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Cost-effectiveness analysis of a road improvement proposal based on sustainability Indicators: Case study Al-Nebai-Baghdad highway

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ABSTRACT

Involving the sustainability assessment in the phases of road development project has become necessary to avoid unforeseen consequences. In Iraq, there is a noticeable lack of the environmental and social assessment of the development project. The economic assessment also needs to consider the project life cycle. The unavailability of validated and comprehensive methodologies of assessment is the main obstacle. Therefore, this study aims to outline a methodology of environmental, social and economic (ESE) assessment during pre-construction stages. The rehabilitation and upgrading project of Al-Nebai-Baghdad Highway is selected for this study. The ESE indicators are selected based on the available data and techniques. The needed data; traffic volume, pavement condition, and geometric design characteristics; are collected to process the engineering and the ESE assessment through aggregating several methodologies and analyse the results using thr cost-effectiveness technique. The results of the engineering assessment showed upgrading the traffic level of service to D due to adding a lane when the pavement condition was upgraded to good condition due to a new overlay. The results of the environmental assessment in terms of vehicle emission stated that the new pavement reduced the emission by1831967 tons but the emission due to widening increased by 1046100 tons. The social assessment indicated that the road casualties reduced by 38.5% but it boosted over the service life. The economical assessment demonstrated the worthiness of the project; the Net Present Value is 76,153,580$, the B/C is 3.45 and the IRR is 35.04. It can be concluded that the ESE assessment is applicable and effective in figuring out the negative and positive consequences over the service life. However, improving the data collection system can enhance the comprehensiveness of the adopted methodologies and consider more indicators.

Keywords: Sustainability assessment; Vehicle emission; Economic evaluation; Road risk assessment; Cost-effectiveness

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1. Introduction

Road infrastructures are an essential element of the modern life because of the tremendous raise in the demand of personalised transport [1]. They also have been contributing to the economic development as they have promoted various economic activities [2]. However, the national economic development produces more infrastructure development projects in which roads are a major part. The road infrastructure projects; including construction, upgrading, rehabilitation and maintenance; have been resulting in sustainable issues which offset their benefits of improving mobility [1, 2]. The main important consequences of these issues are environmental, social, and economic consequences. Therefore, incorporating the indicators of the sustainable assessment in terms of environmental, social, and economic indicators (ESE) in the road project phases have become crucial and essential to consider the balance between the negative and the positive consequences of a proposed road development project in short and long- terms time [2].

2. ESE Assessment multi-stages

The mandatory ESE assessment has been established as an essential preventive strategy aims to identify, minimize, and prevent the negative consequences of road infrastructures development and transportation operation. ESCAP [2] and Jamshed et al. [1] consider the ESE assessment as a multi-stage, that each stage should be conducted in a separated phase of road project life cycle. These stages are as follows [2-4]:

1. ESE assessment during pre-construction phase
2. ESE assessment during construction phase
3. ESE assessment during post-construction phase

2.1 ESE assessment during pre-construction phase

The pre-construction phase is the first phase of road infrastructure life cycle divided into three sub-phases; conception, planning, and design sub-phases [1-3]:

a. The conception sub-phase is the initial phase of the road project. As developing a new road infrastructure is almost a policy decision, a comprehensive and macro level plan is prepared in this stage. The overall feasibility and efficiency including the sustainable implications should be conducted according to the national constraints. The ESE measures are assessed in this phase through screening stage to identify if the project needs ESE assessment or no [1], to provide information regarding the scale and type of the project, to identify the measures of ESE, to propose alternatives of projects and choose the best one based on the ESE measures, to gain government approval and public acceptance, and to provide the necessary input of planning phase.
b. Planning phase: the alternatives of the project are evaluated according to the sustainable requirements through identifying goals, taking inventories of the current situation, forecasting needs, and qualitative and quantitative assessment. The integrity scale of the ESE measures with the proposed project is examined in this stage. Full-scale means full integration of the ESE measures and partial-scale means integrating some of the ESE measures. The main purposes are identifying the most important measures, prescribing and improving the action plan, identifying and collecting the necessary data, and outlining the procedures of the further stages.
c. Design Phase: the best alternative is selected in this phase based on the results of the ESE impact analysis. The design of the road is prepared through incorporating the recommendations of the previous phase on the design details and according to the design specification. The final design report is submitted to start the construction phase. The purpose of this stage is identifying the key issues that worth full ESE analysis and that require only brief discussion. To analyse the ESE impact during design phase, the following steps are considered: identifying and collecting additional data, analysing systematically the ESE of the proposed alternatives, designing the ESE mitigation measures, developing the ESE management plan, and developing programmes for further stages. The findings of this stage with list recommendations of new road design or rehabilitation of existing one with comprehensive management plan are presented and submitted in a final report at the end of the planning phase.

2.2 ESE assessment during construction phase

In this phase, the ESE measures are monitored with respect to the approved mitigation measures to address the substantive ESE measures. The adhering of the involved agencies to the recommended strategies are also checked [2-4].

2.3 ESE assessment during post-construction phase

Post-construction phase represents the service life of the project including operation and maintenance activities. The aim of this stage is to evaluate the performance of a project during the service life to ensure that the ESE measures are extended to cover its life. Short-term and long-term ESE assessments are considered in this stage. The purposes of this stage is to evaluate the quality, effectiveness and appropriateness the of the implemented ESE recommended measures, and to identify the successful practices which can be recommended for further actions [1-4].

