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Analysis of the economic benefits of an appraisal of an intersection

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ABSTRACT

Ethiopia's government proposes paving existing roads or building modern intersections in cities to reduce maintenance costs. An unimproved signalized intersection at 6° 51' 47.9" N and 37° 45' 50.1" E is selected for this research. Cost-benefit analysis is used to evaluate the proposed innovative approach to designing and implementing an intersection and to compare whether the new road projects will have an adequate return. This research suggests converting the current intersection into a signalized roundabout to calm traffic. Signalized roundabouts have a higher net present value and a modified internal rate of return than improved signalized crossing intersections. Considering the country's high inflation rate, three scenarios recommend using a signalized roundabout.

KEYWORDS

cost benefit analysis, rate of return, signalized intersection

1. INTRODUCTION

The economic net benefits of maintaining unpaved roads in developing countries and paved roads show that they need periodic and routine maintenance, which affects the net present value of public benefits, the Internal Rate of Return (IRR), the benefit-cost ratio, and the Vehicle Operating Cost (VOC) of the projects [1, 2]. Prescriptive and descriptive approaches to discount rates employ shallow rates as opposed to marginal costs, which are insufficient for explaining the net benefit of a project [3].

For instance, when roads are thought of as an asset in Hungary, a synthetic method can be used to figure out how much it would cost to replace the main parts of the roads [4]. By determining the signal timing of an intersection based on travel time, it is possible to reduce the intersection's social cost, thereby increasing the intersection's throughput efficiency [5]. Ethiopia is one of the landlocked countries in Africa. Its entire transportation system is based on road and rail networks, with 90–95% of all freight and passenger movement between cities occurring on the road [6].

In the Wolaita Zone, Ethiopia, there are several roads that need periodic or routine maintenance and rehabilitation. However, because of financial constraints, it is difficult to implement it as a requirement. One of the city's first asphalt roads, which still provides services, has high congestion at a crossing intersection in the city center because of the merging of vehicles. The existing intersection lacks clear zebra stripes and does not have a stop line for cars to stop before entering the intersection. This makes driving uncomfortable and crossing the street difficult for pedestrians and cyclists. So, the scope of this study is to

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assess the economic benefit that might be obtained from the rehabilitation and upgrading of the proposed intersection.

2. DATA AND METHODS

Wolaita Sodo has seven outlet roads to neighboring districts. Many of the cities' major access roads pass through this study area, and the length of the road addressed by this research is 0.46 km, which has potholes, rutting, and cracking like edge, longitudinal, and traverse cracks. As it is shown in Fig. 1, the signalized unimproved crossing intersection is in the heart of Sodo City at 6°51'47.9" N and 37°45'50.1" E. The intersection from Agip St. to Saint Mary Church St. lacks clear lanes. There are two clearly separated lanes from Abebe Zeleke St. to Otona St. The proposed project length L is 0.7 km, and the new proposed intersection consists of St. Mary Church St. and Agip St., with three new lanes on the approach and two on the exit, and has increased length to connect the next intersection on both sides, but the lanes on Abebe Zeleke St. and Otona St. will remain unchanged. Directional traffic flow counts are performed on the special market days of December 21, 25, and 28 in 2021; January 1, 2022; and January 5, 2022. The special market days are busy days in the city, with most people walking or driving to the market. Almost 13 years after the 1994 census, the city's population has doubled, and by the time of the next census, the population is expected to double again or even increase even further. In addition, the city has experienced a substantial increase in the number of vehicles, prompting researchers to recommend the implementation of two new intersection designs over regular roundabouts: the Signalized Roundabout (SR) and the Improved Signalized Crossing Intersection (ISCI), with the assumption that both can accommodate a 30% increase in hourly volume and have high safety [7, 8]. Drivers are aggressive, and most of the time, priority given to pedestrians and cyclists is ignored. So, safety is another factor in favoring signalization over regular intersections. Every hour, around 1,095 Passenger Car Units (PCU) and 1,632 people pass through the intersection at its current maximum capacity.

