DEVELOPMENT OF WHOLE LIFE COST MODEL FOR ROAD TUNNELS

A Thesis

submitted in partial fulfillment of the requirements for the award of the degree of

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with specialization in

CONSTRUCTION MANAGEMENT

by

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CERTIFICATE

This is to certify that the work which is being presented in the thesis titled ***"Development of Whole Life Cost Model for Road Tunnels"*** in partial fulfillment of the requirements for the award of the degree of Master of Technology in Civil Engineering with Specialization in **Construction Management** and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Nikhil Rathore** (Enrollment No.162604) during a period from July 2017 to May 2018 under the supervision of **Dr. Gyani Jail Singh (**Assistant Professor), Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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Suggestions for improvement are most welcome.

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ABSTRACT

Construction of infrastructure involve large capital investments along with future costs to operate and maintain these assets. Decision making in planning and design of roads will impact the need of future operation and maintenance activities. The primary decision making process in civil engineering construction often considers only the construction costs; but in case of road tunnels the maintenance and lightning costs also plays a major role and cause a major cash flow. A road tunnel has construction cost as major capital cost component while the annual cost components include electricity cost, lightning equipment cost, pavement repair cost, cost incurred in cleaning and drainage etc. Therefore, there is a great need to plan the construction, operational and maintenance costs to attain a cheapest solution possible.

For successful execution of whole life costing in road planning, design and administration, various conditions are needed to be understood. In this thesis the application of whole life costing on a road tunnel has been examined. The main case selected was a road tunnel 2.8 km long situated at Aut in Chandigarh-Manali national highway. This case was examined to identify the most sensitive parameter, by using sensitivity analysis and net present value method, that affect the total cost of the tunnel to a great extent.

Keywords: Construction cost, Whole life cost, Sensitivity analysis, Tunnel.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

1.1.1 DEFINITION OF WHOLE LIFE COSTING

Whole Life Cost analysis (WLCA) is a practical approach for evaluating the total cost of a program or a project ownership. WLC analysis is utilitarian when project options that meets the same performance demands, but differ w.r.t. maintenance and operations costs, are to be equated in order to choose the one that capitalize on net economies while the standards of required quality can be maintained simultaneously. Its practical application means considering total costs including costs of acquiring, constructing, owning and finally disposing or handling of a structure or structural utility.

This approach has earlier been called by many names: life cycle costing (LCC), costs-in-use, total-life-costing, ultimate life cost, total cost, total-cost-of-ownership, and terotechnology. Various researchers and project managers have defined WLC according to their simplicity:

WLC has many definitions and the most basic of which is: “WLC includes the systematic consideration of all costs and revenues associated with the acquisition/construction, usage, maintenance or repair and disposal/demolition of an asset”.

Kirk and Isola [1] depict WLC as “methodology to identify the substantial costs associated with different alternatives in hand, add groups of costs by year, discount them back to a common base period (known as study period) and finally to select the most optimum cost alternative”.

Kishk et al. [2] defined WLC as an analytical tool to assist in evaluating the cost performance of construction works, whose sole aim is to help project managers to choose between the choices where there are alternate means of achieving the client’s objectives and where those alternate means differ in their initial costs as well as in their subsequent operational and maintenance costs. Emblemsvag [3] defined WLC as the total costs that are incurred, or might be incurred, in all phases of the element's life cycle. According to Smith [4] "WLC allows the financial implications of future savings due to additional investments made at present for enhancing performance (e.g. energy efficiency or durability of materials) which ought to be evaluated for decision making". According to Fuller [5] there are number of costs related with acquiring, constructing, operation, maintenance/rehabilitation, and disposal of a building or a building system. As indicated by him the building-related expenses typically fall into the accompanying classes:

- Initial Costs—Purchase, Acquisition, Construction Costs
- Energy or Fuel Costs
- Operation, Maintenance, and Repair Costs
- Disposal Costs or Residual Value (depreciation)
- Replacement Costs
- Non-Monetary Costs

Heralova [6] describes that whole life cost generally consists of an initial investment, i.e., construction costs and the subsequent costs, such as ordinary payments (energy, cleaning, utilities, and maintenance, irregular costs for replacement or renewal), while in some WLC methods costs related to demolitions are also included.

Boussabaine and Kirkham [7] defined WLC as "the sum of the total indirect, total direct, total nonrecurring, total recurring, and other costs incurred or estimated to be incurred in the design, development, production, operation, maintenance, support and final disposition of a system over its anticipated useful life span.

Few points regarding the principle goals of WLC according to Fuller [5] are as: (1) Recognizing the aggregate cost responsibility as opposed to focusing on the initial capital expenses; (2) Encouraging a viable decision between elective techniques for accomplishing an expressed target; (3) Particularization of the current working expenses of advantages, for example, singular building components (i.e. warming systems, rooftop covers), or finish building frameworks; (4) Recognizing those territories in which working expenses may be diminished, either by a change in working practice e.g. hours of activity, or by changing the pertinent framework and (5) Deciding the elements of support costs keeping in mind the end goal to diminish it.

1.2 NEED OF THE STUDY

The absence of sufficient and appropriate data is a major barrier to the application of WLC in construction industry. The application of WLC is trapped in a vicious circle containing: lack of sufficient data, lack of real evaluation, lack of confidence in any result and no real feedback on performance. WLC analysis is more of a hypothetical concept rather being a practical one in construction industry. The most of the research in the field of WLC analysis is devoted to water resources and transportation projects, including highways, bridges, and pavements. WLC is an emerging concept in construction industry and a very little work has been done in field of road tunnels. This thesis focuses on applying the WLC analysis on a road tunnel.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

While managing a typical project at all stages, excluding project initiation, have a potential use of WLC. The application of WLC exists on two levels: (1) Management tool, is a lower level of WLC and is used to aid the decision making process. (2) Management system, is a higher level of WLC whose working dictates that responsibilities for asset management should be retained. To understand the concept of WLC and to find the research gap some of the literatures related to the present work are considered as:

2.2 LITERATURE REVIEW

Sherif and Kolarik [8] traced the advancement of the LCC strategy in the United States, grouped archived LCC literature by both model type and application and distinguished the framework qualities which add to the achievement of the LCC techniques. The LCC analysis gained major importance during early 1960's and according to them the LCC was initially created as a formal examination tool by the US Department of Defense. The development of a LCC model suffers because of following factors: (1) varying degrees of system performance, specifications etc. (2) sensitivity to plan changes, planner user interface and so forth. (3) qualities of frameworks, for example, activity and maintainability (4) environmental condition (5) impacts of development and support process (6) data integrity and future projections etc.

Novick [9] reported about existence cycles, designing contemplations, examines and training required for completing LCC investigation. He ordered the building contemplations in every life cycle as: capital programming idea, think about/choices examination, arrangement of outline and contract reports, development activities, investigation, support, repair or recovery and recreation or substitution. As indicated by him the urban plan measures ought to be widely adjusted to reflect balanced assessments of life-cycle costs in light of new outline criteria that reflect likely recreation intended to most recent 150 years or more. Yet, this procedure will be long, troublesome, complex, and exorbitant since the work requires building chiefs and development contractual workers who are learned and experienced in reproduction under movement, railroad, and interstate tasks, and development techniques in every one of these orders.

Fwa and Sinha [10] examined the pavement performance in LCC analysis of a road thinking about the roadway offices and street clients having inclinations for procedures with better pavement performance. Two methodologies to be specific, quantitative performance measure and building up a connection between quantitative advantages and asphalt serviceability esteems were proposed for quantitative appraisal of the inclinations. For each approach, the expository edge work for incorporating asphalt execution contemplations into LCC examination was sketched out. To think about the diverse general asphalt exhibitions of different techniques, the principal approach influences utilization of a present serviceability to list and Pavement execution quality list. The second approach relies upon building up a connection between quantitative advantages and asphalt serviceability esteems. It was discovered that the consolidation of asphalt execution thought into a financial examination offers a more total assessment of various asphalt techniques.

Dale [11] Historically, the cheapest alternative for construction was considered the best financial option and hence the designs were solely intended at minimizing the initial cost of construction. However, during the 1930s stakeholders and building owners began to realize that the operation costs of buildings (repair, re-installment of equipment, energy consumption etc.) also plays a crucial role in overall cost of a building. It was found that the alternative with the lowest cost of construction was not always the cheapest solution over the whole life of a building. Thus it become indispensable that some financial analysis tools, that take into account the operation cost of the project, must be taken into consideration.

Arditi and Messiha [12] led a study of the biggest districts in the U.S. to research the utilization of LCC investigation. The overview pointed that lone 40% of the districts utilize LCC investigation while the staying 60% did not utilize LCC. Generally littler urban communities were observed to be more reformist in expanding the degree of undertakings where LCC is utilized. A large portion of the examination in the field of LCC investigation is dedicated to water assets and transportation ventures, including roadways, extensions, and asphalts. A more utilization of LCC in customary support ventures and amid the offering and development stages is expected to accomplish the full points of interest of LCC examination. The principle purposes behind not utilizing LCC investigation in urban communities are the absence of standard or formal rules for the utilization (65%), absence of dependable past information (30%), the incapacity to decide future expenses and factors (26%) and different reasons (27%).

Frangopol et al. [13] illustrated a lifetime optimization methodology for planning the repair and inspection of concrete structures that deteriorate over time. A Reinforced Concrete T-girders from a highway bridge subjected to corrosion were used to illustrate the approach. The optimization depended on limiting the expected total LCC that incorporated the initial expense and the expenses of preventive maintenance, examination, repair, and failures. By analyzing down the T-girder results were obtained for both uniform review time interims (where just the quantity of investigations was improved) and non-uniform assessment time interims (where both the quantity of examinations and the time interims were improved). The impacts of fluctuating consumption rates, distinctive examination systems, and alternate expenses of failure on the ideal arrangement were likewise analyzed. An event tree examination was utilized to explore all conceivable repair events related with the repair or no repair activities. They found that (1) the ideal non-uniform time interim examination/repair methodology is more financially economic and requires less lifetime investigations/repairs than that in light of uniform time interim reviews. (2) the ideal number of examinations and the ideal expected total cost both increases as the corrosion rate increments. (3) the cost of failure fundamentally influences the ideal assessment and repair strategy. A higher failure cost prompts an ideal arrangement requiring more examinations and repairs at a higher total cost. (4) the normal total cost was most delicate to the corrosion rate and the cost of failure and was moderately insensitive to the nature of assessment and the quantity of lifetime examinations over the optimum number.