3. The problem statement

The ESE assessment strategy is widely implemented in most countries but still ineffectively or incompletely considered in other countries; such as Iraq. The main reason is the ineffective conception and planning stages of the infrastructure projects in which this assessment should be introduced as an integral tool [1, 2]. There is also a lack of integrating the sustainable assessment into the design, implementation, monitoring and evaluation stages despite of the general sustainable awareness among administrators and road professionals. In addition, the unavailability of adequate data collection system and incomplete dataset has led to inadequate baseline condition for sustainable assessment. Furthermore, the unclear and ill-defined of the respective roles of approving authorities and the undertaken agencies have resulted in ineffective regulation and guideline system of the sustainable assessment, weak coordination with projects stakeholders and inadequate enforcement system. Therefore, there is a need to find a comprehensive methodology that considers the above issues to apply the ESE assessment stages; especially during the pre-construction phase when there is no direct method to measure the indicators. In addition, there is a need to identify the most influenced indicators among the indicators that can be measured from the available data. This may help to reduce the size of the needed data and simplify the processing of the ESE assessment.

4. The aim and objectives of the study

This study aims to outline a methodology of the ESE assessment of road infrastructures in Iraq during pre-construction phase through achieving several objectives:

1. To determine the potential ESE Indicators that can be used to investigate the impact of the road infrastructure projects on the sustainability development.
2. To quantify the selected indicators.
3. To analyse the impact of the road project on the selected indicators using cost-effectiveness technique.

5. Study methodology

To achieve the aim and the objectives of this study, the following steps are carried out:

1. Selecting a proposed road development project based on:
   - The type of project, new road construction, upgrading, rehabilitation or maintenance.
   - The phase of the project life to focus on the pre-construction phase
   - The availability of the project details and needed data
2. Identifying the potential ESE indicators based on literature review and selecting the ESE indicators used on this study based on the available data, techniques and methodologies.
3. Selecting validated methodologies to assess each of the selected ESE indicators individually
4. Collecting the necessary data to quantify the identified ESE indicators
5. Quantifying and qualifying the identified indicators
6. Evaluating the impact of the selected road project on the identified ESE indicators through comparing the quantity of indicators before and after the project implementation using cost-effectiveness analysis.

6. The case study

Several drafts of road projects are reviewed to choose the case of this study based on the required criteria mentioned in section [4]. The project of rehabilitation and upgrading of the Al-Nebai-Baghdad highway is selected [5]. The selected segment is four-lane multilane divided highway of 51 km length, directed from Al-Nebai area to the intersection point with the ring road no.1 at the gate of Baghdad City. This road is mainly used by heavy vehicle, truck types 3 and Type 3S-3 [6], because it connects commercial and industrials centres in the north part of Iraq with Baghdad city. In addition, it connects the main source of the raw construction material, which is Al-Nebai centre, that produces the highest quality material used commonly by the construction companies in Baghdad City and the around areas.

The selected project aimed to improve the Al-Nebai-Baghdad highway which has low traffic service level and low road condition level with noticeable roughness and deformation along the road segment. The suggested improvements are upgrading the selected road segment to six-lane multi lane highway to accommodate the heavy traffic volume of trucks, and rehabilitation of the existing pavement to improve the pavement surface condition and treat the existing deformation. Therefore, it is suitable for ESE assessment during pre-construction phase. Figure 1 shows the selected road with pictures showing the deformation of the pavement surface resulting from the high volume of trucks.

Figure 1. Study area and the selected road project

7. Identifying and selecting the engineering and the ESE indicators

The effectiveness will be measured through assessing the impact of the developed project on a set of indicators. These indicators are grouped into engineering and the ESE indicators.

7.1 The Engineering indicators

The indicators that belong to the engineering group represent the main design characteristics of the selected road that require improvement. In the selected case study, the potential indicators are those reflect the level of traffic service and the pavement condition.

1. Traffic service indicators. The traffic service can be measured by the highway capacity manual (HCM) [7] methodology as it is the most common validated methodology used to qualify the traffic performance of multi-lane highways [8-10]. The HCM methodology is adopted in assessing the traffic performance in the selected study and in suggesting the solution of upgrading the selected segment to six-lane divided highway. On the other hand, the adopted methodology of estimating the operation cost incorporates the traffic performance in terms of travel time cost [11]. Therefore, these indicators are assumed as aggregated engineering-economic indicators.
2. Pavement quality indicators. The quality of the pavement surface is measured by several indicators such as the International Roughness Index (IRI), the Present Serviceability Rating (PSR), and the Present Serviceability Index (PSI) [12, 13]. The (IRI) was developed by pavement experts under the sponsorship of the World Bank to summarize the longitudinal surface profile. According to the ASTM Standards [14], pavement roughness is defined as “the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and pavement drainage”. It is usually related to the serviceability, deterioration, and structural deficiencies of the road pavement [12, 15, 16]. The IRI is selected to measure the quality of the road pavement because of its widely used in assessing the pavement condition and its significant correlation with vehicle operating cost, road safety, riders comfort and speed of vehicles. It is also can be easily measured subjectively through field observation, that the new pavement can be rated as good and the deteriorated surface can be indicated by poor condition [12, 15, 17]. The IRI can be estimated based on the field evaluation using Table 1 [16, 18].

Table 1. The pavement condition status based on the IRI [16]

IRI Value	**Pavement Conditions**	**IRI Value**	**Pavement Conditions**
IRI < 4	Good	8 ≤ IRI≤ 12	Bad
4 ≤IRI≤ 8	Fair	IRI > 12	Poor

7.2 The ESE indicators

This group of indicators contains the environmental, social and economic indicators. Studies of the sustainable assessment of road project were reviewed to identify the most common indicators. Selection of the indicators in this study is based on the available validated methodologies and techniques of quantifying these indicators and the available data.

1. The environmental indicators. The considered environmental indicators in the ESE studies are classified into soil, water, ecosystem, landscape, and air indicators. The indicators of each class are shown in the reviewed studies [1-4, 19-22]. The indicators related to air, landscape and ecosystem are the most common considered. Air pollution caused by vehicle emissions and that generated through construction activity has negative impact on human health and it is highly used in previous assessment studies. While the loss of habitat and destruction of vegetation are examples of ecosystem indicators. The landscape indicators are reflected by land devoted, destruction of trees and change in the drainage patterns [2].

