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Road User Costs for Highway Construction Projects Involving a Lane Closure

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Abstract: While for years most American State Highway Agencies (SHAs) have performed Road User Cost (RUC) calculations, no uniformity from state to state has been established. There is scant research available that documents the testing and validation of existing RUC calculation methods for highway rehabilitation projects. Especially scarce are studies addressing the unique problem of accurately calculating RUC in the event of lane closures. This research addresses this problem by describing and comparing two methods of making such calculations: A manual method developed by the Texas Transportation Institute (TTI), and adopted by many other state agencies, such as the Florida Department of Transportation (FDOT), and a commercial software package.

Keywords: road user cost; highway rehabilitation; lane closures calculation

1. Introduction

The use of roads, especially the highway, has a variety of range of impacts on sustainable issues, including CO_2 emissions. The evaluation of the use of highway can be critical to the sustainable issues, not only the environmental issue but also the economic issue, such as opportunity cost. Highway congestion reduces motorists' productivity. This productivity loss includes motorists' opportunity cost, also known as road user cost (RUC). Most State Highway Agencies (SHAs) have performed RUC calculations for years. However, to date, there is no formal uniform method used nationwide in the US. States follow their own processes or those developed by others [1,2]. Even less formalized is the calculation of RUC when a lane must be closed for construction, even though most rehabilitation projects require such lane closures [3,4]. The author found very little in the way of research employing field studies to validate any method. Thus, the purpose of the present work is to demonstrate the RUC calculation method employed by the state of Florida through four case study projects where work zone lane closures were necessary and compare the results to those obtained using a newer, automated method employing the same data. Because State DOT's adopt various measures to calculate RUC, validating the impact of various input factors, such as geographic area, traffic volume, and value of time, becomes more critical. The author performed extensive field experiments to validate the impact of the variables. Thus, this research aimed to collect field data with a lane closure to measure the impact of those input variables and validate them.

To calculate RUC, the Florida Department of Transportation (FDOT) uses "Techniques for Manually Estimating Road User Costs Associated with Construction Projects." This official method emanated from a research project entitled "Development of Road User Cost Method" conducted by the Texas Transportation Institute (TTI) and sponsored by the Texas Department of Transportation. Previous research showed similar methodology applied with the exception of using updated statistics to estimate the value of delay time for passenger vehicles, for instance, the median hourly wage rate for all occupations obtained from the Bureau of Labor Statistics [5]. According to the TTI methodology, RUC is defined as "the estimated daily cost to the traveling public resulting from road improvement work (construction work) being performed." The cost stems primarily from the time delay caused by various conditions such as:

- Detours and rerouting that require additional travel time,
- Reduced roadway capacity that slows travel speed and requires additional travel time, and
- Delay in the opening of a new or improved facility that prevents users from gaining a time benefit [6].

From the case studies analyzed here, the author measured the delay time caused by reduced roadway capacity brought on by lane closures. Conditions were divided into four categories, and a different analysis approach was used for each. Tables 1 and 2 are taken directly from the method report. Table 1 explains the attributes of each analytical approach and Table 2 indicates the associated project category.

Table 1. Attributes of analysis approach [6].

Analysis Approach	Attributes
Phase-by-Phase	The calculated user costs can be used as the basis for liquidated damages for milestone completions of each phase or selected phases of the project. This approach is most applicable to those projects with severe capacity restrictions during construction where phase completion time is critical.
Before vs. After	As opposed to a phase-by-phase approach, a "before and after" comparison of user costs focuses on the delay in the final completion of a new or improved facility. Each day the final improved facility is delayed is another day that users are unable to realize travel time savings and other benefits from the additional roadway capacity.
During Construction vs. After	This approach is a combination of the two described above and is applicable to projects where the final improvements do not result in an increase in capacity, i.e., rehabilitation projects. The during construction versus after approach compares the user costs associated with lane restrictions during construction against the user costs after the construction is completed.

Table 2. Category of projects for application of RUC [6].