Moreover, the vehicles were classified according to their sizes, which were then categorized, and the average Annual

Traveling Distance (ATD) is 51,000 km [9, 10]. Comparing 2022 to the previous year, the inflation rate ranges between 30.49 and 37.7% [11].

At the time of the traffic count, the exchange rate for 1 USD to ETB was 48.6125 [12], the average fuel consumption was 16.56 \$/l/km; the cost of petroleum and benzene was 0.77 \$/l, and the free flow speed was calculated to be 40 km/h. Due to inflation, the Fuel Adjustment Factor (FAF) is considered 1.6 \$/veh for SR and 1.5 \$/veh for ISCI, and the Non-Fuel Adjustment Factor (NFAF) is considered 1 for both proposed intersections. Based on the survey for the average economic cost of vehicles, the Operating Cost (OC) for vehicles is calculated to be \$36,717.78, and incentives based on the additional cost of a delayed trip can be considered to appreciate the contractor's early completion of work, which is 1.96 \$/h as a value of time.

To determine the total traffic over the design life of the road, the first step is to estimate the Daily Traffic (DT) and Average Daily Traffic (ADT), followed by the Annual Average Daily Traffic (AADT) at year 0, by considering 2024 as the base year. It is recommended to account for Daily Factors (DF) of 0.5 when assuming that a particular day's hourly volume represents the entire day's hourly volume. With a 10% growth rate, the $AADT_{2024}$ is used as the basis for calculating the traffic volume over the road's design life and for the next twenty years, as follows [13],

$$DT = \frac{\text{Hourly Volume}}{\text{day}} \cdot DF, \quad (1)$$

$$DT_{2022} = 1095 \frac{\text{veh}}{\text{h}} \cdot \frac{24\text{h}}{\text{day}} \cdot 0.5 = 13140 \text{veh/day}.$$

If all days of the survey period have the same DT data, then the ADT can be calculated from Eq. (2) by dividing the sum of five-day daily data by five days; this can be taken as a representation of the monthly average daily traffic data:

$$ADT = \frac{1}{n} \sum_{i=1}^n \text{Volume}_i, \quad (2)$$

$$ADT_{2022} = \frac{(13140 \text{veh/day} \cdot 5)}{5} = 13140 \text{veh/day}.$$

Since Wolaita City is a commercial center, the AADT for 2022 can be estimated with Eq (3) by applying a Seasonal Correction Factor (SCF) of 1.2, as is recommended in the literature [14]. So,

$$AADT_{2022} = ADT_{2022} \cdot SCF = 13140 \text{veh/day} \cdot 1.2 = 15768 \text{veh/day}. \quad (3)$$

According to the Ethiopian Road Authority (ERA) geometric design manual, the AADT of the two new projects falls into the category >10,000 veh/day category, which is determined to be a Design Category (DC) 8 standard [10].

The current intersection cannot accommodate the existing vehicles at 1095 PCU/h depending on the population and vehicle growth in the city, but ERA estimates that a two- or three-lane road in one direction with mixed traffic can have a basic capacity of 3100 PCU/h based on Highway Capacity Manuals (HCM). Because the proposed new



Fig. 1. Wolaita Sodo City site location (Source: photo by Kidist Bassa)

intersection has three lanes at the entry and two at the exit, along with signalization that helps to increase the safety of users, the capacity can be calculated using Eq. (4) as follows:

$$C_a = C_b \cdot f_g \cdot f_w \cdot f_{ds} \cdot f_{smv} \cdot f_s \cdot f_{ui}, \quad (4)$$

$$C_a = 3100 \cdot 0.95 \cdot 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1 = 2945 \text{ veh/h},$$

where C_a is the actual capacity under prevailing roadway and traffic conditions; C_b is the basic capacity (3,100 pcu/h); f_g is the adjustment for grade = 0.95; f_w is the adjustment for lane width of 3.6 m = 1.0; f_{ds} is the directional split, 50/50 = 1.0; f_{smv} is the slow moving vehicles effect, which is negligible till their proportion in the traffic stream is less than or equal to 10% = 1.0; f_s is the Shoulder condition, good = 1.0; f_{ui} is the surface unevenness = 1.0. So, based on the survey estimation the calculated capacity is suitable for the proposed SR and ISCI with a capacity of 2,945 veh/h.