   The pavement and vehicle emission in terms of the carbon dioxide CO_2 emission per lane-km is the most conducted indicators because they are related to the global warming issue. The CO_2 emission in the construction phase accounts about 15% of the CO_2 emission resulted from a road project while the maintenance activities emit about 10-20% of CO2 emission. The sulfur dioxide SO2 and nitrogen dioxides NO2 are also used to indicate the air quality [23-30]. Despite the importance of the environmental indicators, there is a lack of validated methodologies to analyse their influences by the road projects. The adopted methodology considered the air quality in terms of vehicle emission. The land devoted by the project is integrated with the economic indicator in terms of construction cost which includes the land cost. Therefore, the vehicle emission is selected in this study to represent the environmental indicators. The land devoted indicator is considered as an aggregated environmental-economic indicator.
2. The social indicators. They represent the impact of the road projects on community activities, displacement and resettlement, cultural heritage, level of noise, human safety and equity [1, 2, 4, 31]. In Iraq, there is a noticeable gap in the road planning research and studies conducted to consider and quantify the social indicators and develop a method of estimating their values. In this study, the social indicators as considered in terms of human health which can be measured by estimating the air pollution resulted from road projects and by estimating the saving in road death and serious injuries resulted from road design quality.

   The air pollution will be measured as an environmental indicator, therefore, the vehicle emission will be considered as aggregated environmental-social indicator while the road safety in terms of percentage of saving life will be used as an individual social indicator. The methodologies of estimating road fatalities and serious injuries (FSI) in the pre-construction phase was reviewed [32] and the International Road Assessment Programme (iRAP) [33] is chosen for this study because of the availability of the data that are needed to process the programme without using accidents data that are not available.
3. The economic indicators. They are the estimated amount of the project expenditures including the construction cost and the expenditures over the project service life, operation cost and the maintenance cost [1, 31]. The economic saving produced from road improvement has been considered in achieving the sustainable performance of road infrastructures [34]. The method of estimating the operating cost and maintenance cost are reviewed; the selected method is chosen based on the availability of the needed data.

8. Data collection

Collecting the necessary data is the most challengeable step in this study. Lack of trusted database and adequate collecting techniques in addition to the difficulties in getting official permission to collect data were the main reason behind the limitation of this study regarding the selected ESE indicators and the adopted methodology. The needed data to process the adopted methodology are traffic volume and speed, pavement condition, and geometric design details.

1. Traffic volume in terms of the average annual daily traffic (AADT) is needed to evaluate the traffic level of service and the level of road safety of the selected road before and after improvement. The AADT is needed also to estimate the overall cost of the project. The traffic volume was collected for seven weekdays from 8:00am to 5:00pm to determine the peak hour, which is used here as the design hourly volume (DHV). The traffic composition was considered, passenger car (PC) and heavy vehicle (HV). Two types of the HV used the selected road, truck Type3-S2 which is assumed as the large truck (LT) and truck Type3 which is assumed as the medium truck (MT) [6]. The peak hourly volume was 410 vehicle/hour, 23% (passenger cars+ mini bus) and 77% heavy vehicles which is divided into 66% of MT and 11% of LT. The forecasted future traffic

volume (FTV) is estimated using growth rate of 3% and analysis time of 21 years, one year for construction and 20 years as service life.

To improve the traffic performance of the selected road, the project planners recommended to adding a lane on each direction to upgrade the road to 6-lanes highway. This was investigated through the planning procedures of the Highway Capacity Manual (HCM) procedures [7]. This has been expected to raise the level of service (LOS) to D. The AADT is determined using Equation 1

$$AADT = \frac{DHV}{30th\text{−}hour\ factor} \tag{1}$$

The 30th-hour factor is assumed as 15 % [6, 13]

$$Average\ traffic\ per\ year = AADT\ \times 365 \tag{2}$$

2. The vehicle speed. The vehicle speed has impact on the traffic produced emissions (Panis et al., 2006). Therefore, the adopted assessment methodology used the vehicle speed to estimate the travel time cost.
3. Road pavement type and condition. The pavement condition before and after improvement is required rating to estimate the pavement emission and to estimate the operating cost. The reconnaissance survey was carried out to evaluate the pavement condition subjectively. The road surface was covered with asphaltic pavement and the road condition was bad; therefore, the IRI is between 8 and 12, 10 is used in this study. After improvement, the new paved road is rated by 4. Table 1 is used to find the IRI of this road type.
4. Road design detail. Details related to the road cross section elements, profile, and the alignment are required to estimate the road casualties. These details are number of lane, grade, delineation, roadside objects, shoulder type and median types [33].

9. Quantifying and evaluating the environmental indicators

The vehicle emissions due to pavement rehabilitation and road widening are quantified to assess the environmental effect of the road project.

9.1 The vehicle emission due to pavement condition improvement.

The adopted methodology of estimating the vehicle emissions; the emission of carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxides (NO_2) is processed through using equations 3-6 [35]. This methodology is based on the Pavement Condition Index (PCI) [36].

$$CO\ Emission\ \left(\frac{\frac{g}{km}}{hr}\right) = 0.1564(PCI)^2 - 24.655(PCI) + 21747 \tag{3}$$

$$NO_2\ Emission\ \left(\frac{\frac{g}{km}}{hr}\right) = 0.0025(PCI)^2 - 0.4451(PCI) + 495.81 \tag{4}$$

$$SO_2\ Emission\ \left(\frac{\frac{g}{km}}{hr}\right) = 0.00003(PCI)^2 - 0.0047(PCI) + 4.4169 \tag{5}$$

$$CO_2\ Emission\ \left(\frac{\frac{g}{km}}{hr}\right) = 9.4609(PCI)^2 - 1573.6(PCI) + 200000 \tag{6}$$

The PCI value can be found from its relationship with the IRI shown in Equation 7 [36]:

$$log(PCI) = 2 - 0.43\,log(IRI) \tag{7}$$

The estimated PCI is around 37.15 and 55 for the old and suggested roads, respectively. The results of emissions are shown in Table 2.

