Economic and Environmental Assessments for Constructing New Roads: Case Study of Al-Muthanna Highway in Baghdad City

Qais S. Banyhussan, Sady A. Tayh and Ahmed M. Mosa

Abstract The geographical area of this study located between the Army canal and Al-Sadr City is characterized by high-density population and lack of high-speed highways. This area is facing a low service level during traffic congestion resulting from an inefficient and poor road network. A traffic study has been done which recommended the construction of a new road parallel to the existing one, but with higher standards. This research aimed to evaluate, economically and environmentally, the feasibility of constructing a road for Al-Muthanna highway. This research is based on the hypothesis that the present road exhibits a relatively severe condition whereas the suggested road will be an asphalt pavement with a high-quality status. The traffic volume data was collected using a manual counting method for seven days from 7:00 am to 4:00 pm to quantify the average daily traffic and peak hour volume. In addition, the number of lanes required for LOS (C) was determined. The construction and maintenance costs for the road were also calculated. Reduction in road user costs for both the present and proposed roads were estimated as advantages. The economic study is done by balancing the reduced total road costs and their advantages to the basic year. The assumed discount rate in this study was 8%. To discover the economic viability, various standards were verified. These standards are Benefit–Cost Ratio (B/C), Net Present Value (NPV), and Internal Rate of Return (IRR). The outcomes revealed that NPV exhibited an encouraging value, that indicated that total benefits were larger than costs. Moreover, the B/C ratio was found to be more than 1.0, which was promising. Lastly, the IRR was found to be greater than 8% as suggested in the road projects.

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1 Introduction

Understanding the prices of road construction, road maintenance, and vehicle operation is important to sound planning and management of road investments. Whereas the prices of road construction projects and maintenance exhaust an outsized amount of national funds, the costs are tolerated by the public using the road for the operation and depreciation of vehicles are still bigger. It is so necessary that road rules take into account the total transport costs. Therefore, measurable strategies for forecasting performance and costs of both vehicles and roads over huge and numerous highway networks may be needed [2].

The highway is one of the principal infrastructures in sustaining the financial and public interests of society. Therefore, it is essential to appropriately operate the road network so that it is predictable to boost the facility and welfare of the society. The condition of pavement can decline because of the effect of environment and traffic. Thus, the repairs effort is required to sustain the highway condition amid its service life. To perform conservation activities right on target, it is essential to have a strategy based on perfect road condition information. One of the highway condition considerations that may be accustomed to govern pavement conditions is pavement surface irregularity that may be stated in the International Roughness Index (IRI) values [4].

The issue of discounting of the long run benefits and costs has been widely mentioned throughout the literature. However, it is still unrevealed clearly and comprehensively. Little agreement is found on issues like what ought to discount, or on the selection of a discount rate. A portion of the matter sits in the truth that supporters of different methods to discounting are often uncertain about what they are maximizing, or what role the discount rate is assumed to behave [6].

When nation incomes are sometimes inadequate, difficulties correlated to the relevance of particular transportation projects and the legitimacy of several possible options appear frequently. Thus, it is rather complicated to take all the associations of transport structure projects into consideration. The ecological influences lonely are compound and diverse, counting noise and air pollution, the influence on the surroundings and the living status of the citizens. The complexity of considering necessitates the utilization of complicated strategies and assessment tools [7].

The cost reduction concerning vehicles use, road repair and travel time have a great role via rising pavement sustainability over keeping the material supplies and decreasing the releases of gases caused by the processing of derivative yields [9].

Vast study works have previously been dedicated to the examination and assessment of projects' investment. The conventional financial concept suggests the net present value (NPV) theory, utilizing a cost of wealth based on the ingrained project hazard. The NPV basis has been censure since it is said that it cannot handle with the probable flexibility that arises with investment projects, causing variations in the initial cash flow model [8].

The impact of dynamic speed controlling on traffic produced emissions has been studied by Panis et al. [17]. The traffic discharges caused by the change in the speed of vehicles are built on an immediate emission model combined with a road traffic replication simulation. The results display that, although the speed controlling has efficiently decreased the typical speed of road traffic, their effect on vehicle discharges is complicated. For the study model, the repeated change in the speed of road traffic in the network has considerably decreased the impact of the lessened average speed on emission [17].

Conventionally, classification and priority of highway segments for maintenance activities in many developing countries are based entirely on the experience and decision of road engineers and repair staffs. Nevertheless, because of the arbitrariness and compound connections of the influences occupied in pavement worsening mechanism, this method is ineffective, susceptible to errors and might guide to inappropriately planned maintenance performances. It is depressing to notice that the majority of the highways in these nations are of poor condition and many of them have converted into a dangerous status that causes financial depletion [16].

Against this background, this article was made to evaluate, economically and environmentally, the feasibility of constructing the Al-Muthanna highway, as well as to give a better judgment for the decision maker to build the alternative road or not, putting into account the interaction of all possible features that influence economic and construction costs.