3. ECONOMIC EVALUATION

The economic cost-benefit analysis of a project considers all societal costs and benefits. Lower VOC and adequate travel distances are the primary benefits of this project. There are social benefits associated with the transportation cost savings between "with a project (W)" and "without a project (Wo)". The costs and benefits over the analysis period are discounted to the base year and compared using their present values. The minimum rate of return on investment for road construction projects in Ethiopia, as determined by the agreement between the government and Ethiopian Development Partners for admission of a project, is assumed to be 12%. According to past experience, most roads in Ethiopia require rehabilitation every 10 years, and Table 1 provides Cost Estimation for each Activity (CEA) to calculate Construction Cost (CC), Periodic Maintenance Cost (PMC), Routine Maintenance Cost (RMC), and Rehabilitation Cost (RC) for both proposed intersections, with a 10% contingency [10]. The CEA computation for each proposed project is calculated as follows:

$$CEA = \text{Length} \cdot \text{Estimated cost},$$

$$CC = 0.7 \text{ km} \cdot 713,712.373 \$/\text{km} = 499,598.66 \$/\text{km},$$

$$PMC = 0.7 \text{ km} \cdot 33,681.615 \$/\text{km} = 23,577.13 \$/\text{km},$$

$$RMC = 0.7 \text{ km} \cdot 9,378.171 \$/\text{km} = 6,564.72 \$/\text{km},$$

$$RC = 0.7 \text{ km} \cdot 475,808.256 \$/\text{km} = 333,065.78 \$/\text{km}. \quad (5)$$

Table 1. Construction cost and maintenance cost per kilometer

Activity	Estimated Cost	10% contingency	Total estimation
CC	\$648,829.43	\$64,882.943	\$713,712.373
PMC	\$30,619.65	\$3061.965	\$33,681.615
RMC	\$8,525.61	\$852.561	\$9,378.171
RC	\$432,552.96	\$43,255.296	\$475,808.256

Four elements affect the highway users' benefit. These include reducing trip time, VOC, maintenance costs, and accident-related expenses. Based on an alternative design that has a sufficient and maximum return, a decision regarding the project is made. Before investing in a road project, a thorough feasibility study is conducted to see whether the advantages will outweigh the costs and ensure the maximum rate of return. For both SR and ISCI, the Fuel Cost (FC) and the Non-Fuel Cost (NFC) are factored into Eqs (6)–(9), which determine the VOC [15]:

$$FC_{SR \text{ or } ISCI} / \text{veh} = L \cdot \text{Fuel Consumption} \cdot \text{crude oil cost} \cdot FAF,$$

$$FC_{SR} / \text{veh} = 0.7 \text{ km} \cdot 16.56 \frac{\$ \cdot \text{lt}}{\text{km}} \cdot 0.77 \frac{\$}{\text{lt}} \cdot 1.6 \frac{\$}{\text{veh}} = 14.28 \frac{\$}{\text{veh}},$$

$$FC_{ISCI} / \text{veh} = 0.7 \text{ km} \cdot 16.56 \frac{\$ \cdot \text{lt}}{\text{km}} \cdot 0.77 \frac{\$}{\text{lt}} \cdot 1.5 \frac{\$}{\text{veh}} = 13.38 \frac{\$}{\text{veh}}. \quad (6)$$