Category	Description of Projects	Area	Analysis Approach
I	Severe capacity reduction Critical completion time	Urban	Phase-by-Phase
II	Signalized/Diamond intersection	Urban	Before vs. After
III	Highway widening (not in I or II) New facility construction	Urban or Rural	Before vs. After
IV	Rehabilitation Non-capacity-added projects	Urban or Rural	During Construction vs. After

Even though FDOT employs the TTI method to calculate RUC, it applies a unique value of time (VOT), as will be described below. For the present research, with the field data collected, RUC was calculated by employing the TTI method with VOT, as per FDOT procedure. Then, the project data were used to calculate RUC via a commercial software package called MicroBENCOST [7]. Finally, the results rendered by the two methods were compared. The comparisons can demonstrate how the RUC calculation can contribute to the economic issue by calculating the opportunity cost from the analysis of the field data using a specific code manual and software package.

2. Methodology

2.1. Project Description

Four ongoing projects with lane closures in north-central Florida were selected, and the traffic movements timed with a stopwatch system setup. For the analysis, the "During Construction versus After" approach was applied since the projects all fell into the fourth category of "rehabilitation in a rural area" (see Table 2). The major difference between the two methods used (i.e., "Before and After" and "During and After") is that while RUC for a typical project consists mainly of the difference in traffic flow before and after construction, a project involving a lane closure causes severe RUC during construction, and these costs must be considered. The "During and After" feature takes these highly increased construction costs into account.

2.2. Project Category

Rural rehabilitation projects typically include lane widening, resurfacing, and the addition of paved shoulders in rural areas. These types of projects usually require lane closures and, as a consequence, larger RUC during construction than do projects without lane closures.

2.3. Average Annual Daily Traffic

Average annual daily traffic (AADT) is a determining factor when calculating RUC. It is defined as "the summation of the yearly volume of traffic divided by the number of days in the year" [2]. Because the typical hours of lane closure for the four case-study projects were approximately ten hours per day, the AADT was modified to reflect the actual time of lane closure by using the hours of daily traffic distribution presented in the TTI method. Table 3 indicates the hourly percentages of AADT during a 24-h day [5]. Assuming that lane closure hours for a typical workday started at 8:00 am and ended at 5:00 pm, the sum of the percentage of AADT during lane closure was approximately 59.2% of the total daily traffic distribution. The AADT was then adjusted by multiplying 59.2% by the AADT value.

Table 3. Day traffic distribution [5].

Hour	% of AADT	Hour	% of AADT	Hour	% of AADT	Hour	% of AADT
1	1.8	7	2.5	13	5.7	19	5.5
2	1.5	8	3.5	14	6.4	20	4.7
3	1.3	9	4.2	15	6.8	21	3.8
4	1.3	10	5.0	16	7.3	22	3.2
5	1.5	11	5.4	17	9.3	23	2.6
6	1.8	12	5.6	18	7.0	24	2.3

The result is shown in Table 4 as "AADT (adjusted)." Table 4 illustrates the characteristics of the four research projects analyzed.

Table 4. Project characteristics.

Project Data	SR-241	SR-121	SR-100	SR-129
County	Alachua	Union	Union	Levy
Project Category	Rural Rehabilitation	Rural Rehabilitation	Rural Rehabilitation	Rural Rehabilitation
Project Cost	$2.9 million	$3.6 million	$2.0 million	$2.6 million
Project Duration	236 work days	279 work days	260 work days	150 work days
Days of Lane Closure	170 days	100 days	90 days	70 days
Typical Hours of Lane Closure	7:00 AM–5:30 PM	8:00 AM–7:00 PM	9:00 AM–4:00 PM	7:00 AM–5:00 PM
AADT	7700	4700	5100	5200
AADT (adjusted)	4558	2782	3019	3078

2.4. TTI Manual Method

Using the "During Construction vs. After" approach, RUC is calculated simply by multiplying the delay time resulting from the work zone condition (i.e., closing lanes) by the VOT. RUC resulting from a work zone lane closure can be calculated using Equation (1).

$$RUC = Delay\ Time \times \text{Value of Time} \times \text{AADT (adjusted)} \tag{1}$$

where Delay Time = (Time with Lane Closure) − (Time without Lane Closure).