Silwferbrand [14] defined the difference between active and passive maintenance of a structure. According to him the active maintenance strategy should be used in combination with a life cycle cost as it is far better than the passive maintenance. The active maintenance is explained as “doing the maintenance when there is a need for it” rather than “doing maintenance with a certain frequency without knowing the actual need”, which is more like passive maintenance.

Lindqvist et al. [15] explained in detail the Whole life cost analysis and railway tunneling. His work was focused on how the LLC analysis can be used to decide the most favorable alternative while constructing and maintaining a railway tunnel. The study was more of a theoretical guideline rather than a practical manual. His study suggested that correct and abundant data is required carry out LCC analysis of a railway tunnel.

Sterner [16] presented the results from the survey which is used to examine the use of LCC in the building sector, the benefits and its extent of use for the users and client perspective. But there were many constraints at various levels i.e. uncertainties to forecasts for long term inexperience in using LCC models, ineffective input data. The conclusion that can be drawn from the survey are: (1) LCC model use was limited by Swedish clients, survey shows that for making investment decision 66% used life-cycle perspective. (2) Advanced LCC calculations were used for installation systems and not for building project. (3) Most important parameter for the LCC of the building is energy investments and maintenance costs. Also disposal cost was included by some clients. (4) There were many constraints at various levels i.e. uncertainties to forecasts for long term, inexperience in using LCC models, ineffective input data. The constraints can be overcome by creating databases that are suitable with LCC models.

Cole and Sterner [17] distinguished a portion of the basic gaps between the hypothesis and practice with regards to LCC investigation to find systems that empower more prominent utilization, portrays and sorts a portion of the key purposes behind its restricted use in practice. As indicated by them LCC has customarily been considered as the methods by which beginning and working expenses are consolidated into a solitary monetary figure over a predetermined timeframe for settling on educated and powerful choices. LCC is regularly seen as an apparatus that can be connected discretely at any purpose of a benefits life cycle to survey the minimum cost choice among contending choices. They found that the restricted direct utilization of LCC in building configuration is essentially identified with imperatives information precision and in current outline hone and without utilizing a formalized LCC approach, cost related issues normally default to utilizing capital cost as the essential premise of contrasting options and in this manner it isn't currently widely practiced.

Aouad et al. [18] sketched out the examination procedure related with the improvement procedure of a coordinated LCC database, information catching mechanism and connected restrictions with the advancement procedure to encourage adaptable techniques for foreseeing all out LCC of development resources and their segments and to limit the effort required to play out the LCC investigation. They directed the LCC investigation on two levels: (1) First level of examination is at the building, or general resource level, and will give a sign of building performance (vitality utilization, administration, cleaning, rates and protection). (2) in second level individual components will be viewed as, considering every single arranged cost (obtaining, upkeep, working, transfer) over the life cycle of that specific segment. Three fundamental database administration framework can be utilized for building up a coordinated whole life costing database: A Relational Database Management framework (RDBMS), an Object Oriented Database Management System (OODBMS) or an Object Relational Database Management System (OORDMS). The decision of the framework relies upon the multifaceted nature of information and the many-sided quality of inquiries that the framework will get. They found that the LCC strategies are not broadly utilized inside the development business as a result of issues related with LCC related procedures, for example, information catch, dependability, conviction and trouble among configuration groups to visualize the effect of their choices on inhabitance costs.

Meiarashi et al. [19] outlined two roadway suspension bridges made of ordinary steel and advanced all-composite carbon fiber fortified polymer (CFRP), and analyzed down their life-cycle costs. (1) got the steel and composite roadway connect plan in the same dimensional particular (2) procured the future cost of the CFRP pultrusion item through hearing examination (3) figured the underlying expenses of the steel extension and CFRP bridge in view of the outline determination and the future cost of CFRP (4) analyzed the life-cycle cost of the steel and CFRP bridge under a few states of rebate rate, repair cost, and cycle (5) found the basic condition where the CFRP bridge turns out to be more LCC viable than the traditional steel connect. They utilized the pultrusion shaping strategy for all composite highway spans as a result of its generally excellent control performance and large scale manufacturing ability and expected that the cost of development work for the CFRP bridge and steel bridge is same. If the LCC analysis is performed using the current material price and if the future material price is reduced only according to the mass-production effect the economic efficiency of steel bridge is more than that of the CRPF bridge. The LCC viability of the CFRP bridge is delicate to specific factors, for example, the genuine rebate rate, the cost of the steel bridge repainting, and the recurrence of the steel bridge repainting and if these fulfill some particular conditions, the CFRP bridge turns out to be more financially cost effective than the steel bridge. The CFRP bridge, under to a great degree delicate ground condition, may offer a noteworthy favorable position over the steel connect in lessening the aggregate cost of the total structure.

Furuta et al. [20] examined the connections among the minimization of LCC, the ideal expansion of auxiliary administration life, and the objective security level by utilizing the multi-objective genetic algorithm. They concentrated on three goals: (1) LCC is minimized. (2) Service life is expanded. (3) Target wellbeing level is amplified. They inspected the connections among these three target capacities for a bridge through the multi-target optimization process and acquired Pareto solutions. They found that the maximization of durabilities or expansion of administration life can't be acknowledged without expanding the cost. Then again, the minimization of LCC can't be acknowledged without diminishing the administration life or potentially the durability level. It was likewise affirmed that LCC, service life and strength level have exchange off relations. So as to acquire these relations and locate an ideal support design, the multi objective genetic algorithm is a helpful tool.

Frangopol and Liu [21] outlined a portion of the current achievements and portrays the future difficulties in LCC analysis for highway bridges. They gave the fundamental foundation keeping in mind the end goal to evaluate elective bridge speculation choices in view of LCC and concentrated on utilization of LCC investigation in computerized administration frameworks of highway bridges with accentuation on ideal maintenance planning using both preventive and essential maintenance strategies. Two diverse support systems that were considered are: silane and do nothing but rebuild. The silane treatment is a time based upkeep intervention that lessens chloride infiltration in reinforced structures and along these lines decreases crumbling of condition and in addition safety. No repair of existing defects or substitution of crumbled parts is done. Rebuild activity is an performance based upkeep technique. One applies this activity when the safety index down crosses a deterministic edge of 0.91. Both condition and safety index are expanded to those of another auxiliary part and after that their deterioration procedures are deferred. Future difficulties were brought up for creating network level BMS that all the while meet both monetary imperatives of maintenance endeavors and typical traffic stream necessities.

Zhang et al. [22] examined the LCC for four bridges (the George Washington Bridge, the Outerbridge Crossing, the Goethals Bridge, and the Bayonne Bridge) and two tunnels (the Holland Tunnel, and the Lincoln Tunnel). A definitive target was to build up a far reaching LCC examination demonstrate for the two extensions and passages over the whole administration life of each. The aggregate LCC sooner or later in time are the total estimation of beginning costs, repair and restoration expenses, and yearly support costs up to that point. It was accepted that 25% of the announced yearly consumptions were for support and the staying 75% were working expenses, and the last are prohibited from this investigation. To think about the time-subordinate advancement of aggregate LCC, the proportions of aggregate LCC to beginning expense proposed that (a) the collected expenses for support, repair, and restoration as a level of introductory development cost are pretty much reliable for spans amid the initial 65 years of their administration life and (b) these expenses for tunnels are for the most part like those for bridges. Alongside this they found that these structures required significant restoration not long after they achieved a time of around 50 years.

Labi and Sinha [23] examined the cost viability of different levels of life-cycle preventive maintenance (PM) for three asphaltic solid asphalt functional class families. The cost parts were assembled into three families and for each practical class the zero-maintenance execution curve was built up. Utilizing the evaluated expenses and adequacy they created factual models to depict the connection between life-cycle PM effort and its viability in expanding the asphalt life, per unit cost. At that point they defined a few elective PM methodologies for every asphalt family, evaluated the execution bounces and expenses of constituent treatments and in this way decided the general life-cycle execution patterns, from which the administration life comparing to every methodology was assessed. The demonstrating results showed that expanding PM is for the most part connected with expanding cost viability broadened asphalt life per unit venture just up to a specific ideal point after which diminishing cost adequacy is watched. The affectability of PM cost viability might be great or terrible, contingent upon the present level of PM subsidizing, the size of the affectability, and reduction or increment in PM financing in a given arranging period.

Liang et al. [24] studied the LCCA of existing prestressed concrete (PC) bridges. A sensible analytical model was set up and provided for evaluating existing PC bridges. The model comprised of design, quality assurance, production, capital benefits and other expenses. Two existing PC bridges (The Ching-shoei bridge and The Keelung Gang-xi viaduct) in Taiwan were used to verify this analytical model. They proposed a method to find out a predicted value of an overall structural cost required bases on the accumulated lifetime. Their approach was to optimize the lifetime inspection and repair strategy of corrosion-critical prestressed concrete (PC) bridges based on the cost-effectiveness and/or failure probability. This method can be used for any type of structural damage whose development can be modeled after some time. The results of their study demonstrate that the analytical model is very reasonable, reliable, and serviceable and can be utilized as an engineering decision-making tool for the repair, fortifying or demolition rankings for existing PC bridges.

Chang et al. [25] focused on transportation facilities to explore its LCC, establish database framework of sign and then offers the administrators as a reference factor when they estimate maintenance budget. Three maintenance strategies defined by them are as: reactive maintenance, preventive maintenance, and assessment maintenance to optimize the sign facility cost. The database of the system includes basic data, inspection data, and maintenance data to provide the prediction base of LCC. According to these three kinds of maintenance strategies, system can calculate cost for each year in the future to provide a budget suggestion for administrators. Their study provides administrators a method to manage sign facilities and to predict its budget. They have used 'transportation infrastructure basic data inspection standard' as general database and design database for sign facilities. By using vulnerability analysis, they determined the environment database.