Based on the above result, the fuel costs for both proposed intersections are calculated as follows:

$$FC_{SR \text{ or } ISCI} = FC_{SR \text{ or } ISCI} / \text{vehicle} \cdot AADT_{2022},$$

$$FC_{SR} = FC_{SR} / \text{veh} \cdot AADT_{2022} = 225,167.04 \frac{\$}{\text{day}}, \quad (7)$$

$$FC_{ISCI} = FC_{ISCI} / \text{veh} \cdot AADT_{2022} = 210,975.84 \frac{\$}{\text{day}}.$$

On the other hand

$$NFC / \text{veh} = \text{Length} \cdot \frac{OC}{ATD} \cdot NFAF,$$

$$\frac{OC}{ATD} = \frac{\$ 36,717.78}{51,000 \text{ km}} = 0.72 \frac{\$}{\text{km}}, \quad (8)$$

$$NFC / \text{veh} = 0.7 \text{ km} \cdot 0.72 \frac{\$}{\text{km}} \cdot 1 \frac{\$}{\text{veh}} = 0.504 \frac{\$}{\text{veh}}.$$

Then

$$NFC = NFC / \text{veh} \cdot AADT_{2022},$$

$$NFC = 0.504 \frac{\$}{\text{veh}} \cdot 15768 \frac{\text{veh}}{\text{day}} = 7947.072 \frac{\$}{\text{day}}. \quad (9)$$

Travel Time (TT) savings are calculated for both W and Wo cases, considering, Congested Speed (CS), Vehicle Occupancy (VO), L and the Value Of Time (VOT) due to recurring congestion under the traffic projections provided [15],

$$TT \text{ cost}_{W \text{ or } Wo} / \text{veh} = VO \cdot VOT \cdot \frac{L}{CS}. \quad (10)$$

Using the Bureau of Public Roads' Volume Delay Function (VDF), where α is 0.15 and β is 4, both of which are determined by the ERA adopted for the road section, and using Eqs (11) and (12). The hourly volume is 1050 PCU/h, assuming free flow speeds of 40 km/h before improvement of L is 0.46 km, and 50 km/h after improvement of L is 0.7 km, assuming basic capacity as 3100 PCU [15],



$$CS_{Wo \text{ or } W} = \frac{\text{free flow speed}_{Wo \text{ or } W}}{1 + \alpha(DT/C)^\beta}, \quad (11)$$

$$CS_{Wo} = 39.9 \text{ km/h},$$

$$CS_W = 49.9 \text{ km/h},$$

$$VO = \frac{\text{total occupant}}{\text{total vehicles}} = \frac{1632}{1095} = 1.49. \quad (12)$$

The total travel time cost with and without project is then calculated using Eq. (10), as follows:

$$TT \text{ cost}_w/\text{veh} = \$ 0.041,$$

$$TT \text{ cost}_{wo}/\text{veh} = \$ 0.034,$$

$$TT \text{ cost saving}/\text{veh} = TT \text{ cost}_w/\text{veh} - TT \text{ cost}_{wo}/\text{veh} = \$ 0.007. \quad (13)$$

Then, based on the above factor, the travel time savings for both proposed intersections are calculated as follows:

$$TT \text{ cost saving} = TT \text{ cost saving}/\text{veh} \cdot AADT_{2022},$$

$$TT \text{ cost saving} = 0.007 \$ \cdot 15,768 \text{ veh/day} \cdot 365 \text{ days},$$

$$TT \text{ cost saving} = 40,287.24 \$.$$

(14)

The Accident Savings Cost (ACS) is calculated using Eq. (15), assuming that the proposed new road will have a lower frequency of accidents involving vehicles and pedestrians due to improvements,

$$ACS_{SR \text{ or } SCI} = VOC/3. \quad (15)$$

The summary of valuations of user benefits at the initial year is given in Table 2. Road maintenance cost savings are considered if the new road project is currently providing vehicular services. The road maintenance savings benefit does not apply to this proposal.