2 Study Area

The geographical area of this study located between the Army canal (Ring road 3) and Sadr City roads is characterized as a high population density area and there is a lack of high-speed highways. The road network in the study area has an inefficient traffic flow due to very limited options for the driver to reach the target point. The road pavement is currently illustrated by ruts, cracks, depressions and potholes, causing the very low quality of riding. Road Pavement behavior has been advanced arbitrarily from time to time for the road in the query, causing frequent unprepared and expensive maintenance activities on it.

The most important intersections in the study area are: (1) Mashtal intersection, which connects between the regions of Kamaliyah and Balediyat. (2) Hamzah roundabout, which connects the areas in Sadr City (Habibiya, Urfali, etc) and areas near Jamila commercial area. (3) The intersection of Al-Quds, which is located on the street that connects between Mashtal and Hamza intersections. The current route has a length of 7.3 km, which connects the Army canal (Ring road No. 3) to Al

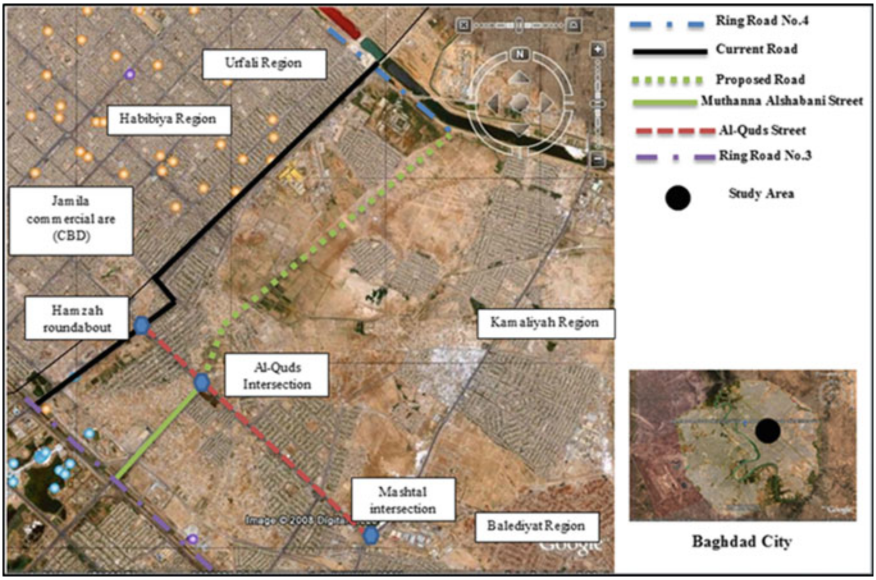

Fig. 1 Study area and the proposed route

Sadda road (the Ring road No. 4) passes through several regions of high traffic density, which suffer a high degree of traffic saturation. The proposed route starts from the Al-Quds intersection to the ring road No. 4 with the length of 7.1 km (including Muthanna Alshabani Street which, itself, needs some rehabilitation). According to the traffic study implicit in the current research area, the road consists of 6 lanes for two ways that operated with a level of serves (LOS) (F). All the above roads and intersections are shown in Fig. 1.

3 Purpose of the Study

As mentioned previously, the study area is facing an undesirable level of service throughout the traffic congestion resulting from an inefficient road network. Thus, a traffic study has been done which recommended constructing a new road parallel to the existing one, but with higher characteristics. The main aim of the present research is to evaluate economically and environmentally the feasibility of constructing the Al-Muthanna highway (proposed road). Besides, the contribution of the current study is to give a recommendation judgment to the decision maker to build or not. The study is based on the theory that the current road has a severe status, whereas the suggested one is with a decent pavement condition.

4 Assessment of Pavement Condition

Pavement condition valuation must be conducted frequently to define current pavement performance and forecast future pavement behavior, whether the road pavement has satisfied its three essential roles, which deliver effective service, safety and has a structural capability for the sustenance of traffic load and influence of the environment [5].

Road pavement irregularity is the most normally utilized status factor to evaluate pavement quantitatively. Road pavement irregularity information is fairly simple to gain, well connected with effective vehicle costs and the most applicable condition factor in road practical condition valuation in the long term [20].

The IRI is defined as the relation between the accumulation of typical vertical vehicle movement (mm or in.) and the distance covered by the same vehicle amid the measurement (m, km or miles). The principles of pavement status based on IRI values on asphalt highway sorts are presented in Table 1 [4].

5 Data Collection

An important challenge for highway and transportation engineers is to supply information and data to the design of a specific transport system or to work out the effectiveness of an existing transport system. This information applies economical and precise design standards and accomplishes the system's goal of transmitting efficient and safe transportation to people and goods. This issue could be a key part of most studies [10].

So as to determine the road condition limitations, information on the road surface under research were gathered at day time from 7:00 am to 4:00 pm for 7 consecutive days to decide the peak hour volume, which represents the design hourly volume in the analysis and calculations of this study, and to gain a comprehensive portrait of pavement and traffic conditions under the ambient climatic and traffic situations.