Kim et al. [26] developed a LCC system to support the feasibility studies for Light Rail Transit construction project in Korea. The investigation was performed by dividing the whole procedure into predesign and post-design stages. In the pre-plan stage, the investigation was finished by utilizing elements, for example, deck, orbit, building, electric power, signal, correspondence, and the streetcar line. It included performing out a monetary investigation before a LRT is planned and is customized to calculate total development and upkeep cost. In the post-plan stage, development cost and support cost were ascertained by entering point by point design data by structure and includes the performance of a more detailed monetary examination after the LRT has been planned. The principle factors that impact structures, for example, bridges and tunnels were characterized, and a database related with unit costs is constructed in view of the current examinations and databases. An algorithm for the LCC examination of LRT was made through a study on the investigation of vulnerability factors and cost breakdown structures that are versatile to LRT. The framework created by them can impressively enhance the productivity of LRT LCC investigation by analyzing the construction cost and LCC income.

Coffelt and Hendrickson [27] developed up a model for assessing tenant expenses and considering their effect in the rooftop administration choice process through an aggregate LCC demonstrate that incorporates client/tenant cost model and associates least aggregate cost with enhanced intercession focuses in the benefit disintegration cycle by utilizing an overview model of tenant expenses because of leaks and involvement with proprietor expenses to gauge an aggregate LCC evaluation. They characterized the parts of life-cycle rooftop cost model for the rooftop frameworks in three essential classifications and exhibited the estimation of LCC models for rooftops and the presence of most minimal cost substitution years and found that the expansion in rooftop spills after some time and the resulting increments in both tenant and proprietor costs impact this least cost substitution year.

Hu et al. [28] completed bridge cost economy investigation in light of current engineering cost framework by utilizing the bridge life-cycle economy analysis technique, built up an estimation model of cost in every period of bridge life-cycle and developed a frame of bridge life-cycle. In view of computer hypothesis of highway development cost they investigated bridge LCC. They isolated the bridge LCC into three phases: development cost, operation cost and transfer or disposal cost, which were additionally subdivided into a few related costs. Bridge construction costs includes planning, project possibility study, planning and developing cost, which has diminishing effect on the future bridge working period costs. Bridge life-cycle financial cost display incorporates a bridge arrangement configuration cost model, building a cost model, administration, support and a repair cost model, and other cost models like project convey advantages to client, society and environmental condition. They found that the financial investigation of bridge LCC is one of the elements that choose feasible design choices that can be looked at and the best plan scheme must be picked by the guideline of LCC minimization.

Kayrbekova et al. [29] suggested that the conventional LCC approach have been discussed in literature for many years but due to the need for large amount of data and inherent uncertainties in the result it is difficult to perform such analysis. They talked about the contrasts between ordinary LCC and activity based LCC (AB-LCC) cost frameworks. The contrasts between regular LCC and AB-LCC investigation was shown by utilizing a straightforward illustration. For cost examination in the design of production facilities to be utilized as a part of new situations, for example, the Arctic, out of these two techniques, they found that the AB-LCC philosophy might be a superior option to utilize. The AB-LCC approach incorporates the activities and endeavors expected to accomplish the desirable level of framework performance and all the while exhibits movement points of interest that will empower the designer or leader to keep away from non-value activities (accepted to expand the quality and proficiency of the characterize exercises and the production facility in general). They found that the AB-LCC is a more reasonable cost framework in the plan stage, as it gives more point by point data on activities, assets, cost and cash flows. Alongside this it can likewise deal with overhead costs which can be traced to the related cost object more sensibly and dependably.

Okasha et al. [30] carried out the LCC analysis by using two approaches (1) deterministic approach and (2) probabilistic approach. In the deterministic analysis different painting scenarios were considered (1) in the upper bound LCC extraordinary case having the most noteworthy recurrence of repainting (10 years interim), the least discount rate (0%), and the most astounding repainting cost ($18/ft2) it was discovered that the LCC of the conventional painted carbon steel girder at 125 years is commonly higher than that of the A1010 steel. (2) in the lower bound extraordinary case having the most minimal recurrence of repainting (20 years interim), the most elevated discount rate (3%), and the least repainting cost ($6 b/ft2) it was discovered that the LCC of the conventional steel winds up higher than that of the A1010 steel after the third repainting at year 60. In the probabilistic examination the vulnerabilities in the input factors were legitimately considered and it was discovered that the A1010 steel is in reality savvy as time goes on and its cost viability increments over the administration life of the scaffold. Amid the initial 10 years there is 0% likelihood that the A1010 steel support is less expensive than the regular steel however it turns out to be relatively sure that the A1010 steel girder is less expensive than the traditional steel girder after around 40 years.

Donald and Madanat [31] displayed a model for limiting the LCC of development and upkeep of adaptable asphalt by utilizing unthinking observational asphalt outline. In perfect usage of M-E design a few models can be utilized to anticipate pavement reaction, like heat transfer models, dampness equilibrium models, penetration and seepage models, and structural models. Out of these models they utilized the structural models and distress forecast models for the pavement investigation and design. Sensitivity examination is performed on the model to see how the ideal design changes as for varieties in the critical design inputs. In sensitivity investigation a base case was set up and the parameters were transformed each one in turn, with all others staying steady, and the adjustments in the ideal solution were noted. Based on the arrangement of the optimization model utilizing typical values for layer expenses and recreation costs, the aftereffects of the model support the conclusion that ideally designed extended life hot blend asphalt pavement for high-volume streets are likely more practical than ordinary pavement that are intended for a 20-year time frame.

Karim et al. [32] aimed for building up another approach for investigating LCC for street hindrances amid the street arranging and configuration process. A technique called Activity-Based Life-Cycle Costing utilizing the Monte Carlo Simulation was utilized to break down and ascertain the LCC. To assess the introduced LCC approach, a 100-km-long street area with a yearly normal every day movement of 15,000 vehicles was picked.

They found that execution of LCC investigation in the street arranging and configuration process is conceivable by considering the financial expenses, alongside support and speculation costs. Likewise, the gathering of information to do a LCC examination for street segments is a troublesome and tedious process. Thusly, an orderly information accumulation process is required with respect to costs and other affecting elements important for completing LCC examination. The consequence of their computations demonstrates that the concrete barrier creates the least LCC as compared to cable and w-beam barriers.

Parrish and Chester [33] discussed part of LCA with regards to supportability appraisal and contends that LCA does not supplant manageability evaluation yet rather goes about as one information point inside a more comprehensive maintainability appraisal. They likewise investigated the strategies for dissecting maintainability on architecture-engineering-construction (AEC) ventures. The present AEC techniques are not satisfactory to routinely convey manageable foundation thus there is an incredible need to investigate diverse strategies for breaking down maintainability on AEC ventures. Via doing 3 contextual analyses they found that the LCAs were utilized essentially for LCC and best tended to the ordinary or undertaking level regardless of intrigue and push to think about natural and even societal effects, while LCA can be utilized to locate the basic data on ecological, financial, and social effects of framework tasks and how to limit those effects.

Engelhardt and Eng [34] delineated the common conditions of cost parameters and established a framework to build up an all-encompassing point of view to acknowledge financial potential for improving and lessening life expenses of passages. To gauge the LCC of such unpredictable and broadened structures alongside considering the time reliance they built up a Modular Process Model. The beginning stage of the life-cycle cost count spoke to the net present value strategy, which is adjusted for tunnels by setting up this model. With the utilization of this model the basic expenses can be distinguished early. The life-cycle of tunnels starts in the early arranging stage, incorporate three principle life stages (development, task and reusing) and closes with the decommissioning of the structure. Rather than applying the net present value technique, the installments amid the life-cycle of a tunnel may likewise be executed into an entire finance arrangement.

Moretti et al. [35] led a LCC investigation which looked at development, upkeep, and lighting costs expected to deal with an expressway tunnel more than 30-year benefit life in the Center of Italy, near Rome. They composed the asphalt as per Italian norms and the lighting framework as indicated by Italian and European specialized standards and inspected three street asphalts, a Continuously Reinforced Concrete Pavement(CRCP), a Jointed Plain Concrete Pavement(JPCP) and an Asphalt Pavement(AP). Their investigation pointed (1) to gauge the aggregate expenses of these asphalts in road tunnels (2) think about development and support expenses of asphalt laying and lighting in street tunnels and (3) to demonstrate the significance of the surface asphalt material. The LCC investigation featured that the development expenses of rigid asphalts are higher than the flexible ones, yet the lower support and lighting costs allows a make back the initial investment point before the fifth year of administration life as respects JPCP, less expensive than CRCP. Considering the lighting costs, both the rigid arrangements are monetarily more profitable than the flexible one.

Heralova [6] highlighted the part of LCCA in the possibility investigation of development ventures, particularly in general society segment. Achievability thinking is typically directed in the early period of development ventures when the best advantage of LCC can be gotten, as the advancement potential in the early outline stages is huge and furthermore shabby. The best trouble at the early plan organize (pre-outline) is accessibility of information for the development venture. An attainability thinks about aides in the improvement of extra task documentation and decide conceivable choices. The adequacy of the achievability consider affects the finishing of a task. An obstruction to LCC execution is low quality information and an absence of modern models for detailing the life cycle execution of structures. Under these conditions, it is convoluted to create LCC figuring's supporting great basic leadership.

Janbaz et al. [36] estimated the capital and annual costs of an Underground Freight Transportation (UFT) system in Texas. Due to lack of historical cost information the LCC analysis of UFT systems is often challenging. The UTF system has major capital cost elements (tunnel construction cost, vehicle propulsion system cost, and vehicle cost) and yearly cost components (maintenance cost, energy consumption cost, and administration cost). They utilized historical tunneling expenses to make a regression model to estimate expenses of tunnels with different sizes, by choosing comparative tunneling ventures and modifying their expenses to assess the UFT burrowing cost. RSMeans cost information (2016) was utilized to appraise expenses of track bedding, terminal and office development. Statements from the business were utilized to appraise cost of vehicles, terminal land buy cost, expenses of LIM equipment, establishment and control framework, and LIM upkeep and vitality costs. Authoritative expenses were evaluated utilizing information from the U.S. Authority of Labor Statistics. Writing information were utilized to assess track cost and tunnel upkeep cost.