4. PROJECT SUSTAINABILITY AND ECONOMIC PERFORMANCE

The Net Present Values (NPV) have been calculated at a 12% Opportunity Cost of Capital (OCC), which is profiled with similar investments at risk in Ethiopia. If the NPV is greater than zero, then the proposed projects are feasible and should be implemented. Based on the initial values from Table 2 for both cost and benefit, they are discounted for the next twenty years. On the other hand, when comparing the costs and benefits of a project with regard to its future risk,

Table 2. Summary of valuations of user benefits in US dollars

Measures	SR	ISCI
Vehicle operating cost savings = FC–NFC	217,219.97	203,028.77
Fuel cost	225,167.04	210,975.84
Non-fuel cost	7,947.07	7,947.07
Travel-time savings	40,287.24	40,287.24
Accident saved	72,141.75	67,467.33

the Benefit Cost Ratio (BCR) is used to check whether the company has a positive net present value or not. When the BCR of a project is greater than 1, it indicates that either project option is viable for investment [16],

$$NPV = \sum_{i=1}^n b_t/(1+r)^t - \sum_{i=1}^n c_t/(1+r)^t, \quad (16)$$

$$B - CR = \frac{\sum_{i=1}^n b_t/(1+r)^t}{\sum_{i=1}^n c_t/(1+r)^t}, \quad (17)$$

where b is the benefit; c is the cost; r is the discount rate; t is the year of analysis inception, and n is the final year of the period of implementation. Estimating the Economic Internal Rate of Return (EIRR) is another way to figure out if a new project is economically viable. To do this, find the discounted rate that equals zero cash flows. If the EIRR is higher than the minimum required rate of return, the project should be done:

$$EIRR = \left[\sum_{i=1}^n b_t/(1+r)^t - \sum_{i=1}^n c_t/(1+r)^t \right] = 0. \quad (19)$$

EIRR has its own advantages, but it also has some drawbacks that may cause decision-makers to choose an investment with a non-standard cash flow and a multiple reinvestment rate. Therefore, it is preferable to base assumptions on a Modified Internal Rate of Return (MIRR) rather than an EIRR because MIRR shows that the firm reinvests positive cash flows at its cost of capital and finances initial outlays at its financing cost. As a result, the MIRR more accurately reflects a project's cost and profitability [16]:

$$MIRR_{for \text{ ISCI or SR}} = \left(\frac{FV_{\text{cash in flow}}}{PV_{\text{cash outflow}}} \right)^{1/n}, \quad (21)$$

where $FV_{\text{cash in flow}}$ is the future value of positive cash flows discounted at the reinvestment rate, $PV_{\text{cash out flow}}$ is the present value of negative cash flows discounted at the financing rate, and n is the number of periods. Then the value of MIRR for both proposed intersections is calculated to be approximately 17.42% and 17.78%, which is greater than OCC's value of 12%. Hence, the result of the economic appraisal in terms of NPV and MIRR shows that investment improvement in the project road is economically viable, as the values of a MIRR for both options are well above the cutoff point of 12% and the values of NPV are positive at a discount rate unit of capital. Due to the budget constraint, the signalized roundabout with the higher MIRR should be selected. The summaries of the economic evaluations for ISCI and SR are listed in Table 3.

Table 3. Summary of proposed intersections

Proposed intersection	NPV	EIRR %	BCR	MIRR %
ISCI	1,899,577	49.94	3.71	17.42
SR	2,057,402	53.76	3.94	17.78



5. SENSITIVITY ANALYSIS MODEL

Quality, cost, and time are the most critical constraints in construction, which might result in the risk of losing a benefit due to cost and benefit reduction. Construction uncertainty is hard to predict, but lowering uncertainty and risk can make them practical.

A sensitivity analysis model has been used to evaluate the economic performance of two proposed options, considering possible changes to construction costs, traffic growth, and other key variables. According to the inflation rate, it is getting higher each year in Ethiopia; now it is about 37.7% compared to the previous year. Within the sensitivity analysis, the following scenarios have been simulated;

- Scenario 1: An increase of 37.7% in capital expenses;
- Scenario 2: A decrease of 37.7% in benefit expenses; and
- Scenario 3: An increase of 37.7% in capital expenses and a reduction of 37.7% in benefit expenses.