2.4.1. Delay Time

For the present research, delay time was measured by timing delays in the particular work zone with a stopwatch. The experiment included ten visits to three projects (i.e., SR-241, SR-121, and SR-100) and four visits to a fourth project (i.e., SR-129). The data from one visit to SR-100 were removed because delay times were greatly increased by a traffic accident that occurred during the experiment. These data were considered outliers. For each project, three or four visits out of ten were made in the afternoon, and the rest were conducted in the morning. Of the visits made to the SR-129 project, one was made in the afternoon.

During these visits, the length of the lane closure was recorded because lengths vary based on conditions such as the geometric features of the road and the contractor's choice. The length of the lane closure is limited to 3.22 kilometers (2 miles) by FDOT for safety reasons. Figure 1 illustrates the design of the delay timing experiment. The first car was stopped by a flagman, and its sitting time was measured (A). Then, the waiting time of the last car in the queue (B) was measured. The number of cars in the queue was counted and recorded in multiples of five. When the number was less than five, the number was recorded as is. By definition, the last car in the queue always joined the line before the first car resumed travel through the work zone. The waiting times of the first and last cars were then averaged to determine the average waiting time of the cars in the queue.

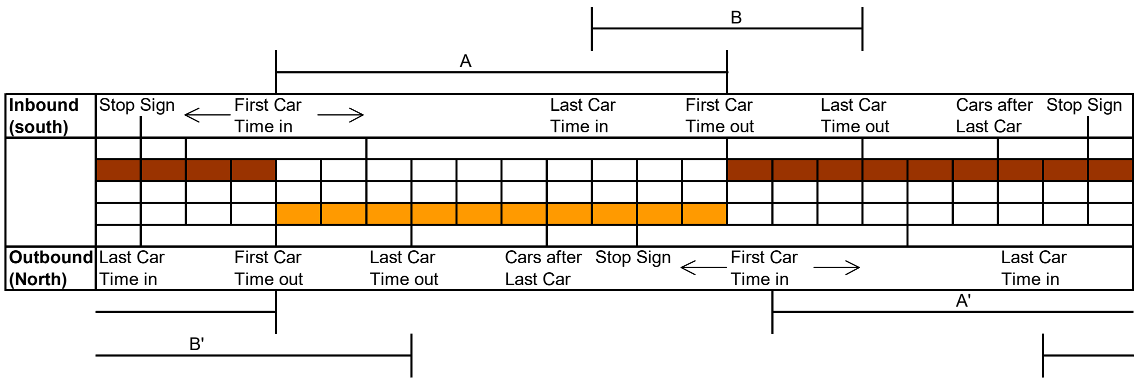

Figure 1. Design of Delay Timing Experiment.

Table 5 shows example average waiting times. The example data include specific time information to represent the in-and-out time of cars, the number of car, waiting time, and work zone speed.

Table 5. Example Data for Measuring Delayed Time.

Test Number	Time of Day	First Car out	Last Car in	Last Car out	Total Last Car	No. of Car in a Row	Waiting Time	Work Zone Speed (Kilo/Hour)
1	7:26 AM	6:01	1:45	6:31	4:46	20	5:23	12.14
2	7:35 AM	9:37	3:14	10:07	6:53	20	8:15	8.92
3	-	9:37	4:34	10:26	5:52	30	7:44	9.37
4	7:51 AM	7:10	3:01	7:44	4:43	20	5:56	11.36
5	-	7:10	4:06	8:03	3:57	30	5:33	11.89

The author then drove the work zone during each visit in order to measure the average driving time. Because of time constraints and safety concerns, these measurements were done only a limited number of times (either three or four) per visit. The time measurement consisted of the time it took the driver to slow down, stop, wait, resume travel, and re-obtain the posted speed limit. Table 6 shows example data used to measure the average driving time. It is important to note that the same waiting and driving times were measured for travel in either direction, based on the same directional AADT distribution. The author randomly measured the waiting times at both ends of the work zone and confirmed similar results from both sides of the road.

Table 6. Example data for measuring work zone driving time.