Rezende [37] worked on the portfolio of road tunnels managed by Vialitoral, a concessionary operating in the Madeira island. Data was gathered from eleven tunnels and this selection was the sole criterion of identification of tunnels that had more data to other members. The costs were divided into two categories (1) direct costs attributable to a tunnel or set of tunnels and (2) costs that generate doubts about what tunnel is associated there with. The work aimed to contribute to a bigger applicability of the methodology of LCCA compared to the amount and quality of the data and information available to organize any asset.The development of LCCA depends on the quantity and quality of available data, the limitation of time, analysis phase and the degree of accuracy required. The developed study leads to the conclusion of the existence of some important gaps on the catchment of the assets' life cycle and suggested that the Vialitoral not give continuity to the same reason of the high percentage of costs without direct association with each tunnel.

Zhang et al. [38] analyzed the WLC of Chicago trunnion bascule bridges. All accessible cost informations for each bridge from the time of its construction until the point when 2002 was gathered. To represent inflation, the Engineering News Record Building Cost Index was utilized to change over real expenses to 2002 dollars. They established a relationship between WLC and bridge age and studied MRR impact on whole life cost. Their study showed that (1) the achievable helpful life of a bascule bridge can be over 100 years (2) the valuable life is characterized as the period from initial development to the point where recreation cost is more prominent than the initial expense. (3) the total

WLC for a 100-year-old bascule bridge can be under five times its underlying cost (4) opportune upkeep, repair and restoration activities can bring down the aggregate whole life cost of a bridge.

After the rigorous literature review the following objectives are set for the present study as:

2.3 OBJECTIVES

The aim of this thesis is to undertake a state-of-the-art review of WLC to identify the various strengths and gaps in the existing knowledge in order to implement the WLC analysis to a road tunnels.

The main objectives of the study are:

1. To determine the principle characteristics of Whole Life Cost Analysis.
2. To identify the appropriate cost model for road tunnels.
3. To carry out Net Present Value and Sensitivity Analysis to Aut Tunnel.

2.4 SCOPE OF THE STUDY

This thesis is an implementation of WLC on a road tunnel, during its operation and maintenance phase, located at Aut (H.P.) and focuses on finding the most sensitive parameter that affects the operation and maintenance cost the most. Along with this the relationship between net present worth and discount rate for the tunnel is also examined.

2.5 RESEARCH METHODOLOGY

The research area of this dissertation is whole life cost analysis consisting of implementation of net present value and sensitivity analysis on a road tunnel project. Initially the concept of WLC is learned by studying various research papers and then the relevant information is applied to the project. The sequence of the work done is as: Literature Survey; Defining WLC analysis economic evaluation criteria; Determining suitable whole life cost models for a road tunnel; Application of net present value and sensitivity analysis to the Aut Tunnel and Conclusions and recommendations.

CHAPTER 3

WHOLE LIFE COST ANALYSIS ECONOMIC EVALUATION CRITERIAS

3.1 TIME VALUE OF MONEY

Money earned now is worth more than the money earned at some point in future. A sum of money earned today has an earning power (as interest can be earned on it) and thus has a greater worth than the money earned at some time in near future. [2] The interest symbolizes the earning power of money and is considered as the cost of using capital or the additional money a borrower has to pay for the funds given by the lender.

Time value of money has become a fundamental financial principle to determine true costs of various assets and has found its importance in long-term as well as in short-term projects.

3.2 CASH FLOW DIAGRAMS [39]

A cash flow diagram is a visual representation of the inflow and outflow of funds. The inflow and outflow of cash doesn't have any definite pattern. Therefore, it is assumed that all transactions take place either at the end or beginning of a definite period, which may be a week, a month, a quarter or a year.

Conventions used in a cash flow diagram:

1. Time is drawn on the horizontal axis (x-axis) in equal increments, up to the duration of the project.
2. The amount involved in the transaction is drawn on vertical (Y-axis), receipts are drawn on the positive side while disbursements are drawn on the negative side.
3. Scale is maintained for the X-axis while the representation on Y-axis is not to scale, efforts should be made to maintain a resemblance of balance.
4. Two or more transfers in the same period are placed end to end.
5. Costs acquired before time, t=0 are called sunk costs. Sunk costs are only taken into consideration only when they have tax consequences in and after tax analysis.

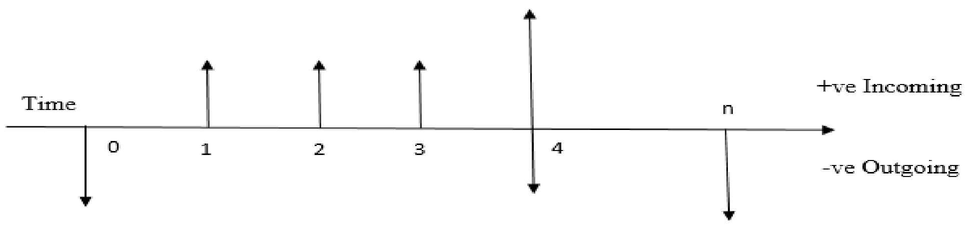


Figure 3.1. General cash flow diagram

Different Cash Flows used in financial management are:

1. Accounting Cash Flow (ACF) = profit after tax (PAT) + depreciation
2. Equity Cash Flow (ECF) = cash inflow – cash outflow in a period
3. Free Cash Flow (FCF) = equity cash flow if the company has no debt
4. Capital Cash flow (CCF) = equity cash flow + debt cash flow

3.3 INTEREST FORMULAS [39]

"Interest formulas are simple mathematical equations that measure the effect of time on money" [2]. To relate the impact of the interest rate in relating rupees spent today and rupees spent in the future, three categories containing eight commonly used interest formulations are presented as under:

3.3.1 CATEGORY A: WITH A SINGLE PAYMENT (SP)

a) **Single payment compound amount factor (SPCAF)**, is one by which a single payment (P) is multiplied to find its compound amount (F) at specified time in future.

$$\left(\frac{F}{P}, i, n\right) = (1 + i)^n$$

Figure 3.2 Cash flow illustration of single payment compound amount factor

b) **Single payment present worth factor (SPPWF)**, is one by which a future payment (F) is multiplied to find its present worth (P) at specified time in present.

$$\left(\frac{P}{F}, i, n\right) = \frac{1}{(1 + i)^n}$$

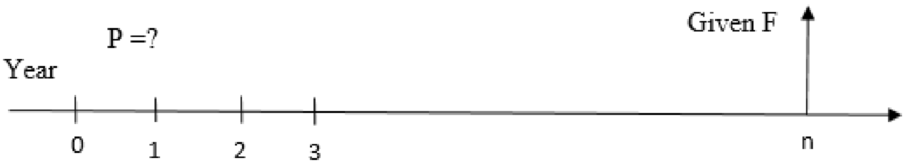


Figure 3.3 cash flow illustration of single payment present worth factor

3.3.2 CATEGORY B: WITH AN EQUAL PAYMENT SERIES (EPS) OR SEVERAL EQUAL INSTALMENTS AS UNIFORM SERIES (US)

a) Compound amount factor (EPSCAF or USCAF), converts a uniform series payment (A) to its compound amount (F).

$$\left(\frac{F}{A}, i, n\right) = \frac{(1+\mathrm{i})^{\mathrm{n}} - 1}{\mathrm{i}}$$

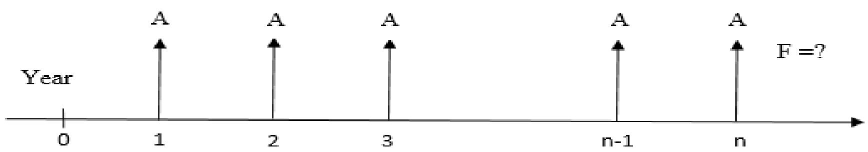


Figure 3.4 Cash flow illustration of compound amount factor

b) Present worth factor (EPSPWF or USCAF), converts a uniform series payment (A) to its present worth (P).

$$\left(\frac{P}{A}, i, n\right) = \frac{(1+i)^n - 1}{i(1+i)^n}$$

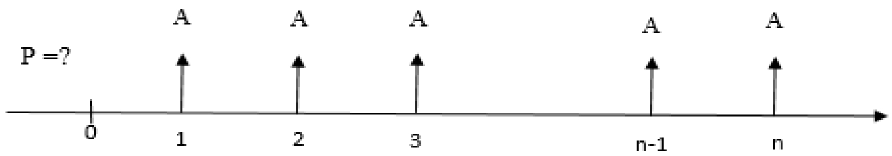


Figure 3.5 Cash flow illustration of present worth factor

c) **Sinking fund deposit factor (EPSSFDF)**, is one by which a future sum (F) is multiplied to find a uniform sum (A).

$$\left(\frac{A}{F}, i, n\right) = \frac{i}{(1+i)^n - 1}$$

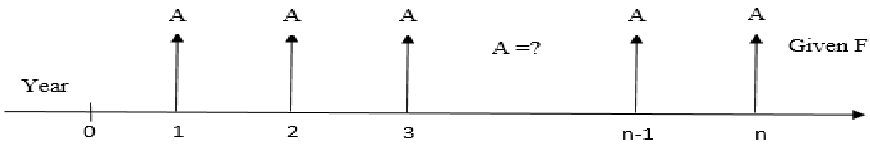


Figure 3.6 Cash flow illustration of sinking fund deposit factor

d) Capital recovery factor (EPSCRF), is one by which a present capital sum (P) is multiplied to find a uniform sum (A).

$$\left(\frac{A}{P}, i, n\right) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

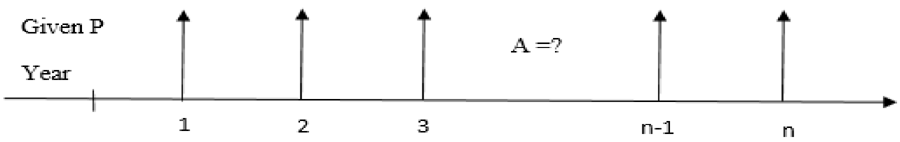
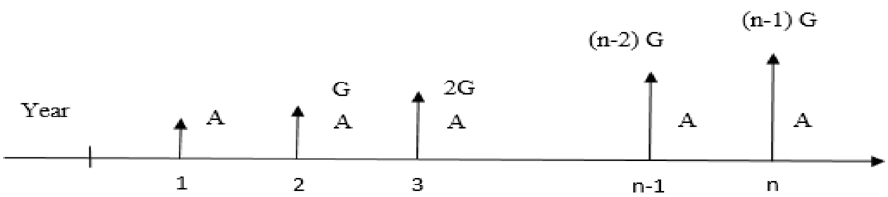