Table 2. Predicted vehicle emissions before and after improvement

Emission	Old condition Road	New condition Road	%Reduction
CO (g/km/hour)	21045.91791	20939.95013	0.868733356
NO_2 (g/km/hour)	482.7248413	480.565368	0.794001245
SO_2 (g/km/hour)	4.283698675	4.263639152	0.806515061
CO_2 (g/km/hour)	1954597.961	1947437.511	0.640885681

The reduction amount is approximately 7146.45 g/km/h which is equivalent to 0.43 tons per LT, 0.57 tons per MT and 0.71 tons per PC. The total emission is 1831967 tons.

9.2 The vehicle emission due to road widening.

The effect of road widening on the vehicle emission is controversial. Adding a lane may lead to traffic congestion relief which in turn lead to higher operating speed, shorter travel time, and less stopping delay. Therefore, the effect of road widening is positive. Williams-Derry [37] stated that building one-lane mile of road results in declining the carbon dioxide emission by 7000 ton over 50 years.

On the other hand, widening roads may causes extra vehicle emission resulted from the construction and maintenance activities and from the extra vehicle travel attracted to use the added lane [25, 37, 38]. Williams-Derry [37] stated that the impact of the additional vehicle travel due to adding lane appears in the 10^{th} year of its service life then the extra emission increases over its service life to reach about 90000 to 100000 tons per mile of CO_2 over 50 years.

The total net emission, then, from widening is about 33000 tons per mile over 20 years [37]. Ducca [28] shows that additional lane increases the CO2 and NO2 by about 17%. Therefore, the estimated increase in the vehicle emission resulted from widening the Al-Nebai-Baghdad highway is 33000 tons per mile multiply by the length of the road of 31.7 mile (51 km), which equals to 1046100 tons.

10. Quantifying and evaluating the social indicators

The social assessment is indicated in this study as the human health affected by the air quality which is already considered in the environmental assessment and this affected by the road safety. The road safety indicator is used to investigate the saving in the fatalities and serious injuries (FSI) produced from the road rehabilitation and upgrading. The iRAP methodology [33] is adopted to estimate the FSI before and after improvement. The main input of this methodology is the road attributes which are coded to quantify the risk factor of each attribute. The change in the number of lane, skid resistance, delineation and road condition are the considerable variables in this study as shown in Table 3. The remaining attributes have not been changed; therefore, the risk factors of these variables have not influenced by the road improvement project.

The input of iRAP programme will be processed to find the results of assessment which are in terms of star rating score (SRS) and star rating (SR); one SR reflects the highest SRS with worst condition while five SR resulted from the lowest SRS and reflects the highest safety level.

The results of the adopted methodology are disaggregated according to the type of accidents and the road user group. The selected road is a rural divided multi-lane which is used by vehicle occupants only because there are no facilities for other road user groups. In addition, the improvement in this segment affects one type of accidents [33] which is the run-off accident. Regarding the other types of accidents considered in iRAP; such as the head-on (loss of control) and head-on overtaking, the likelihood score of these types is affected by the suggested improvement but in case of undivided highways only. The intersection and access point accidents are not affected by the road condition or number of lane. Therefore, the results are the SRS and the SR of vehicle occupants, run-off accident on the passenger side and on the driver side as shown in Table 3. It can be noticed that the SRSs decreased by about 42% for both types which reflect the improvement in the level of road safety. However the SR is still in its lowest value which means the road is risk condition. The details of the risk factors shown in iRAP [33] explained that the roadside condition should be considered in the improvement project to upgrade the level of road safety.

Table 3. The input variables of iRAP that changed after improvement with the SRS and SR results.

Road attribute	Current condition	New condition	
Number of lanes	2/direction	3/direction	
Road condition/skid resistance	Poor/poor	Good/adequate	
Delineation	Poor	Adequate	
SRS of run-off (driver side)	3.06	1.78	% Saving SRS =42%
SRS of run-off (passenger side)	9.44	5.47	% Saving SRS =42%
SR for both types	1	1	Upgrading in SR=0

The SRS, then, will be used to estimate the FSI in the current situation by multiply the SRS by the AADT resulted from Equation 2 and modified factors by the iRAP [33]. The FSI is estimated also for the improved condition for each year of its service life because the forecasted AADT is increased yearly based on a constant growth rate of 3. The saving in the FSIs over the service life is estimated and shown graphically in figure 2 assuming that the annual maintenance will be carrying out to keep the road condition in good level. It can be noticed that the percentage of saving FSI is decreasing within the service years because of the increase in the forecasted AADT.

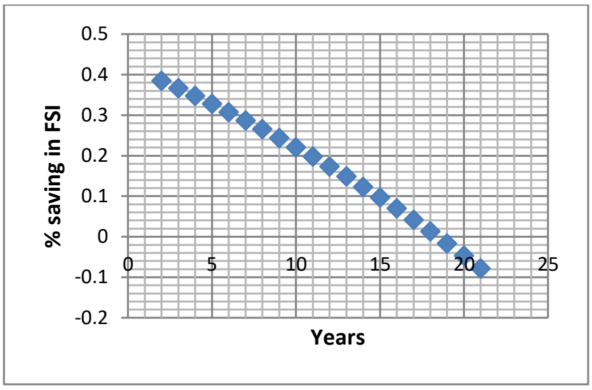

Figure 2. The % saving life resulting from improving the selected road segment over its service life

11. Quantifying and evaluating the economic indicators

The followed steps to estimate the overall saving in the project cost are estimating initial cost, maintenance cost, operating cost, and benefits [22].