In scenario 1, a 37.7% increase in capital costs decreases the anticipated benefit for signalized crossing intersection improvements by 13.90% and for signalized roundabouts by 38.16%. Therefore, if the decision-makers wish to invest, it is strongly recommended that they select an ISCI over SR. But with this option, MIRR can be used to reflect the cost and profitability of a project more accurately. Based on this analysis, the indicated roundabout has a positive cash flow and a positive initial investment.

In scenario 2, a 37.7% reduction in the expected benefit cost reduces the NPV of an ISCI by 84.11% and the SR by 50.53%. However, if the decision-makers wish to invest in the new project, it is strongly advised that they choose SR because of its NPV and MIRR.

For scenario 3, increasing the cost by 37.7% and reducing the benefit cost by 37.7% shows that the reduction of NPV from the normally calculated one is 65.50% for an ISCI and 63.37% for SR. This demonstrates that, with the time value of money and a minor difference between increased cost and lower expected benefit cost, the proposed projects have a good reason to invest, leading decision-makers to discuss the selection process further by providing additional criteria.

As it is depicted in Table 4 and Fig. 2, even though the NPV of the two offered options exceeds zero, the higher the NPV, the greater the advantage of the investment option. As a result, based on the NPV comparison criteria for scenarios 2 and 3, it is better to build a signalized roundabout rather than an improved crossing signalized intersection if there is no budget constraint. In scenario 1, the projects are distinct, and the MIRR of a signalized roundabout exceeds that of an

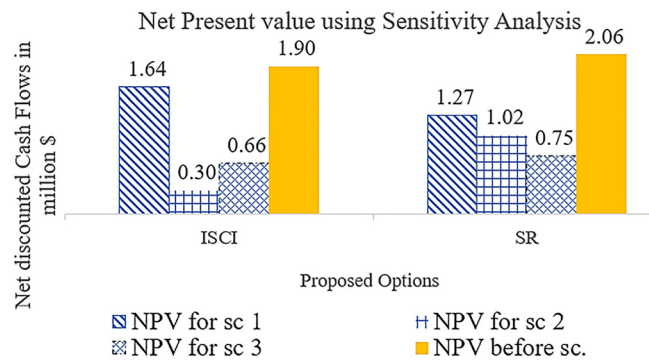


Fig. 2. Net present value model using sensitivity analysis

enhanced signalized crossing intersection. Those independent projects whose MIRR is higher than the acceptable rate are excluded.

6. CONCLUSION

Rehabilitating the Wolaita Sodo city road project has been assessed using cost-benefit analysis. The 37.7% inflation rate and three scenarios were used for sensitivity analysis. Scenario 1 proposes investing in an enhanced ISCI with a 13.94% greater NPV than the previous one, but a signalized roundabout with a comparatively high MIRR of 16.11% suggests investing in SR. Scenarios 2 and 3 advice decision-makers to invest in SR with an NPV change to the worst case. All models advocate rehabilitating or upgrading the existing intersection with a signalized roundabout rather than an upgraded signalized crossing intersection, regardless of the budget. However, under pessimistic forecast scenario 3, decision-makers are certain that the project is worthwhile unless and until SR with an NPV of \$2,057,402 is chosen. Researchers can make more predictions in future studies involving unsignalized intersections as an option to determine if comparable programs are worthwhile. Additionally, comprehensive microscopic models can be created to examine the substantial impact of transforming urban road intersections into improved intersections.

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Table 4. Summary for sensitivity analysis

Proposes intersections	Scenario 1		Scenario 2		Scenario 3	
	MIRR	BCR	MIRR	BCR	MIRR	BCR
ISCI	15.39	2.70	14.43	2.31	12.45	1.68
SR	16.11	3.01	14.80	2.45	12.82	1.78



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