The traffic count has been classified into two main categories: passenger car (PC) and heavy vehicle (Hv). The peak hour volume was 2396 vehicle/h that denotes the design hourly volume (DHV). The traffic survey displayed that the traffic was categorized into 95% passenger cars and 5% heavy vehicles. The major

Table 1 The principles of pavement status based on IRI [4]

IRI value	Pavement conditions
IRI < 4	Good
$4 \leq$ IRI ≤ 8	Fair
$8 \leq$ IRI ≤ 12	Bad
IRI > 12	Poor

types of heavy trucks are Type 3 and Type 3-S2 with 3% and 2%, respectively. In this study, truck Type 3-S2 is assumed as the large truck (Lt) and truck Type 3 represents the medium truck (Mt).

The collected information was examined, and the estimated target traffic volume was established using a 5% growth rate with 22 years of analysis time, two years for road construction and 20 years for design life. The needed number of lanes was then, indicated according to the Highway Capacity Manual (HCM) procedures [12]. Six-lanes for both directions are appropriate to reach a level of service (LOS C). The proposed road is classified as A6/33 with a lane width of 3.75 m according to the requirements of the Iraqi specifications [21].

The annual average daily traffic (AADT) is determined according to Eq. (1):

$$AADT = \frac{\mathrm{DHV}}{\mathrm{K}} \tag{1}$$

where DHV is the hourly design volume, and K is 30th-hour factor and can be assumed as 10% for urban roads [11].

$$Annual\ Average\ Traffic(AAT) = AADT \times 365 \tag{2}$$

As stated by the ITMP [14], and after the accomplishment of the reconnaissance survey, the present road condition is fair pavement status. The attributes of this road type are displayed in Table 2.

In addition to the mentioned units of costs of the vehicle working, vehicle maintenance cost is assumed as 30% of the vehicle value with 250,000 km life for passenger car and 500,000 km life for heavy trucks. Moreover, the assumed car prices are 10,000 US$ and 50,000 US$ for passenger car and heavy vehicle, respectively.

The focal aim of this research is to evaluate the economic feasibility of the new-suggested road by calculating benefits resulting from user costs saving (i.e. the differences in costs between the existing and new road conditions) and the costs required to construct the suggested road. As stated in ITMP [14], the type of new-suggested asphalt pavement can be classified as a good pavement condition, and it has characteristics including a low international roughness index (IRI), as shown in Table 3. For this kind of road condition, the vehicle maintenance costs are assumed as equal to 15% of the vehicle price with the same vehicle prices stated above [19].

6 Components of Feasibility Study of Road Projects

The economic feasibility studies of road projects consist of comparing their costs with their revenues (benefits). To be more practical about what reduction rate to employ, its purpose should be clear. It is recommended that its reason is to benefit

Table 2 The attributes of the present road with unit costs [14]

	IRI (m/km)	Average IRI influence speed (km/h)	Fuel consumption (L/km)	Tire life (1000 km)	Oil consumption (L × 1000 km)	Fuel cost (US$/L)	Tire cost (US$/tire)	Oil cost (US$/L)	Average number of tires/vehicle
Passenger car	6	65	0.079	27.8	2.45	0.035	30	1.75	4
Medium truck	6	50	0.179	27.8	3.97	0.02	200	1	8
Large truck	6	40	0.217	27.8	6.05	0.02	200	1	16

Table 3 Characteristics of the new road and unit costs [14]

	IRI (m/km)	Average IRI influence speed (km/h)	Fuel consumption (L/km)	Tire Life (1000 km)	Oil consumption (L × 1000 km)	Fuel cost (US$/L)	Tire cost (US$/tire)	Oil cost (US$/L)	Average number of tires/vehicle
Passenger car	4	100	0.075	40.7	2.15	0.035	30	1.75	4
Medium truck	4	80	0.143	40.7	3.67	0.02	200	1	8
Large truck	4	60	0.16	40.7	5.75	0.02	200	1	16

selected individual projects that may give higher net benefits than particular other reduction rates. This method that is behind all the basis for benefit-cost strategy assists to merge different recommended techniques for calculating the reduction rate [6].

6.1 Costs

6.1.1 Construction Costs

According to Schoon [22], the main road construction costs are bridges, earthwork, pavement, drainage, and land acquisition. For roads and bridges, the costs consist of initial construction costs in which the total costs contain engineering work, planning, and design costs. Another sort of costs is maintenance, which is consumed during the service life of a particular road.

In this research, the class of the suggested road is designed to be A6/33. Furthermore, the embankment depth comprising asphalt pavement and sub-base layers are determined to be 1.5 m. The total construction costs are determined as displayed in Table 4.

The total road maintenance cost is assumed to be 0.8% of the total construction cost [1]. This assumption is based on the experiences with some existing highways having the same attributes [15].