11.1 Estimating the initial cost

The initial cost represents the expenditures of constructing the project including planning, design, land acquisition, earthwork, pavement, drainage system, equipment and work team [22, 39]. The initial cost of the Al-Nebai-Baghdad highway improvement project was equal to the rehabilitation and widening cost which are got from the source of the study [5] as shown in Table 4.

Table 4. Estimated cost of rehabilitation and construction new lanes of the selected road [5]

Road widening($)	Rehabilitation (Overlay) ($)	Total Cost ($)
20,400,000	7,450,000	27,850,000

11.2 Estimating the maintenance cost

Maintenance cost is the cost of maintaining the road pavement during it operation time paying annually as uniform payments. AASHTO [40] estimated the maintenance cost as 0.8% of the initial cost [41].

11.3 Estimating the road user cost

The road user costs (RUCs) represents the expenditures of operating vehicles in terms of vehicle operation costs (VOCs) and cost of time consumed in travels in terms of travel time cost (TTC). The VOCs correlates with the road condition and its serviceability level while the TTC aggregates the passenger and freight cost during the journey time [42, 43].

11.3.1 Vehicle operation costs (VOCs)

Vehicle operating cost incorporates the cost of fuel consumption (Fc), oil consumption (Oc), tire life (Tl), and vehicle maintenance cost (Vmc). These reflect the significant characteristics of vehicles that are affected by road attributes; especially the road condition and alignment [44]. The fuel consumption cost (Fcc) in Iraq is relatively low at the study time; therefore, the related cost has not significant as in another situation. The estimating procedure of the VOC elements is adopted from ITMP [18]. The quantities of Fc and Oc are estimated in litre per length unit and the Tl is estimated in 1000km unit based on the IRI value, pavement type, vehicle type, and the road attributes. Then the estimated cost per one unit for each element of VOC is estimated in $ per quantity unit. Table 5 shows the attributes and unit cost of the current condition and the cost estimation for the new conditions. Regarding the Vmc, its values depend on the vehicle values and pavement condition. The vehicle value is assumed equivalent to the common vehicle prices; 10,000$ for PC with 250,000 km life and 50,000 $ for HV with 500,000 km life. The Vmc is assumed as 30% of the vehicle price in case of bad road condition and 15% of the vehicle price when the road is recently paved [45].

Table 5. The characteristics of the selected road at the current and the new conditions with the unit costs [18]

Current Condition									
Veh. Type	IRI [m/km]	Average IRI influence speed [km/h]	Fc [l/km]	Tl [1000 km]	Oc [l x 1000 km]	Fcc [$/l]	Tl cost [$/tire]	Oc cost [$/l]	Tires/vehicle
PC	10	46	0.102	11.5	3.05	0.35	30	1.75	4
MT	10	37	0.231	11.5	4.57	0.2	200	1	8
LT	10	28	0.301	11.5	6.65	0.2	200	1	16
New condition									
Veh. Type	IRI [m/km]	Average IRI influence speed [km/h]	Fc [l/km]	Tl [1000km]	Oc [l x 1000 km]	Fcc [$/l]	Tl cost [$/tire]	Oc cost [$/l]	Tire/vehicle
PC	4	100	0.075	40.7	2.15	0.35	30	1.75	4
MT	4	80	0.143	40.7	3.67	0.2	200	1	8
LT	4	60	0.16	40.7	5.75	0.2	200	1	16

The estimated cost per quantity unit is converted to costs per kilometer in both conditions as shown in Table 6. It is noticed that the total costs reduced from 0.200 to 0.080 ($/vehicle-km) as a result of improving the road condition.

Table 6. The estimated VOC /km ad the current and new pavement condition

VOC elements / Veh Types	Fcc ($/km)	Tl cost($/km)	Oc cost ($/km)	Vmc ($/km)	Total costs ($/km)	vehicl e %	**$/vehicle-km**
Current Road							
PC	0.0357	0.01043478 3	0.005337 5	0.012	0.06347228 3	23	0.014598625
MT	0.0462	0.13913043 5	0.00457	0.03	0.21990043 5	66	0.145134287
LT	0.0602	0.27826087	0.00665	0.03	0.37511087	11	0.041262196

VOC elements / Veh Types	Fcc ($/km)	Tl cost($/km)	Oc cost ($/km)	Vmc ($/km)	Total costs ($/km)	vehicle %	**$/vehicle-km**
						∑ Costs	0.200995108 *
New condition							
VOC elements / Veh. types	Fcc ($/km)	Tl cost ($/km)	Oc cost ($/km)	Vmc ($/km)	Total costs ($/km)	vehicle %	**$/vehicle-km**
PC	0.02625	0.002948403	0.0037625	0.006	0.038960903	23	0.008961008
MT	0.0286	0.039312039	0.00367	0.015	0.086582039	66	0.057144146
LT	0.032	0.078624079	0.00575	0.015	0.131374079	11	0.014451149
						∑ Costs	0.080556302

Figure 3 shows that the tire cost is more expensive for HV than PC while the oil and fuel cost are cheaper; the tire costs are 16.5% for PC, 63% and 74% for MT and LT as a percentage of the VOC. Figure 4 shows the VOCs before and after improvement. It is obvious that the VOCs in the current condition reduced due to rehabilitation and upgrading.