Test Number	Distance (Kilometer)	Time of Day	Time for Distance	Time to Speed Limit
1	1.61	9:35	2:43	2:57
2	n/a	11:13	2:25	2:58
Average Driving Time	n/a	n/a	2:34	2:57

Work zone speed is defined as the distance traveled by each vehicle divided by the sum of the travel times recorded for each vehicle. It was calculated and averaged, as shown in Equations (2) and (3).

$$Work\ Zone\ Speed = Length\ of\ Work\ Zone\ (Distance\ of\ Lane\ Cloure) \div (Average\ Waiting\ Time + Average\ Driving\ Time) \tag{2}$$

$$Average\ Work\ Zone\ Speed = Sume\ of\ Work\ Zone\ Speeds \div Number\ of\ Experiments \tag{3}$$

For instance, in the first test shown in Table 5, the average waiting time for 20 cars in a row was 5 minutes, 23 seconds, and the average driving time was 2 minutes, 34 seconds, as shown in Table 6. By dividing the length of the lane closure of the day (i.e., 1.61 kilometers, or 1 mile) by the sum of the average waiting time and average driving time, a speed of 12.15 kilometers per hour was calculated. Based on each work zone speed, an average work zone speed of 11.18 kilometers per hour was measured on that day.

2.4.2. Value of Time

According to the AASHTO Red Book, the value of time (VOT) is defined as "a value is commonly placed on travel time savings by selecting a unit value of time and multiplying this unit value by the amount of time saved. The manual also indicated that travelers are willing to make money expenditures in exchange for time saving" [2].

The manual takes vehicle operator, vehicle operating, and accident costs into account when calculating the VOT. For vehicle operator cost, the average hourly wage rate is multiplied by the number of adults per vehicle. For accuracy, the average wage rate is updated according to the Consumer Price Index (CPI) in a timely manner and may vary from place to place. The number of adults per vehicle depends on the trip type. Table 7 shows the example included in the manual.

Table 7. Example of adults per vehicle [2].

Trip Type	Adult per Vehicle
Work	1.22
Social-recreational	1.98
Personal business	1.64
Average	1.56

Vehicle operating costs include fuel, oil, tires, maintenance, and depreciation. The VOT is also updated using the CPI, as presented in Table 8 [6].

Table 8. Updating value of time [6].

Vehicle Type	Value of Time	Value of Time Adjusted
Small passenger car	$9.75	$12.16
Medium/large passenger car	$9.75	$12.16
Pickup/Van	$9.75	$12.16
Bus	$10.64	$13.27
2-axle single unit truck	$13.64	$17.01
3-axle single unit truck	$16.28	$20.30
2-S2 semi-truck	$20.30	$25.32
3-S2 semi-truck	$22.53	$28.10
2-S1-2 semi-truck	$22.53	$28.10
3-S2-2 semi-truck	$22.53	$28.10
3-S2-4 semi-truck	$22.53	$28.10

When updating the VOT, the formula introduced in the AASHTO Red Book is applied, as shown in Equation (4).

$$VOT\ for\ Selected\ Year = \left(\frac{CPI\ for\ Selected\ Year}{CPI\ in\ Base\ Year}\right) \times VOT\ in\ Base\ Year \tag{4}$$

2.4.3. Example Using the FDOT Method

FDOT uses the TTI manual method with a slight alteration in the area of the VOT. For this value, FDOT combines the vehicle operator and operating costs and excludes accident cost because the expected accident rate is usually not substantially different after road improvement. The operating cost, however, is included because that cost varies significantly depending on how much the vehicle speed changes after road improvement. For example, the user cost per hour employed by FDOT in 1995 was $11.43 per hour per vehicle. This was calculated by taking the average hourly wage rate of the vehicle operator ($8.55) and adding that to the average hourly operating cost ($2.88). The result is updated based on economic indicators (such as CPI), as described above. The CPI values in 1995 and 2019 were 139.1 and 255.7, respectively. Thus, the VOT can be converted using Equation (5), as follows.

$$VOT_{2019} = \frac{255.7}{139.1} \times \$11.43 = \$21.01 \tag{5}$$

FDOT multiplies the derived VOT by the amount of time delay caused by the work zone lane closure. Some state departments of transportation apply the same method as FDOT except that the VOT is multiplied by a factor that causes the result to better satisfy the needs of that agency. The Illinois DOT, for example, multiplies the VOT by the average number of passengers per vehicle, which is currently 1.25 [2].

