects based on the Network-Level Life Cycle Cost (NL-LCCA). This framework consists of four major phases; network identification, Network-level life cycle costing, proposing highway development projects and economic performance analysis, prioritization and optimization. Through these phases, Total Cost of Ownership (TCO) and LCC are calculated for a pre-determined analysis period, referred to as a life cycle. Highway development projects in terms of constructing new sites or modification of the existing network can be prioritized and ranked by the amount of savings they can bring to network LCC.

While PL-LCCA is a tool for comparing various alternatives of a project within a highway network, NL-LCCA can be used for other applications including economic evaluation of existing network, economic impact analysis of proposed development projects, proposing economically justified projects, budget allocation optimization and evaluation of policies and strategies. In addition to the above-mentioned applications, prioritization of highway projects based on NLCC can be done by NL-LCCA framework. The framework extends the current applicability of LCCA from just analysing a number of alternatives within a single project boundary to the assessment of the whole highway network.

The resolution of data essential for NL-LCCA is lower compared to the project-level PL-LCCA which translates to lower degree of accuracy needed for the analysis. This is because the scope of NL-LCCA is larger and the decisions must be made for the whole network. However, for more detailed decisions, the results of NL-LCCA framework go through further scrutiny with conventional PL-LCCA approach.

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چکیده

ارائه چارچوب ارزیابی اقتصادی پروژه‌های توسعه راه بر مبنای تحلیل هزینه چرخه عمر در سطح شبکه

برای ارزیابی اقتصادی پروژه‌های توسعه راه‌ها باید معیارهای مختلفی در محدوده جغرافیایی و زمانی گسترده‌تر از محدوده پروژه مورد سنجش و ارزیابی قرار گیرد. در این تحقیق، چارچوبی بر مبنای هزینه چرخه عمر سطح شبکه برای ارزیابی تاثیر پروژه‌های توسعه راه‌ها بر پایه معیارهایی نظیر قابلیت جابه‌جایی، ایمنی، اقتصاد، محیط زیست و سایر معیارهای قابل تبدیل به معیار مالی پیشنهاد شده است. در این رویکرد، تاثیر پروژه‌ها در محدوده فیزیکی شبکه و در چرخه عمر شبکه سنجیده می‌شود. تصمیم‌گیری‌های مرتبط با ارزیابی و رتبه‌بندی مجموعه پروژه‌های از پیش تعریف شده، تعریف پروژه‌هایی جدید با کارایی اقتصادی قابل قبول، ارزیابی کارایی اقتصادی شبکه راه‌ها و بهینه‌سازی تخصیص بودجه از قابلیت‌های چارچوب پیشنهادی است.

کلمات کلیدی

هزینه چرخه عمر، سطح شبکه، سطح پروژه، ارزیابی اقتصادی

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