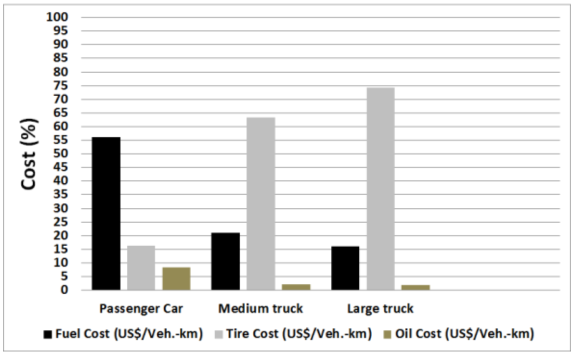

Figure 3. VOC components for different vehicles

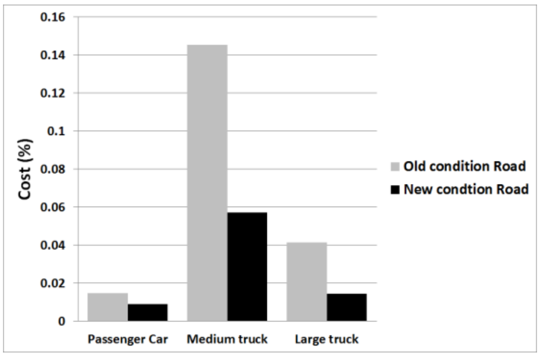

Figure 4. VOC of old and new condition

11.3.2 Travel time cost (TTC)

The improvement in the road condition leads to driving with higher speed which resulted in saving considerable travel time (TT). The saving in the TTC can be estimated as the expenses of driving extra distances in a specific pavement condition [18, 41]. In this study, the TTC is assumed equal to 1.2752 $/hour-passenger for PC and 0.0184 $/hour-ton for freight [18]. The overall TTC is estimated as the total TTC for all passengers and the total gross weight of all vehicles. The average vehicle occupancy rate (Vor) is 6 people for both PC and MT and 1.5 people for the HV. The TT is estimated from the speed formula shown in Equation (8).

$$Travel\ time\ (hour) = \frac{road\ length\ (km)}{speed(\frac{km}{hour})} \tag{8}$$

Table 7 shows the results of estimating the average TT and the TTC of the current and rehabilitated road. It can be stated that the TTC are significantly declined as a result of shorter TT at the improved road condition; the TTC were 4.699 ($/vehicle) for the current condition and 2.171 ($/vehicle) for the rehabilitated road.

Table 7. The TTC estimation of the current and new road conditions

Veh. Type	Average IRI influence speed [km/h]	TT (h)	People per vehicle	Ton per vehicle **	TTC ($/vehicle)	Vehicle %	TTC ($/vehicle)
			Current condition				
PC	46	1.10	6	0	8.482	23	1.951056
MT	37	1.37	1.5	27	3.321	66	2.192084757
LT	28	1.82	1.5	47	5.059	11	0.556512
						∑ Costs	4.699652757
			New condition				
PC	100	0.51	6	0	3.902	23	0.897
MT	80	0.64	1.5	27	1.536	66	1.013
LT	60	0.85	1.5	47	2.360	11	0.259
						∑ Costs	2.171

** Legal gross weight permitted on a motor vehicle in regular operation in Iraq [6]

11.4 Estimating revenues

The saving in the VOCs and the TTC are considered the revenues of the project.

1. Revenues due to saving VOCs. It is produced from saving the VOCs after improvement the road, computed as the difference between the total VOC before and after improvement as shown in Figure 5. The total estimated VOCs of the current condition with a length of 51 km was 10.25 ($/vehicle), while the total VOCs of the improved condition was 4.10 ($/vehicle). Thus, the benefit of VOCs was 6.14 ($/vehicle).
2. Revenues due to saving TTC. The saving in the TTC, for both PC and HV, are considered as a part of the total benefit of the improvement project. The saving in the TTC was 2.52 ($/vehicle) as shown in Figure 6.

   Thus the total revenues produced from saving RUC 8.66 ($/vehicle).

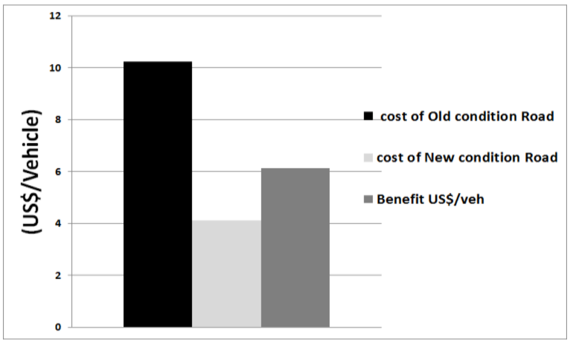

Figure 5. Benefits resulting from VOC saving

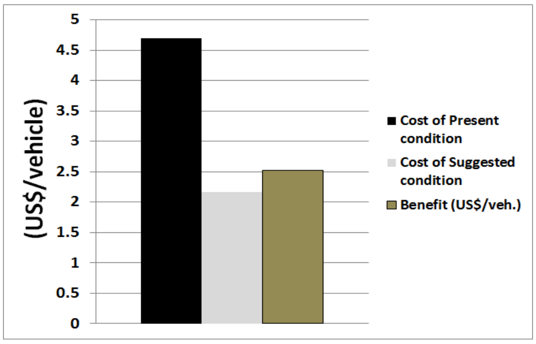

Figure 6. Benefits resulting from TTC saving

11.5 Economic evaluation

The aim of this step is to find the economic indicator that reflects the total economic benefit produced from the road improvement project through comparing the cost with the revenues. If the improved road resulted in higher net profit then it is more efficient. Three techniques that are used to evaluate the selected road project economically are [46, 47]:

1. Net present value (NPV), is the difference between the total equivalent cost and the total equivalent revenues at the present time. When the NPV is positive, the project is economically worth.
2. Benefit-cost ratio (B/C), is the ratio of the total revenue to the total cost. When B/C is greater than 1, the project is considered viable. This method is more preferable for transportation projects [48, 49].
3. Internal rate of return (IRR), is the discount rate resulted from net profit equal to zero. If the result is greater than the minimum attractive rate of return (MARR), the project is viable.