3. Results from Field Studies

The results reported in this section are those obtained from the FDOT method, as described above. Table 9 shows the results of the measurements for the four projects. Once the work zone speed on a given day was averaged, the distance (i.e., length) of the lane closure was divided by the average work zone speed to calculate the time within that work zone. This was the "During" element of the "During vs. After" method.

Table 9. Result summary of average daily delay cost.

Projects	AADT Adjusted	Average Daily Delay Cost
SR-241	4558	$3932.97
SR-121	2782	$2397.49
SR-100	3019	$2175.54
SR-129	3078	$3403.24

Next, the distance of the lane closure was again divided by the posted speed for the work zone area, and the time without a lane closure zone calculated. This was the "After" situation, since a rehabilitation project (non-capacity added) usually results in no change in posted speed after construction. However, the posted speeds may be increased if the construction includes adding a paved shoulder. If this is the case, the time without the work zone is reduced and, as a consequence, the daily delay cost increases.

Delay time was calculated by subtracting the time without the work zone from the time with the work zone. This value was then multiplied by the VOT to derive the daily delay cost per vehicle. Finally, multiplying the adjusted AADT to the daily delay cost per vehicle provided a total daily delay cost. That total daily delay cost is summarized in Table 9.

4. MicroBENCOST Application

After calculating the RUC using the case study projects, the value was recalculated using MicroBENCOST 2.0 software. The results were then compared. MicroBENCOST version 2.0 is a software package developed by TTI [6] and used to analyze benefits. As mentioned above, the RUC for rehabilitation projects mainly comes from the difference in user cost between the time during improvement, which features a work zone, and after improvement, where there is no work zone in place. Figure 2 shows the structure of the MicroBENCOST [6] software applied to compute the RUC.

As seen in Figure 2, the RUC during improvement was first retrieved by inputting the appropriate information for the existing route in each category. This information included work zone data from the traffic operation category. Then, new values for the proposed route (i.e., after improvement) were entered, and the RUC for the new roadway calculated. The difference between the two scenarios was used to derive the user benefit value, which was then employed to calculate the daily RUC caused by the improvement.

4.1. Project Information

First, general project information was entered. This included area type, project type, and total construction cost. "Area" was categorized as either rural or urban. "Project Type" was one of seven options: added capacity, bypass, intersection/interchange, pavement rehabilitation, bridge, safety, or highway-railroad grade crossing. All of the projects selected for this study fell into the "pavement rehabilitation" category. "Total Construction Cost," another information field, is self-explanatory.