Figure 3.7 Cash flow illustration of capital recovery factor

3.3.3 CATEGORY C: WITH UNEQUAL PAYMENT SERIES

a) Arithmetic gradient factor (AGF), the increase/ decrease in instalments, whether it is payment or disbursements, follows an arithmetic pattern.

$$\left(\frac{A}{G}, i, n\right) = \frac{1}{i} - \frac{n}{(1+i)^n - 1}$$



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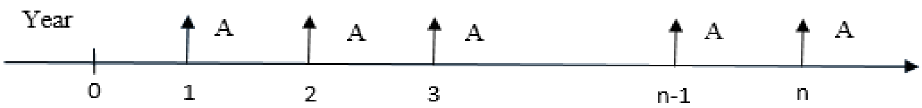

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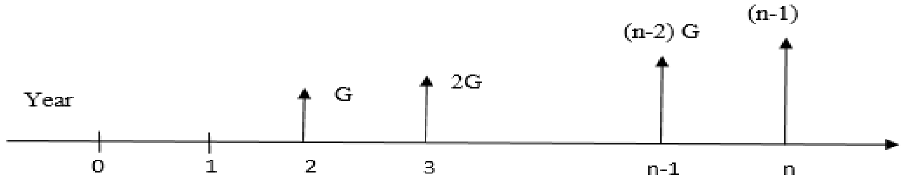

Figure 3.8 Cash flow illustration of arithmetic gradient factor

b) Geometric gradient factor (GGF), the increase/ decrease in instalments, whether it is payments or disbursements, follows a geometric pattern.

$$\left(\frac{P}{G}, i, n\right) = \frac{1 - \frac{(1+g)^n}{(1+i)^n}}{(i-g)}$$

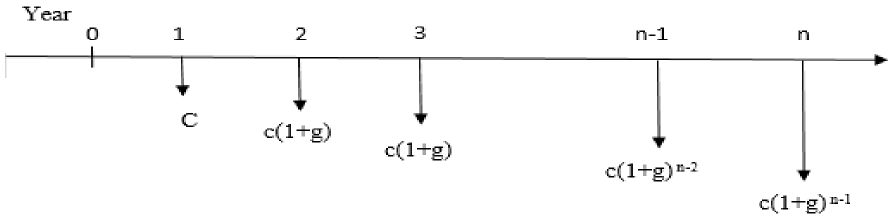

Figure 3.9 Cash flow illustration of geometric gradient factor

3.4 NET PRESENT VALUE (NPV)

NPV is technique for assessing a project's financial worth to a company. The net present value of a time series of cash flows, both benefits and costs, is the sum of the present values of the individual cash flows. In the case when all future cash flows are incoming and the only outflow of cash is the construction price, the NPV is calculated by subtracting the construction cost from the PV of future cash flows. NPV is a standard strategy for utilizing the time value of cash to assess long-term ventures. Utilized for capital budgeting, and broadly through economics, finance, and accounting, it quantifies the abundance or deficit of cash flows, in present worth terms.

Let CPVx be the present value of costs and BPVx be the present value of benefits of a project x. Then, for MARR = i over a study period of n years,

$$BPV_y = \sum_{t=0}^{n} Bt, y(1+r)^{-t}$$

$$CPV_y \sum_{t=0}^{n} ct, y(1+r)^{-t}$$

Here, BPVy = Present Value of Benefits; CPVy =Present Value of Costs; r =discount rate; $(1+r)^{-t}$ is a discount factor.

The present value is calculated by multiplying this factor to both the benefits and costs. The two products are then subtracted to get the present value. The net present worth of the venture is ascertained as the summation of differences between the present estimation of the benefits and the present value of the benefits and the present value of the costs in the time series:

$$NPV_y = BPV_y - CPV_y$$

3.5 DISCOUNT RATE

So as to include and analyze cash flows that are acquired at various circumstances amid the life cycle of a venture, they must be made time equivalent. To make cash flows time-equal, the LCCA strategy changes over them to present values by discounting them to a common point in time, as a rule the base date. The interest rate utilized for discounting is a rate that reflects a financial specialist's chance cost of cash after some time, implying that an investor needs to accomplish a return at any rate as high as that of his or her next best venture. Consequently, the discount rate frequently speaks to the speculator's base adequate rate of return.

3.6 STUDY PERIOD METHOD

Length of study period: The study time frame starts with the base date, the date to which all cash flows are reduced. The investigation time frame incorporates any planning or development or usage period and the administration or inhabitance period. To make effective comparison on different alternatives, the length of study should be the same for all choices considered.

Service period: The service period starts when the finished structure is occupied or when a framework begins its operation. This is the period over which operational, maintenance costs and benefits are evaluated.

Contract period: It begins when the venture is formally acknowledged, venture expenditures begin to accrue, and contract payments begin to be due.

3.7 RATE OF RETURNS [42]

3.7.1 Internal Rate of Return (IRR)

The internal rate of return (IRR) is characterized as the discount rate which sets the net present worth of a series of cash flows over the investigation time frame zero. IRR is utilized as a benefit measure since it has been distinguished as the "marginal efficiency of capital" or the "rate of return over cost". It gives the return of a venture when the capital is being used as though the investment comprises of a single cost at the start and returns a surge of net benefits a while later.

It is important to note however, that the IRR does not think about the reinvestment opportunities related to the timing and intensity of the expenses and returns at the transitional focuses over the study period. For cash flows with at least two sign changes of the cash flows in any time frame, numerous values of IRR may exist. In such cases, the numerous values of IRR are liable to various interpretations. The equation for computing the IRR is given below

$$\boldsymbol{NPV_y = \sum_{t=0}^{n} \frac{Bt, y - Ct, y}{(1 + r)^n} = 0}$$

3.7.2 Modified Incremental Rate of Return (MIRR)

The MIRR and IRR are comparative however the MIRR is hypothetically predominant in that it overcomes certain shortcomings of the IRR. The MIRR considers the reinvestment at the project's expense of capital and evades the issue of different IRRs. However, it should be noted that the MIRR is not utilized as broadly as the IRR in practice.

3.7.3 Minimum Acceptable Rate of Return (MARR)

Also known as hurdle rate is the minimum rate of return, an organization is willing to accept before continuing with an undertaking, given its risk and the opportunity cost of renouncing different projects. MARR represents the required or minimum internal rate of return for a project investment. There is no distinctive formula for the MARR. This value is usually given and is compared a certain project's IRR. If the IRR is greater than MARR, then the project is deemed to be acceptable.

3.8 PAYBACK PERIOD (PBP)

The payback period (PBP) denotes to the time span within which the benefits obtained from a venture can reimburse the costs caused amid the time in question while disregarding the rest time periods in the planning horizon. Indeed, even the discounted payback period showing the "capital recovery period" does not reflect the extent or direction of the cash flows in the rest of the periods. However, if an undertaking is observed to be profitable by different measures, the payback period can be utilized as an optional measure of the financing prerequisites for a project. Take for instance the comparison of having a traditional power plant and a geothermal power plant.

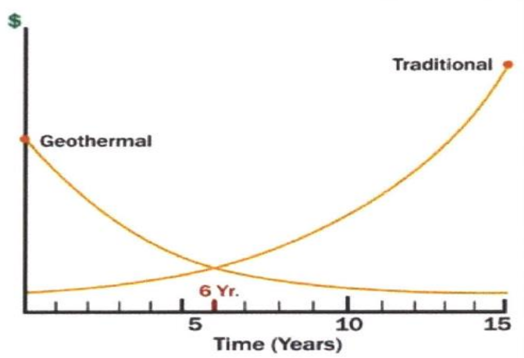

Figure 3.10 Payback period of Geothermal Plant[40]

Figure 3.10 shows how the initial investment of a geothermal power plant is much greater than that of a traditional plant. It can also be seen that as time progresses, the costs incurred by the geothermal plant decrease while the traditional plant's costs increase. The time it takes for the two curves to intersect shows the payback period of investing in a geothermal power plant. Figure 10 shows that despite having a bigger initial investment in the geothermal plant, the investment starts to pay off after six years into its operation. The equation to calculate the Payback period for any investment is given below

$$\boldsymbol{Payback\ period} = \frac{\textbf{Investment required}}{\boldsymbol{Net\ annual\ cash\ inflow}}$$

3.9 BENEFIT TO COST RATIO [39]

The benefit to cost ratio (BCR) is the ratio of discounted benefits to the discounted costs at a similar point in time, is a profitability index in view of discounted benefits per unit of discounted costs of a venture. It is also known as the savings-to-investment ratio (SIR) when the benefits are gotten from the reduction of unfortunate impacts. Its application likewise relies upon the choice of a study period and a MARR. Since a few savings might be interpreted as a negative cost to be deducted from the denominator or as a positive benefit to be added to the numerator of the ratio, the BCR or SIR is not an absolute numerical measure. However, if the ratio of the present value of benefit to the present value of cost is greater than one, the venture is profitable regardless of various interpretations of such benefits or costs.

$$BCR = \frac{\sum_{r=1}^{n} \frac{B}{(1+r)^t}}{\sum_{r=1}^{n} \frac{C}{(1+r)^t}}$$

Here, B = Benefit at a certain time; C = Cost at a certain time; r = discount rate

While this method is frequently utilized in the assessment of public projects, the outcomes might misdirect if appropriate care is not practiced in its application to mutually exclusive proposals. However, a project with the maximum benefit-cost ratio among a group of mutually exclusive proposals generally does not really prompt the maximum net benefits. Unfortunately, more analyses will be required to determine which project has better value. This approach is not recommended for use in choosing the best among mutually exclusive proposals.

3.10 RETURN ON INVESTMENT (ROI)

At a point when an accountant reports income in each year of a multi-year venture, the series of cash flows must be separated into yearly rates of return for those years. The ROI usually implies the accountant's rate of return for each year of the venture span in view of the ratio of the income (revenue less depreciation) for every year and the asset value (investment) without depreciation for that same year. Hence, the ROI varies from year to year, with a very low value at the early years and a high value in the later years of the project. This is typical of construction project since initial costs are incurred by the contractor at the start and payments for services are made at later times of the project duration. Figure 3.11 shows an example of a return on investment of $1,000.