6.1.2 Road User Costs

The road user costs (RUCs) incorporates vehicle operation costs (VOCs), that may increase with low levels of serviceability (e.g. bad road status, poor or lack of maintenance, etc.) and travel time cost (TTC) consumed on the passengers and freight during journeying from origin to destination.

Vehicle Operation Costs (VOCs)

Generally, the major estimated VOCs are fuel, lubricants and tire costs. It is worth to mention that these costs are not taking into account all the matters that are usually included in the vehicle operating costs, but only those thought to be the more distinguished ones by the user.

Table 4 Estimated costs of the newly planned road

	Road construction	Culverts	Design	Total
Cost (US$)	10,450,333	50,000	100,000	10,550,333

Fuel consumption is mostly thought to be as a significant element of VOC that is affected by some factors like vehicle characteristics, road condition and alignment, traffic volume and driving type. Because the fuel unit cost in a country like Iraq is relatively low at the current time, the associated cost is not predominant as in other situations. Though, this condition may be suddenly modified in the future according to the policy of road user charging.

The total costs per kilometer of the current and suggested roads for all kinds of surveyed vehicles are shown in Table 5. It is obvious that the average total costs for the existing road (ATCE) decreased as a result of improving the road condition as represented by the recommended road. The average total vehicle costs are decreased from 0.313 US$/vehicle-km for the current road to 0.0183 US$/vehicle-km for the recommended road. This reduction will be used later as benefits.

Figure 2 shows a rise in tire costs contrasted with oil and fuel costs regarding vehicle operating costs. It is clear to notice that the tire costs are 18.5% for passenger cars and 74% for heavy vehicles as a percentage of VOC. Figure 3 illustrates the VOCs for the present and suggested roads. The figure shows that the VOCs in the present road is, generally, higher than that in the suggested one.

Travel Time Cost (TTC)

Normally, highway developments can influence the increase in travel speed, thus contributing to considerable time saving for the drivers and passengers who are using the existing routes. This cost saving can be determined in terms of the costs of driving for an extra distance to save time [15]. Though, in this study, the travel time cost of the247 passenger is assumed to be 1.2752 US/h passenger and 0.0184 US/h ton for freight [14]. Furthermore, the average vehicle occupancy rate (VOR) in a passenger car is supposed to be two persons against 1.5 persons for heavy vehicles. The travel time required to drive on the current and suggested roads can be determined using Eq. (3).

$$\text{Travel time (h)} = \frac{\text{road length (km)}}{\text{speed}\left(\frac{\text{km}}{\text{h}}\right)} \tag{3}$$

Table 6 explains the average travel time costs of existing and suggested roads respectively taking into account the passengers and freights that are transferred. The travel time costs of the current road are considerably minimized because of the decreasing time consumed during the trip by increasing the traveling speed that is achieved by improving the road condition. The results state that the travel time costs were 0.2928 US$/vehicle for the current road compared with 0.1850 US$/vehicle for the suggested road. Therefore, benefits obtained from travel time costs reduction (saving) can be added to the benefits of vehicle operation costs, which were determined before.

Table 5 Perceived vehicle operation costs per kilometer

	Fuel cost (US$/km)	Tire cost (US$/km)	Oil cost (US$/km)	Vehicle maintenance cost (US$/km)	Total costs (US$/km)	Vehicle %	US$/vehicle-km
The existing road							
Passenger car	0.002765	0.004316547	0.0042875	0.012	0.023369047	95	0.022200594
Medium truck	0.00358	0.057553957	0.00397	0.03	0.095103957	3	0.002853119
Large truck	0.00434	0.115107914	0.00605	0.03	0.155497914	2	0.003109958
						$\sum$ Costs	0.028163671[a]
The suggested road							
Passenger car	0.002625	0.002948403	0.0037625	0.006	0.015335903	95	0.014569108
Medium truck	0.00286	0.039312039	0.00367	0.015	0.060842039	3	0.001825261
Large truck	0.0032	0.078624079	0.00575	0.015	0.102574079	2	0.002051482
						$\sum$ Costs	0.018445851[b]

[a]The average total costs of the existing road (ATCE)
[b]The average total costs of the new road (ATCN)

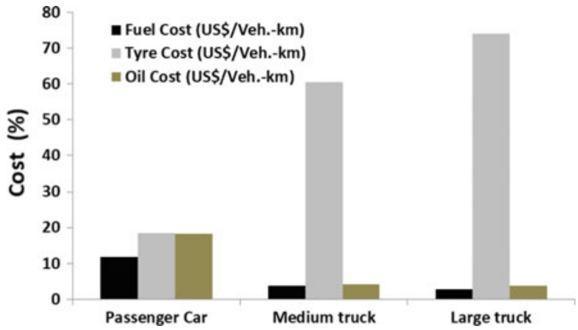

Fig. 2 Costs of the vehicle operating components for different vehicles

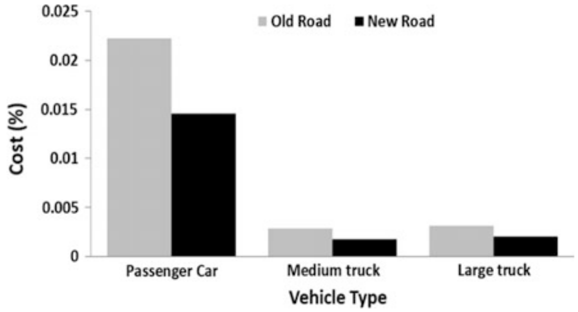

Fig. 3 Vehicle operating costs of old and new-suggested roads for different vehicles