These techniques will be processed after using different discount rates, between 8% and 50% [46, 47]. To find the NPV, the estimated annual costs and benefits are discounted to find the equivalent value in the present time. Six discount rates are tested in this study 8%, 20%.30%, 35%, 40%, 50%. The present worth (P) of the annual values is determined using Equation (9):

$$P = F\left[\frac{1}{(1+i)^n}\right] \tag{9}$$

Where F is the future costs or benefits values, n is the number of years from the base year, and i is the discount rate. The total benefits and the total cost are determined for all the forecasted traffic volume and the average annual traffic computed using Equation 2 as shown in tables 8 and 9 respectively. The initial cost and benefit at the present study year is estimated as zero. The cost at the construction year, which is the year 1, is equal to the construction costs estimated in section 11.2.1 while the benefit is zero at this stage. The P of all the future costs and revenues are computed at different i_s using Equation 9; the total then is found. Tables 8 and 9 show the results of some of the estimated Ps and the total P for all the service life years.

Table 8. The equivalent P of the estimated revenues at different is.

Year	**FTV* (vehicle/year)**	**Total Benefits ($)**	**The discount rate (i)**					
			8%	**20%**	**30%**	**35%**	**40%**	**50%**
0	997667	0	0	0	0	0	0	0
1	1027597	0	0	0	0	0	0	0
5	1156569	10015888	6816645	4025161	2697570	2233678	1862299	1318965
10	1340781	11611160	5378214	1875267	842252	577481	401417	201355
20	1801897	15604428	3347902	407027	82107	38599	18650	4693
21	1855954	16072561	3192907	349365	65054	29449	13721	3222
		Total =	103966065	42814422	25865668	21122702	17656700	12994295

*FTV=Future traffic volume

Table 9. The equivalent P of the estimated cost at different is.

Year	**Total Costs ($)**	**The discount rate (i)**					
		8%	**20%**	**30%**	**35%**	**40%**	**50%**
0	0	0	0	0	0	0	0
1	27850000	25787037	23208333	21423077	20629630	19892857	18566667
5	222800	151634	89538	60007	49687	41426	29340
10	222800	103200	35983	16161	11081	7703	3864
20	222800	47801	5812	1172	551	266	67
21	222800	44261	4843	902	408	190	45
	Total Discount Costs	27812484	24112452	21991353	21099998	20290239	18863644

The result of the NPV, B/C and the IRR for 8% discount rate (DR) are shown in Table 10 which all indicate the worthiness of the projects.

Table 10. Economic evaluation results

Evaluation Technique	Result
$NPV_{[8\%]}$($) =	76,153,580
B/C $Ratio_{[8\%]}$ =	3.74
IRR(%) =	35.04

11.6 Sensitivity analysis

Sensitivity analysis is stated to investigate the change the project viability resulted from changes in one or more features [50, 51]. The purpose of this step is to support the decision makers regarding the suggested improvement. The details of this step are shown below.

1. Analysing the sensitivity of increasing fuel unit. The expected increase in the fuel price with all the remaining variables are constant will lead to decrease the saving rate in VOCs. When the fuel price is going to be double, the saving in the VOCs will drop by four unit costs but it still greater than zero. Beyond that, it is expected that the fuel price has inverse effect as shown in Figure 7.

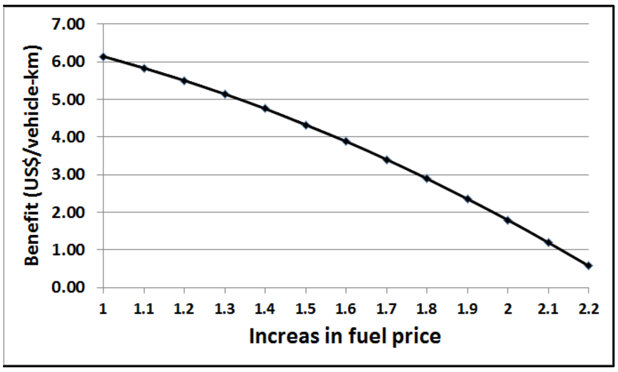

Figure 7. Impact of increase the fuel price on the VOC saving

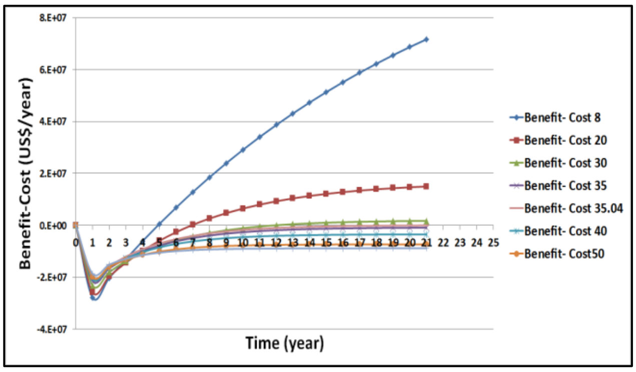

Figure 8. Effect of different discount rates on the returned benefits

2. Analysing the sensitivity of the discount rate. The effect of changing the discount rates, from 8% to 50%, on the balancing the revenues and the costs is investigated to determine the discount rate that produces positive net profit, NPV>zero. The results are shown in Figure 8. This analysis can be carried out using the IRR method; that when IRR is greater than minimum attractive rate of return (MARR), the project is economically reasonable.

3. Analysing the sensitivity of the traffic growth factor and construction cost. The effect of changing the growth rate with different construction costs is investigated at different B/C ratios as shown in Figure 9. It can be seen that the B/C values is between 0.93 and 3.74. The changes resulting in B/C greater that 1 is considered feasible.