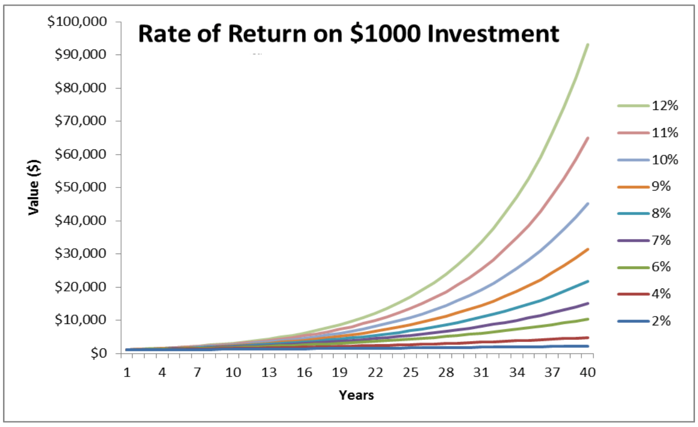

Figure 3.11 Return on Investment[43]

CHAPTER 4

WHOLE LIFE COST MODELS

Depending up on the amount of information or data assets available, time constraints, the level of accuracy, and different other factors, for example, data availability, four fundamental distinctive methods for performing LCCA exists. These are the Analogy, Parametric, Engineering Cost and Cost Accounting Models. These different methods have their own distinct advantages and disadvantages.

4.1 ANALOGY MODELS

WLC analysis that are produced through an analogy model identify a similar project or component and adjust its costs for differences between it and the target project. It is crude to handle costs this way since direct labor and overhead expenses are not addressed directly. These costs are not accounted for directly, since it simply looks at what the costs have been historically and scales them according to the most important cost driver. Such models can be effectively implemented when extensive historical material is available.

4.2 PARAMETRIC MODELS

Parametric Models are considered to be more developed and advanced than analogy models. A parametric LCCA model requires anticipating a project's or an element's cost either altogether or for different activities by utilizing a few models describing the relationship between cost and project or process related parameters. These parameters could be:

1. Installation Complexity
2. Design Familiarity
3. Performance
4. Schedule Compression

When compared to the analogy model, three main differences exist. First, the analogy model relies up on a single, dominant cost driver though a parametric model can utilize several parameters. Second, an analogy model depends on linear relationships amongst cost and cost drivers, while parametric models depend up on at least one non-linear regression models. Third whereas analogy models utilize an analogy as a driver, parametric models are regression, or response surface, models that can be linear, quadratic, and multidimensional. Similar to analogy models, parametric models do not deal with overhead costs directly. [41]

4.3 ENGINEERING COST MODELS

Engineering Cost Models are employed where there are detailed and accurate capital and operational cost data for the project under study. Unlike the two previous models, it includes direct estimation of a specific cost element by examining the project part by part. But as the name suggest, they are very handy in engineering and development situations to obtain an early cost estimate.

4.4 COST ACCOUNTING MODELS

A Cost Accounting Model can be seen as a data framework because it relies on distinct data such as units produced and labor hours. Project costs as well as additional data can be obtained through a predetermined costing system methodology.

This technique accepts that a project causes expenditures and costs. Each time the construction of a unit or block of a project happens, costs are incurred. For a dominant part of the overhead activities, the share of activity really utilized by a specific project does not relate to a single cost driver. This is valid for modem administrations, where products or items are manufactured through a combination of technology and labor. [41]

The traditional cost accounting model makes utilization of a volume-based driver such as machine hours or direct labor hours for allotting the total construction overhead expenses. Therefore, a decrease in overhead costs may cause a decrease in quality of projects as compared to a long-lasting reduction in the costs. The quality of the project could decrease if less labor hours and machine hours are spent on it.

Considering the advantages and disadvantages of the different WLC models, a combination of the Engineering Cost Model and Cost Analysis Model can be selected. Since accurate data on the costs related to the road tunnel exists, these two models can be applied to economically evaluate road tunnel projects.

CHAPTER 5

APPLICATION OF THE NPV AND SENSITIVITY ANALYSIS TO THE AUT TUNNEL

5.1 INTRODUCTION

The Aut tunnel, 2809.16 m in length, is located at Bagitar near Thalout in district Mandi (H.P.) on NH 21. It is the 2nd longest double lane traffic tunnel in Asia. The Aut Tunnel was completed and started to commercially operate in Aug 2006.

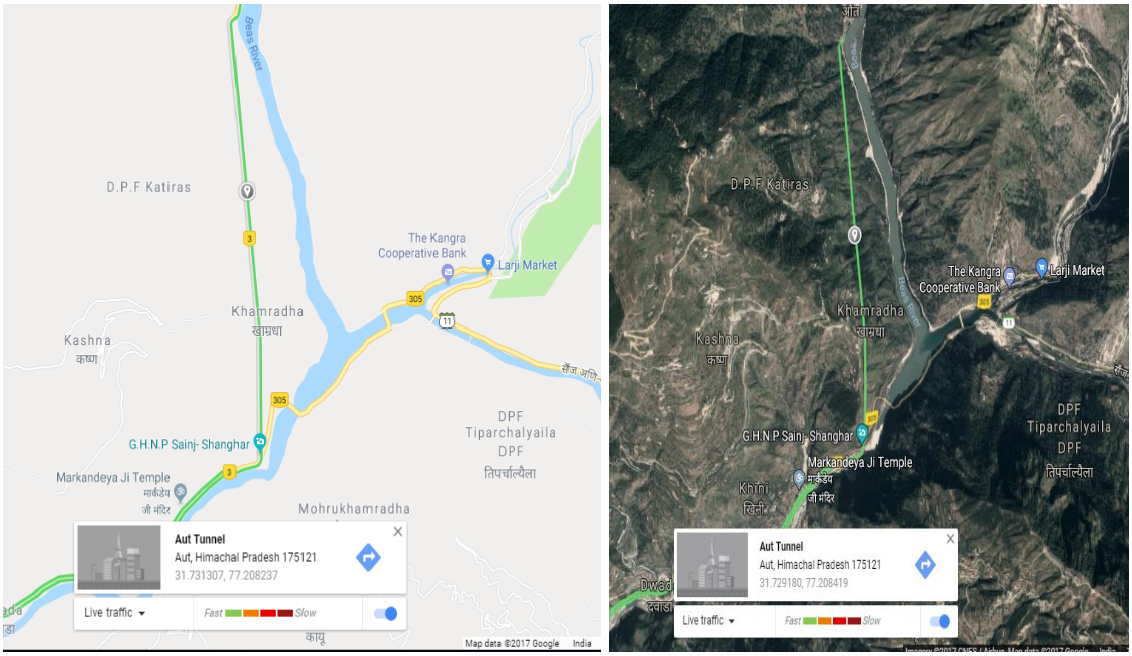

Figure 5.1 Location of Aut Tunnel (Google maps)

5.2 AVAILABLE INFORMATION

The following are major cost components that need to be considered.

1. Costs of Construction

2. Operational and Maintenance costs

The expenditure on account of Cost of Construction is as follow

i. On account of construction of traffic tunnel Rs. 651,942,973.00

ii. Electrical installation of traffic tunnel Rs. 13,436,451.00

Total cost of construction *Rs. 665,379,424.00*

Table 5.1 shows the information on maintenance and operation costs incurred in the Aut Tunnel project through 2007 to 2017. It can be seen that the costs consist mostly of operational and maintenance costs.

Table 5.1 Maintenance and operation costs incurred in Aut Tunnel

Year	Electricity cost (INR)	Lightning equipment cost (INR)	Pavement repair cost (INR)	Cleaning and drainage cost (INR)
2007-08	288,764	505,444	129,288	50,278
2008-09	292,875	3,186,913	180,985	55,000
2009-10	290,736	1,044,486	267,818	53,750
2010-11	321,825	2,136,563	366,869	56,890
2011-12	311,628	1,382,207	327,478	50,880
2012-13	323,961	1,250,907	743,882	54,950
2013-14	322,146	1,277,689	524,227	51,400
2014-15	301,693	3,919,988	208,342	53,190
2015-16	319,528	3,009,819	199,905	52,780
2016-17	311,698	1,768,415	521,138	50,230

To be able to demonstrate the use of the NPV method and sensitivity analysis, information on annual costs incurred during the first ten years (2007 - 2017) of the Aut Tunnel project were used. Note however that only information on costs and none on benefits is available. Another factor to keep in mind is that there is no actual information on the discount rate for this project. Even if this is the case however, the NPV can still be computed by using different values of the discount rate with the cost data available. Very importantly, the calculated NPV's are very useful for comparing different investment alternatives.

In addition to the application of the NPV method, sensitivity analysis was also conducted to answer two questions:

1. What is the effect of varying the discount rate on the NPV?
2. Which annual cost item has the most effect on its corresponding annual PV?

The results of all the calculations yield a negative value. This is acceptable due to the fact that no income data were used in the calculations. Although a complete WLCA would have costs and benefits in its calculation, the results of using only costs is very useful to investors in making a decision, e.g. to compare projects with different alignments.

5.3 APPLICATION OF NPV METHOD

To obtain the NPV of the project, the different costs incurred in the first ten years of operation of the traffic tunnel were all converted to their corresponding present values in the base year. The assumed base year for this project is 2007. In summary, costs in 2007 were assumed to be construction costs only and operational and maintenance costs came later on in the years 2008, 2009 and so on up to 2017. Thus, the only costs really influenced by the discount rate are the costs related to operations and maintenance. Since construction costs occurred during the base year, the denominator in the PV calculation becomes 1 thus leaving the construction cost value as it is. Costs from 2008 to 2017 were all projected back to 2007 at discounts rates ranging from 1 to 10 percent as shown in table 5.2. This was done since the value of the actual discount rate was not available.