7 Benefits

The saving in vehicle operation costs (VOCs) along with the travel time costs (TTC) are transferred into benefits. This process is as follows:

7.1 *Benefits Due to VOCs Saving*

Figure 4 displays benefit in vehicle operating costs resulting from the development of the current road status. The total VOCs of the old road with a length of 7.3 km was 0.2055 US$/vehicle, while the total VOCs of the suggested road with a length of 7.1 km was 0.130 US$/vehicle. Thus, the benefit of VOCs was 0.07462 US$/vehicle.

7.2 *Benefits Due to TTC Saving*

The enhancements in pavement condition lead to smoother and faster movement of vehicles and, consequently, shorter travel time. The saving in travel time costs, for

Table 6 Average travel time costs of the existing road

	Average IRI influence speed (km/h)	Travel time (h)	Person per vehicle	Ton per vehicle[a]	Travel time costs (US$/vehicle)	Vehicle %	Travel time costs (US$/vehicle)
The existing road							
Passenger car	65	0.112307692	2	0	0.286429538	95	0.272108062
Medium truck	50	0.146	1.5	27	0.3518016	3	0.010554048
Large truck	40	0.1825	1.5	47	0.506912	2	0.01013824
						$\sum$ Costs	0.29280035
The suggested road							
Passenger car	100	0.07	2	0	0.1810784	95	0.17202448
Medium truck	80	0.09	1.5	27	0.213852	3	0.00641556
Large truck	60	0.12	1.5	47	0.328682667	2	0.006573653
						$\sum$ Costs	0.185013693

[a]Legal gross weight permitted on a motor vehicle in regular operation in Iraq [21]

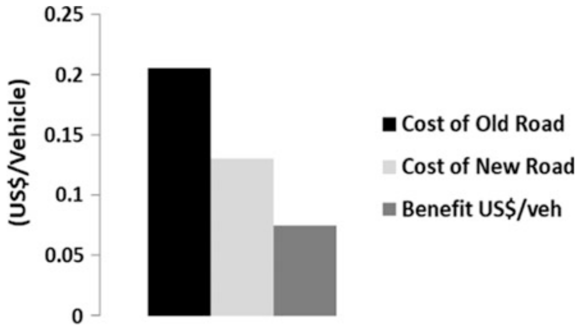

Fig. 4 Benefits resulting from VOC saving between the existing and suggested roads

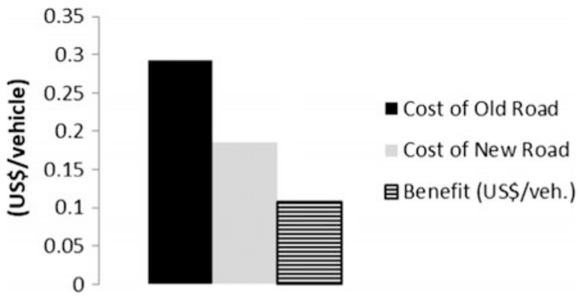

Fig. 5 Benefits resulting from travel time cost saving between old and new-suggested roads

both passengers and freights, can be transferred to benefits. The average total benefit as saving in TTC was 0.1077 US$/vehicle as can be seen in Fig. 5. The total benefit from saving in vehicle operating cost (VOC) and saving in travel time costs (TTC) is summed to be 0.1824 US$/vehicle. This benefit is included when the economic feasibility is prepared.

7.3 Salvage Value

Other benefits that may be involved in the economic studies are the salvage value of structures that may be used for components with a relatively longer life than the road. The remaining value of bridges and culverts after the end of the design life of the road should be considered as benefits. The design life of concrete, steel, and composite bridges is about 120 years besides 50 years design life for concrete culverts, which is more than the design life of the flexible pavement (20 years). Therefore, 75 and 60% of the bridge and culvert construction costs may be assumed as salvage value.

8 Economic Evaluation

After implementing a discount rate, the economic analysis is done by balancing the reduced total cost of the road and their advantages to the base year. Normally, the discount rate is taken as 8% for road projects [24].

Some economic principles ought to be obtained for a demonstration if the project is economically practicable or not. These principles are reviewed as follow:

1. Net Present Value (NPV). It is the variation between the sum of reduced benefits and reduced costs. The larger the difference, the worthier the project is.
2. Benefit–Cost Ratio (B/C). It is the quotient of reduced benefits and reduced costs. The project is considered more viable if it's B/C $\geq$ 1.0. It is a tool utilized to support decision making regarding transportation infrastructure [7].
3. Internal Rate of Return (IRR). It is the sum of the discount rate at which the reduced costs and reduced benefits are equal. The larger the variance from the minimum attractive rate of return the more viable project is.