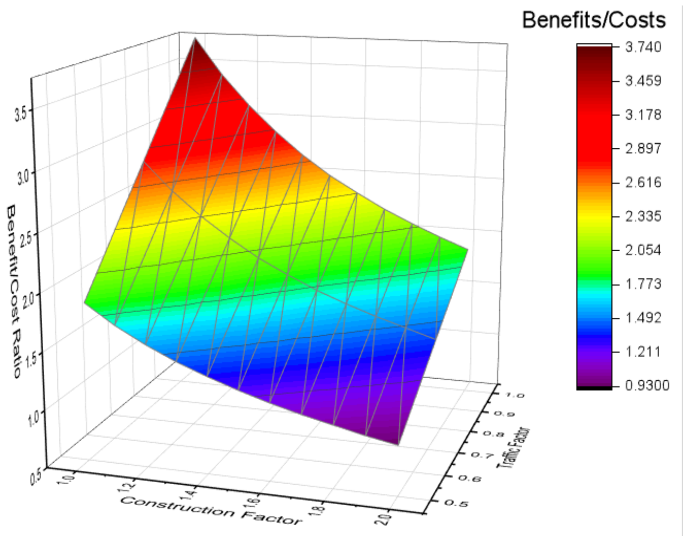

Figure 9. The results of the sensitivity analysis of construction cost, the traffic growth factor, and B/C ratio

12. Discussion

1. The engineering assessment shows that the level of the traffic safety before improvement was F and it is upgraded to D due to road widening based on the HCM methodology [7]. This indicates that the traffic service is unstable and it is reaching the traffic saturated condition with frequent stopping and long travel time. The road condition assessment is based on the IRI rating; it was 10 in to reflect the deformed surface with high roughness level, and it is declined to 4 after improvement to indicate the best road condition resulted from new overlay.
2. The vehicle emission is affected positively by improving the road condition. As the vehicle speed is higher when pavement condition is better, then the travel time will be shorter and the vehicle emission is less. The reduction amount is approximately 7146.45 g/km/h which is equivalent to 1831967 tons.

   On the other hand, the road widening increases the vehicle emission by about 1046100 tons due to the increase in the attracted travel vehicles using the new lane. However, this negative impact will appear after 10 years from the construction year. This is offset by the positive effect of the congestion relief resulting from widening. This will reduce the vehicle emission because of the shorter travel time.

   Then the net emission caused by the road improvement is reduced by about 785866.8 tons
3. The improvement of the selected road has positive effect on the safety level to reduce the rate of road FSI by about 38.5% in the first year after construction. However, the FSI rate will increase over the service life due to the traffic growth. In addition, the overall safety situation is still dangerous because of the roadside characteristics which are not considered in the improvement proposals. This enhances the need of ESE assessment in the pre-construction stage to avoid unexpected issues.
4. The estimated initial cost of this project includes material cost, land acquisition, material transportation, equipment, and crew fees. It was about 27,850,000 $. In addition, the annual expenditures required to maintain the road surface and keep the road condition in its good level was about 222800 $. However, this amount is offset by the annual revenues produced from the saving in the VOC and the TTC. The VOC is resulted from fuel cost, tire cost, oil cost, and vehicle maintenance cost. The RUCc significantly decreased as a result of improving the pavement condition; as the VOC reduced from ((10.25 $/vehicle) to ((4.1 $/vehicle) and the TTC declined from 4.699 ($/vehicle) to 2.171 ($/vehicle) after improving the road.
5. The economic evaluation demonstrated that the project is almost worth with net present value of 76,153,580$and B/C of 3.74. The IRR producing zero profit is which is greater than the minimum rate of return.
6. The overall ESE evaluation according to the selected indicators is that the project is economically beneficial and effective in improving the traffic and pavement performance but it requires to consider the environmental and social indicators significantly. Therefore, the integration of the ESE in the project planning was weak.
7. It is concluded from the sensitivity analysis that the project keeps its viability when the estimated traffic growth rate reaches 50% and the construction cost increases to 200%.
8. It is noticed that some of the selected indicators can be used as an aggregated indictor. For example, the TTC can be considered engineering-economic indicator. The vehicle emission can be used to indicate the human health. Therefore, it can be considered social-environmental indicator. The land devoted is environmental-economic indicator. Therefore, the selected indicators can be aggregated to use one index reflecting the overall assessment.

13. Conclusions

1. In Iraq, there is a significant lack of sustainable development studies of road infrastructures to conduct the ESE assessment.
2. The pre-construction phases of road project needs activated to consider the conception stage and the planning stage which should precede the design stage. The ESE assessment should be involved in each stage to avoid any unforeseen issues.
3. The inadequate available database in Iraq and the difficulties of getting permission to collect the needed data for this kind of studies limited the scope of this study regarding the selected indicators and techniques of estimation. Therefore, this assessment is still incomplete and incomprehensive.

4. The developed methodology of ESE assessment is based on validated individual methodologies and techniques used to estimate individual and aggregated indicators. It can be concluded that the developed methodology in this study is simple to process, it does not need big database and it can be updated with new techniques of estimation. However, it needs to test its validity in the post–construction stage.
5. The overall result of ESE assessment of Al-Nebai-Baghdad highway based on the selected indicators shows the effectiveness of the proposed improvements in achieving the upgrading in the level of traffic service and road condition and its efficiency in saving significant amount of vehicle and travel time cost. However, the project produces emission which increases the air pollution and affects negatively the human health. In addition, the improvement does not consider the risk of road resulted from the impact of the roadside characteristics. These reflect the importance of involving the ESE assessment in the planning phases to avoid the unexpected risk and to propose mitigation measures to consider in the design phase.
6. The integrity scale of the ESE in this project can be considered partial as more indicators needs to take into account.

14. Recommendations

1. Improving the roadside characteristics by to consider the shoulder type and width, and to consider the side objects size and distance.
2. Improving the adequacy of the data collection system to include all the necessary data for sustainable development studies. This is most likely to promote this kind of studies in Iraq and encourage the involved agencies to adhere to the sustainable assessment process.
3. The Environmental and social indicators need to consider deeply and comprehensively in the future road development studies.
4. The developed methodology in this study requires validation test by comparing the results of the ESE assessment in pre-construction stage with the results in the post-construction stage.
5. Evaluating the aggregation techniques to find an aggregated ESE index.

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