Table 5.2 Variation of PV and NPV w.r.t. Discount Rate

Discount Rate (i)	Cost of construction	PV of 2008-2017 at base year 2007	NPV
1%	665,379,424.00	25,036,984.81	690,416,408.81
2%	665,379,424.00	23,627,474.21	689,006,898.21
3%	665,379,424.00	22,326,441.21	687,705,865.21
4%	665,379,424.00	21,124,597.08	686,504,021.08
5%	665,379,424.00	20,011,785.58	685,391,209.58
6%	665,379,424.00	18,982,153.56	684,361,577.60
7%	665,379,424.00	18,025,648.01	683,405,072.00
8%	665,379,424.00	17,138,488.25	682,517,912.20
9%	665,379,424.00	163,134,03.54	681,692,827.50
10%	665,379,424.00	155,44,955.42	680,924,379.40

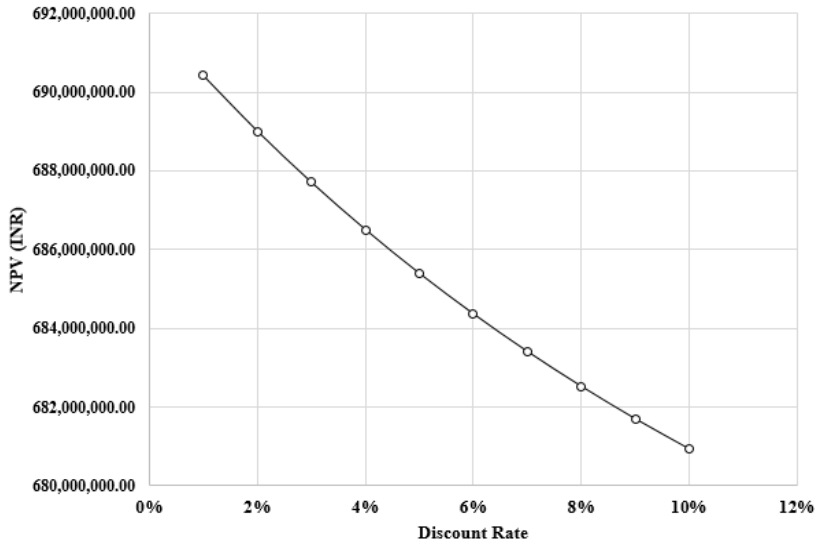

Figure 5.2 NPV vs Discount Rate

5.4 SENSITIVITY ANALYSIS

5.4.1 INTRODUCTION

Sensitivity analysis is generally used to identify the impact, on WLC, of a change in a single risky or uncertain parameter used in the calculation of WLC such as, for example, discount rate, initial capital cost, or running costs. It identifies the sensitivity of WLC to variation in each of these parameters. Sensitivity analysis has two major uses: (1) it indicates for a particular option, the certainty that can be resided in the LCC calculation based on best estimates of all parameters. If the decision-maker is interested in reducing uncertainty or risk exposure, then sensitivity analysis will identify those areas on which his efforts should be concentrated in order to improve the parameter estimates. (2) it indicates in the comparison of alternatives the conditions under which the ranking of these alternatives will change. [42]

5.4.2 APPLICATION OF SENSITIVITY ANALYSIS TO RELEVANT DATA FROM THE AUT TUNNEL

The goal of applying this sensitivity analysis in this case is to determine which costs are most likely to affect the NPV the most and how a variation of discount rates affects the NPV. Sensitivity analysis was done on each input cost while holding others constant.

For example, a sensitivity analysis was conducted on the costs (given in table 5.1) using Microsoft Excel. There are several resources that discuss the procedure of conducting a sensitivity analysis using Microsoft Excel Spreadsheets. The discount rate used in all the calculations is five percent and the base year considered is 2007. The cost of each maintenance and operational item was varied by 10 percent increment and decrement and is shown as below:

1. The ***electric cost*** for the traffic tunnel for the year 2008-2017 was originally 2,372,914.01 INR. The fourth row of table 5.3 shows the original value (in bold) of the cost as well as its different variations. These different variations are computed for 10 percent increment and decrement up to 30 percent. For example, 70 and 130 percent of 2,372,914.015 is 1,661,039.81 and 3,084,788.219 respectively. The change in values of the electric cost was then correlated to the Net Present Value of the same year.

Table 5.3 Variation of electricity cost

% variation	PV (INR)	NPV (INR)
-30	1,661,039.81	684,679,335.4
-20	1,898,331.21	684,916,626.8
-10	2,135,622.61	685,153,918.2
0	**2,372,914.01**	**685,391,209.6**
10	2,610,205.41	685,628,500.9
20	2,847,496.82	685,865,792.4
30	3,084,788.22	686,103,083.8

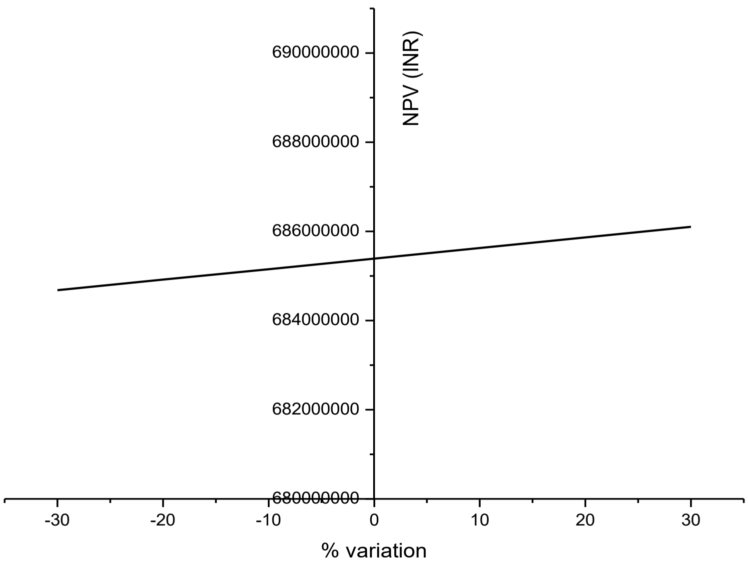

Figure 5.3 NPV vs Variation in electricity cost

2. The ***lightning equipment cost*** for the traffic tunnel for the year 2008-2017 was originally 14,635,139.08 INR. The fourth row of table 5.4 shows the original value (in bold) of the cost as well as its different variations. These different variations are computed for 10 percent increment and decrement up to 30 percent. For example, 70 and 130 percent of 14,635,139.08 is 19,025,680.8 and 10,244,597.35 respectively. The change in values of the lightning equipment cost was then correlated to the Net Present Value of the same year.

Table 5.4 Variation of lightning equipment cost

% variation	PV (INR)	NPV (INR)
-30	10,244,597.35	681,000,667.9
-20	11,708,111.26	682,464,181.8
-10	13,171,625.17	683,927,695.7
0	**14,635,139.08**	**685,391,209.6**
10	16,098,652.99	686,854,723.5
20	17,562,166.89	688,318,237.4
30	19,025,680.80	689,781,751.3

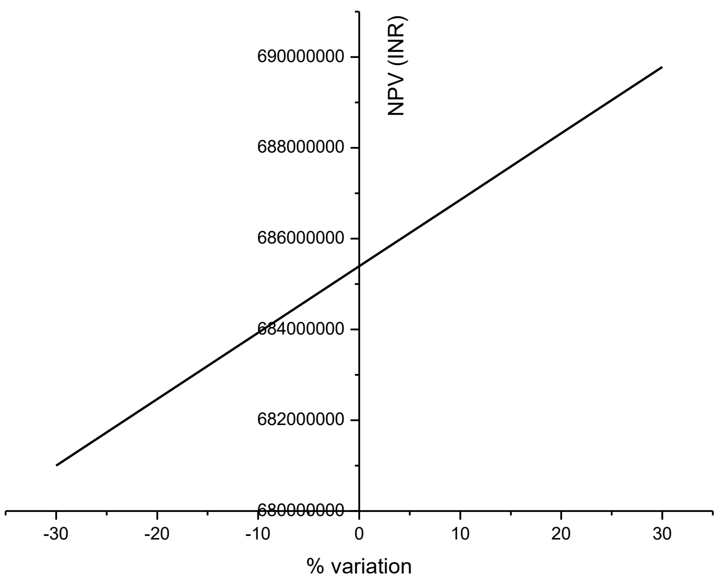

Figure 5.4 NPV vs Variation in lightning equipment cost

3. The ***pavement repair cost*** for the traffic tunnel for the year 2008-2017 was originally 2,594,474.738 INR. The fourth row of table 5.5 shows the original value (in bold) of the cost as well as its different variations. These different variations are computed for 10 percent increment and decrement up to 30 percent. For example, 70 and 130 percent of 2,594,474.738 is 1,816,132.317 and 3,372,817.159 respectively. The change in values of the pavement repair cost was then correlated to the Net Present Value of the same year.

Table 5.5 Variation of pavement repair cost

% variation	PV (INR)	NPV (INR)
-30	1,816,132.32	684,612,867.2
-20	2,075,579.79	684,872,314.6
-10	2,335,027.26	685,131,762.1
0	**2,594,474.74**	**685,391,209.6**
10	2,853,922.21	685,650,657.1
20	3,113,369.69	685,910,104.5
30	3,372,817.16	686,169,552.0

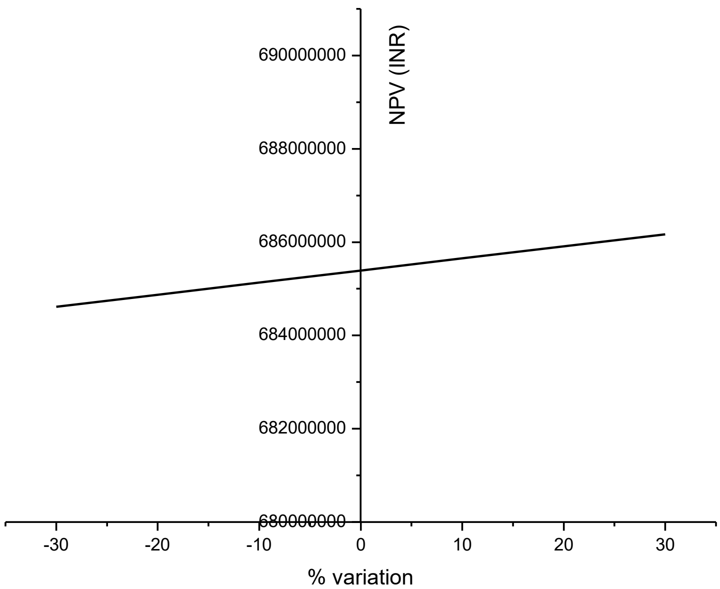

Figure 5.5 NPV vs Variation in pavement repair cost

4. The ***cleaning and drainage cost*** for the traffic tunnel for the year 2008-2017 was originally 409,257.7472 INR. The fourth row of table 5.6 shows the original value (in bold) of the cost as well as its different variations. These different variations are computed

for 10 percent increment and decrement up to 30 percent. For example, 70 and 130 percent of 409,257.747 is 286,480.423 and 532,035.071 respectively. The change in values of the cleaning and drainage cost was then correlated to the Net Present Value of the same year.