The current worth (PW) of benefits or costs in the future is discounted. The PW process includes reducing all future sums to the present. The discount rate is assumed in this study to be 8%. The PW can be determined by Eq. (4):

$$P = F\left[\frac{1}{(1+i)^n}\right] \tag{4}$$

where P is the reduced current value of costs or advantages, F is the costs or benefits values in the future, n is the number of years from the base year, and I is the discount rate.

The average annual traffic (Eq. 2) and the future traffic by using 3% traffic growth rate are determined to gain the total annual benefits that could be saved from reducing the vehicle operation and travel time costs. Furthermore, road construction cost is determined to be two years. The sum of the discounted present worth for future benefits and costs at different discount rates are found as shown in Tables 7 and 8, respectively. The economic analysis is done by balancing the benefits and costs with a particular discount rate (8% for road projects) via economic elements (NPV, B/C ratio, and IRR). The outcomes demonstrate that NPV has an encouraging value of 10,281,548 US$, that indicates that the benefits are higher than costs. Moreover, the B/C ratio of 2.02 compared with a value of 1.0 is an encouraging value. Lastly, the IRR is positioned between reduction rates of 15% and 20%, with a value of 17.79% which is greater than that suggested in the road pavement projects (8%). Table 9 demonstrates the economic criteria calculated to find the feasibility of constructing a new road.

Table 7 Discounted benefits with different discount rates

Year	Future traffic (vehicle/year)	Total benefits (US$)	DR[a] 8%	DR 12%	DR 15%	DR 20%	DR 25%
0	7,845,400	0	0	0	0	0	0
1	8,237,670	0	0	0	0	0	0
2	8,649,554	0	0	0	0	0	0
3	9,082,031	1,656,707	1,315,147	1,179,211	1,089,312	958,743	848,234
4	9,536,133	1,739,542	1,278,616	1,105,511	994,589	838,900	712,517
5	10,012,939	1,826,520	1,243,099	1,036,416	908,103	734,037	598,514
6	10,513,586	1,917,846	1,208,568	971,640	829,138	642,283	502,752
7	11,039,266	2,013,738	1,174,997	910,913	757,039	561,997	422,311
8	11,591,229	2,114,425	1,142,358	853,981	691,209	491,748	354,742
9	12,170,790	2,220,146	1,110,626	800,607	631,104	430,279	297,983
10	12,779,330	2,331,153	1,079,775	750,569	576,225	376,494	250,306
11	13,418,296	2,447,711	1,049,781	703,658	526,119	329,432	210,257
12	14,089,211	2,570,096	1,020,621	659,680	480,369	288,253	176,616
13	14,793,672	2,698,601	992,270	618,450	438,598	252,222	148,357
14	15,533,355	2,833,531	964,707	579,797	400,459	220,694	124,620
15	16,310,023	2,975,208	937,910	543,559	365,637	193,107	104,681
16	17,125,524	3,123,968	911,857	509,587	333,842	168,969	87,932
17	17,981,801	3,280,167	886,527	477,738	304,812	147,848	73,863
18	18,880,891	3,444,175	861,901	447,879	278,307	129,367	62,045
19	19,824,935	3,616,384	837,960	419,887	254,106	113,196	52,118
20	20,816,182	3,797,203	814,683	393,644	232,010	99,046	43,779
21	21,856,991	3,987,063	792,053	369,041	211,835	86,666	36,774
22	22,949,840	4,186,416	770,052	345,976	193,415	75,832	30,890
	SV[b] = 0.6 culvert		5518	2479	1386	543	221
	Total disc. benefits		20,399,024	13,680,222	10,497,615	7,139,656	5,139,510

[a]*DR* Discount rate
[b]*SV* Salvage value

9 Environmental Evaluation

Another factor that ought to be taken into account within the viability studies of pavement project is the rise in the combustion of fuels and air quality at different levels which has attracted great attention from researchers. Since the adverse effects of NO_x and SO_2 have become evident, methods have been followed attempting to invert the process. Recently awareness reverted to community health impacts with attention to urban air quality because of fine atom releases from road traffic that are currently thought to be the highest contaminated component of a complex mixture given the effective abatement of the former culprits CO, SO_2, NO_x and Pb [13]. Furthermore, health consequences are constantly attained in new epidemiological researches at low ambient attentions [17, 18].

Some pavement condition indicators can be achieved and employed to manage pavement management valuations. Pavement condition index (PCI) and the

Table 8 Discounted costs with different discount rates

Year	Total costs	DR 8%	DR 12%	DR 15%	DR 20%	DR 25%
0	0	0	0	0	0	0
1	5,275,167	4,884,413	4,709,970	4,587,101	4,395,972	4,220,133
2	5,275,167	4,522,605	4,205,330	3,988,784	3,663,310	3,376,107
3	84,403	67,002	60,076	55,496	48,844	43,214
4	84,403	62,038	53,639	48,257	40,703	34,571
5	84,403	57,443	47,892	41,963	33,920	27,657
6	84,403	53,188	42,761	36,490	28,266	22,126
7	84,403	49,248	38,179	31,730	23,555	17,701
8	84,403	45,600	34,089	27,591	19,629	14,160
9	84,403	42,222	30,436	23,993	16,358	11,328
10	84,403	39,095	27,175	20,863	13,632	9063
11	84,403	36,199	24,264	18,142	11,360	7250
12	84,403	33,517	21,664	15,775	9466	5800
13	84,403	31,035	19,343	13,718	7889	4640
14	84,403	28,736	17,270	11,929	6574	3712
15	84,403	26,607	15,420	10,373	5478	2970
16	84,403	24,636	13,768	9020	4565	2376
17	84,403	22,811	12,293	7843	3804	1901
18	84,403	21,122	10,976	6820	3170	1520
19	84,403	19,557	9800	5931	2642	1216
20	84,403	18,108	8750	5157	2202	973
21	84,403	16,767	7812	4484	1835	778
22	84,403	15,525	6975	3899	1529	623
Total discount costs		10,117,476	9,417,884	8,975,359	8,344,703	7,809,819

Table 9 Economic parameter values of the present study

Economic parameters	Value
$NPV_{[8\%]}$ (US$)	10,281,548
B/C $ratio_{[8\%]}$	2.02
IRR (%)	17.79

international roughness index (IRI) are two of these indicators. The IRI is usually obtained utilizing specified equipment that indicates the smoothness of roadway segment pavement surface based on verified computer algorithms, while the PCI is based on a particular rating of pavement distresses number. Each one of these two indicators can be calculated from the other [3].

To find the equivalent pavement condition index (PCI), which is based on the IRI, Eq. (5) has been used [3]:

$$\log(\mathrm{PCI}) = 2 - 0.43\log(\mathrm{IRI}) \tag{5}$$

where PCI is the pavement condition index, and IRI is the international roughness index.

Currently, the existing road status is bad to very bad with around 14 m/km IRI value against 4 m/km for the suggested road. By using Eq. (5) above, the predicted PCI may be around 46.28 and 55 for the old and suggested roads, respectively.

Depending on the pavement status of the current and suggested roads, some vehicle emissions like carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxides (NO_2) are approximated by utilizing Eqs. (6)–(9) below [23], which are based on the PCI.

$$CO\ Emission\left(\frac{\frac{\mathrm{g}}{\mathrm{km}}}{\mathrm{h}}\right) = 0.1564(PCI)^2 - 24.655(PCI) + 21747 \tag{6}$$

$$NO_2\ Emission\left(\frac{\frac{\mathrm{g}}{\mathrm{km}}}{\mathrm{h}}\right) = 0.0025(PCI)^2 - 0.4451(PCI) + 495.81 \tag{7}$$

$$SO_2\ Emission\left(\frac{\frac{\mathrm{g}}{\mathrm{km}}}{\mathrm{h}}\right) = 0.00003(PCI)^2 - 0.0047(PCI) + 4.4169 \tag{8}$$

$$CO_2\ Emission\left(\frac{\frac{\mathrm{g}}{\mathrm{km}}}{\mathrm{h}}\right) = 9.4609(PCI)^2 - 1573.6(PCI) + 200000 \tag{9}$$

The enhancement in the road pavement conditions denoted by IRI had boosted the value of PCI calculated by Eq. (5) and this, in turn, had led to decreasing emissions conforming to the fact that emissions per kilometer can be decreased with a rise in driving speed [17]. Table 10 shows the vehicle emission of the current and suggested roads that has a good status, within which decreases in total emissions are noticed. The typical reduction in emission is 1.13% due to the improvement of pavement status.

Table 10 Predicted vehicle emissions of old and suggested roads

	Old road	New road	Reduction %
CO (g/km/h)	20,939.95013	20,863.085	0.367074063
NO_2 (g/km/h)	480.565368	478.892	0.348208196
SO_2 (g/km/h)	4.263639152	4.24915	0.339830635
CO_2 (g/km/h)	1947437.511	1,942,071.223	0.275556386

10 Sensitivity Analysis

Sensitivity is stated as the current change in one or more features which may change a decision among project choices or reverse a decision about the economic acceptability of a particular project. Sensitivity analysis is utilized to investigate what occurs to a project's viability after the predictable values of study features are improved.

10.1 Effect of Increasing Fuel Unit Price

In the future, if the fuel price increased two times keeping all the remaining components constant, oil and tire, the saving rate in VOCs will decrease, however, still within the positive region as revealed in Fig. 6.