Table 5.6 Variation of Cleaning and Drainage Cost

% variation	PV (INR)	NPV (INR)
-30	286,480.42	685,268,432.3
-20	327,406.19	685,309,358.1
-10	368,331.97	685,350,283.8
0	**409,257.74**	**685,391,209.6**
10	450,183.52	685,432,135.4
20	491,109.29	685,473,061.1
30	532,035.07	685,513,986.9

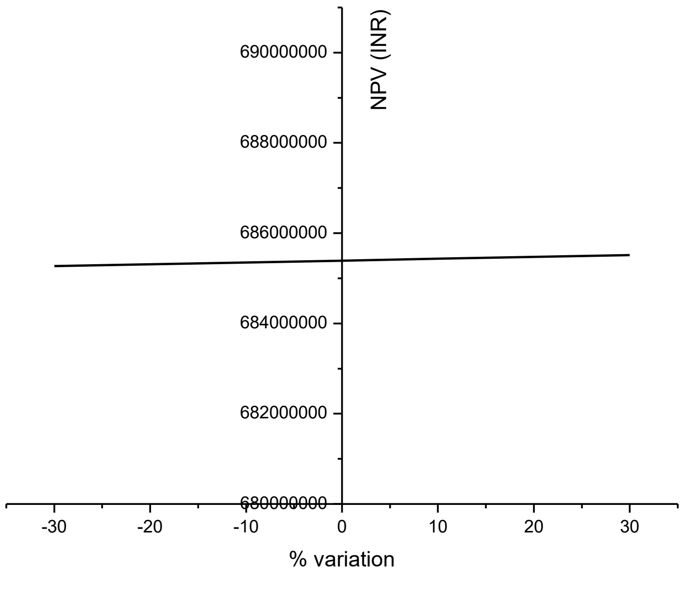

Figure 5.6 NPV vs Variation in cleaning and drainage cost

5. The ***service life*** for the traffic tunnel was originally 10 years. The first row of table 5.7 shows the original value (in bold) of the cost as well as its variation. The variation is computed by 10 percent decrements up to 30 percent. For example, 70 percent of 10 years is 7 years. The change in values of the life cycle was then correlated to the Net Present Value of the same year.

Table 5.7 Variation of Service Life

% variation	NPV (INR)
10 yrs.	**685,391,209.60**
9 yrs.	683,763,465.39
8 yrs.	681,454,487.60
7 yrs.	678,420,249.01

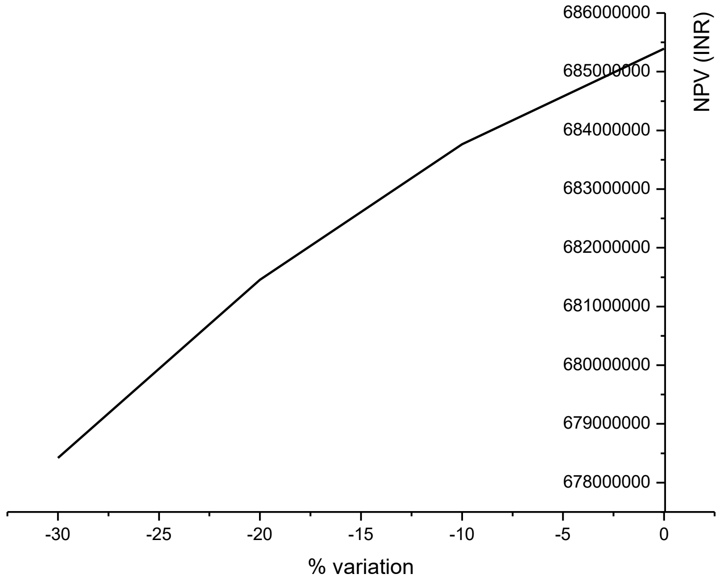

Figure 5.7 NPV vs Variation in service life

6. The ***interest rate*** for the traffic tunnel for the year 2008-2017 was originally taken as 5%. The second row of table 5.8 shows the original value (in bold) of the interest rate as well as its variation. These different variations are computed by 60 percent increment and decrement. For example, 40 and 160 percent of 5% is 2% and 8% respectively. The change in values of the operation and maintenance costs was then correlated to the Net Present Value of the same year.

Table 5.8 Variation of Interest Rate

% variation	NPV (INR)
8%	682,517,912.25
5%	**685,391,209.60**
2%	689,006,898.21

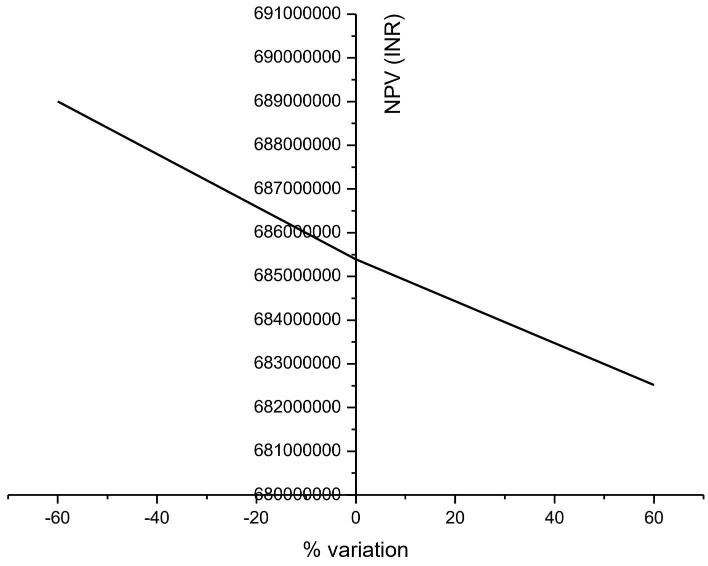

Figure 5.8 NPV vs Variation in interest rate

5.4.3 Spider Web Diagram

The slope of the sensitivity lines in figure 5.9 indicates the sensitivity of a particular variable under consideration. The steeper the slope of the line, the more sensitive the variable, and the milder the slope of the line, the less sensitive the variable. It can also be seen from the above figures that variables such as interest rate and service life are very sensitive, while variables such as electric cost and pavement repair cost are less sensitive.

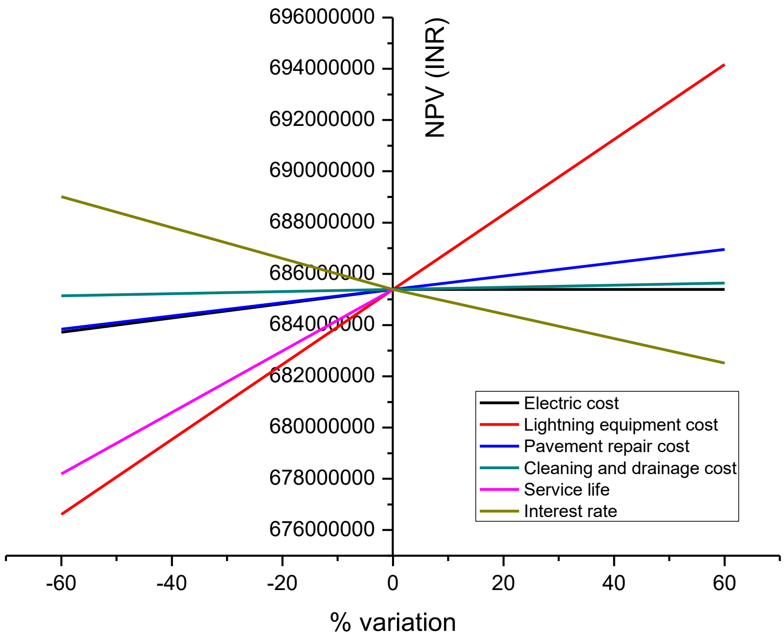

Figure 5.9 NPV vs Variation in different variables

Table 5.9 Slope of lines from graphs

Parameters	Tan Ө	Slope (Ө)
1. Electric cost	23729.14	89.9975°
2. Lightning equipment cost	146351.39	89.9996°
3. Pavement repair cost	25944.7483	89.9977°
4. Cleaning and drainage cost	4092.578	89.9860°
5. Service life	232385.35	89.9997°
6. Interest rate	1081497.667	89.9999°

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Observations that can be made from the results of the analysis are as follows:

1. A combination of the Engineering Cost Model and Cost Accounting Model can be applied to economically evaluate road tunnel projects.
2. The PV's of 2008 to 2017 decreases as the discount rate increases.
3. The NPV's sensitivity to the discount rate decreases as the discount rate increases.
4. The NPV method is well suited in conducting a Whole Life Cost Analysis of a road tunnel.
5. The increasing order of the sensitivity of the different variables under consideration is: cleaning and drainage cost, electric cost, pavement repair cost, lightning equipment cost, service life and interest rate.

From the application of NPV method, one can draw conclusions regarding future applications of the NPV to WLC Analysis as:

When comparing projects, for instance different tunnel alignments, one can combine the different construction costs and operation and maintenance costs for each project (tunnel alignment) and use the resulting different NPV's to aid in deciding which project to choose.

6.2 RECOMMENDATIONS

In line with the study, more studies might be done on the Aut Tunnel in order to develop a more accurate whole life cost model. Since life cycle evaluation criteria rely heavily on actual data to come up with results, it is crucial that the costs incurred during the entire project's lifecycle be monitored and recorded. Doing so will provide researchers with ample data to develop whole life cost models that can illustrate the economic worth of this project more clearly.

Another recommendation is to use a probabilistic approach to whole life costing. Probabilistic techniques quantify risk exposure by deriving probabilities of achieving different values of economic worth from probability distributions for input values that are uncertain. Since all construction projects all have some level of uncertainty and risk, using this approach can give project investors a more realistic picture of a certain project's value.

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