10.2 Effect of Discount Rate

The IRR strategy is the most generally utilized rate of return methodology for implementing the economic analysis. This methodology resolves for the interest rate that equivalents the worth of road construction project cash entry to the equivalent worth of cash losses. The resultant rate of interest is denoted as the internal rate of return (IRR). The IRR is occasionally referred to as the breakeven interest rate. Figure 7 represents the influence of different values of the discount rate (i.e. 8–20%) on the equalizing between benefits and costs. The positive value of discount accumulated net cash flow refers to the acceptable project. Depending on the IRR decision rule, if IRR is greater than MARR, the project is economically reasonable.

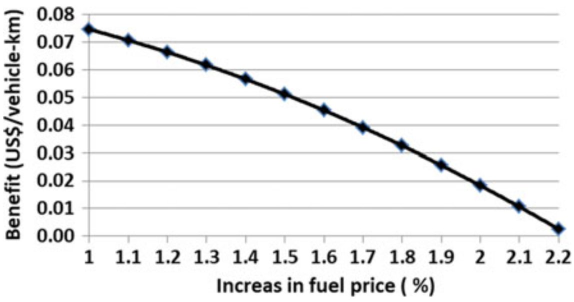

Fig. 6 Impact of increasing fuel cost on the VOC saving

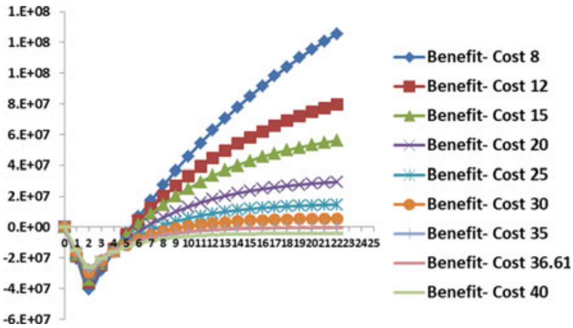

Fig. 7 Effect of discount rate on the recovered benefits of the study project

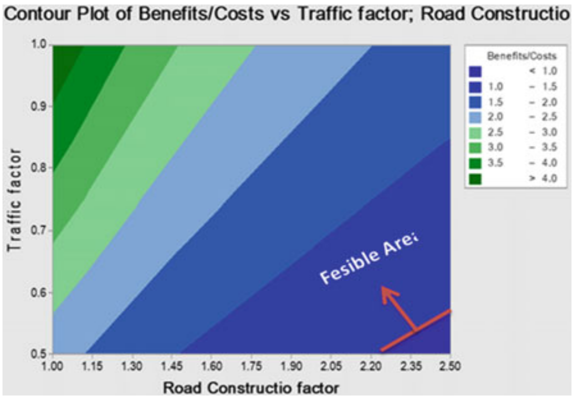

Fig. 8 Effect of decreased traffic growth rate and increased reconstruction cost on the B/C ratio of the study project

10.3 Effect of Traffic Growth Factor and Construction Costs

Figure 8 represents the feasible area (i.e. B/C > 1) at which the project will be considered as a viable one. The B/C is in the range of 1–2 depending on the decrease or increase in traffic growth rate versus the change in reconstruction costs.

11 Conclusions

In the present research, efforts were concentrated on evaluating the economic viability of constructing a proposed road over an existing one which has a bad condition. The following conclusions were derived from the analysis of results:

- The road user costs dramatically decreased as a result of improving the road condition. Regarding VOC, it is reduced from 0.02816 US$/vehicle-km or 0.2055 US$/vehicle to 0.01844 US$/vehicle-km or 0.130 US$/vehicle for old and new-suggested roads, respectively.

- With respect to travel time costs, a similar trend was found, in which the results stated that the travel time costs were 0.2928 US$/vehicle and 0.1850 US$/vehicle for the old and new roads, respectively.
- The total saving (reduction) in the vehicle operating costs (VOCs) and saving in the travel time costs (TTCs) was 0.1824 US$/vehicle, which is considered as benefits.
- Regarding the economic criteria, the outcomes showed that NPV has an encouraging value of 10,281,548 US$, which implies that advantages are higher than costs. Besides, the B/C ratio was 2.02, compared with a value of 1.0, which is a promising value.
- From the emission functions in Eqs. (6)–(9), it can be seen that the emissions may be governed not only by vehicle speed but also by pavement condition. Therefore, several vehicle emissions such as Carbon monoxide (CO), Carbon dioxide (CO_2), nitrogen dioxides (NO_2), and Sulphur dioxide (SO_2) were reduced due to the improvement in pavement condition, which enhances the regularity and encourages increasing the driving speed and comfort.
- According to the sensitivity analysis, some parameters like future traffic volume, road construction cost, and discount rate were assessed. It was concluded that if the estimated traffic will be negatively factored to 50%, the suggested project will still be beneficial with all other constant. Moreover, even if the road construction cost increased to 150% and without any changes in other variables, the project remains viable.
- The outcomes of this research are valid for other developing countries with comparable traffic, climate, and soil condition.

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