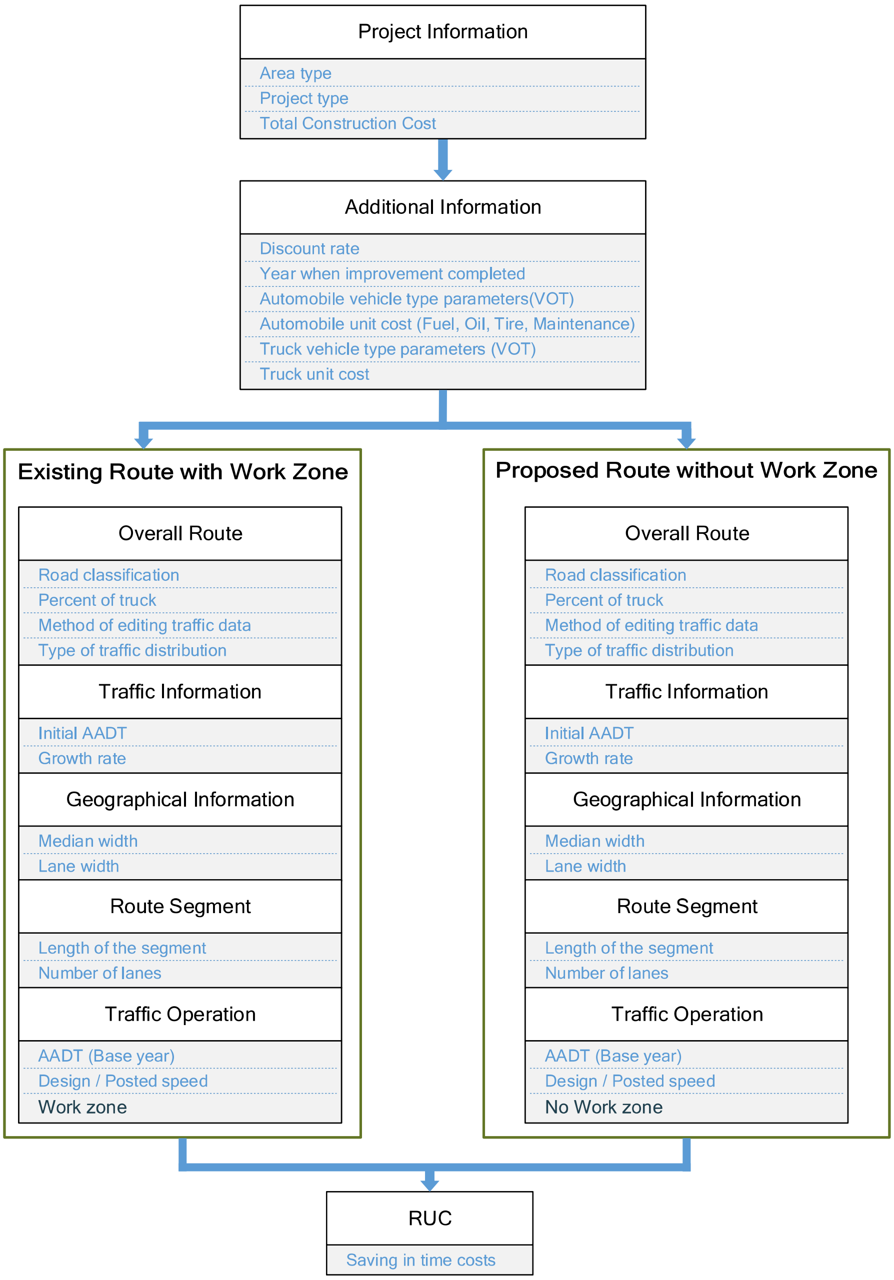

Figure 2. Structure of MicroBENCOST with work zone [7].

4.2. Additional Information

Additional information included the discount rate, year when the improvement was completed, automobile vehicle type parameters (e.g., the VOT), automobile unit costs (i.e., fuel, oil, tire, and maintenance), truck vehicle type parameters (e.g., VOT), and truck unit costs. Automobile vehicle type and truck type parameters (e.g., the VOT) for the state of Florida were $12.92 and $22.36 for automobiles and trucks, respectively [8]. Automobile and truck unit costs refer to the costs of fuel, oil, tire, maintenance, and depreciation. These costs were also adjusted to reflect current cost escalation.

4.3. Overall Route Information

The road classifications used were consistent with the roadway classifications defined as below [8–10].

1. "Functional classification means the assignment of roads into systems according to the character of service they provide in relation to the total road network. Basic functional categories include

arterial roads, collector roads, and local roads, which may be subdivided into principal, major, or minor levels. Those levels may be additionally divided into rural and urban categories."

2. "Arterial road means a route providing service which is relatively continuous and of relatively high traffic volume, long average trip length, high operating speed, and high mobility importance. In addition, every United States numbered highway is an arterial road."
3. "Local road means a route providing service which is of relatively low average traffic volume, short average trip length or minimal through-traffic movements, and high land access for abutting property."
4. "Collector road means a route providing service which is of average traffic volume, average trip length, and average operating speed. Such a route also collects and distributes traffic between local roads or arterial roads and serves as a linkage between land access and mobility needs."

For the truck percentage, the default value of 9.66% was applied. The process for editing the traffic data allows the user to select from three traffic forecasting methods: Intermediate and forecast volumes, annual growth rate, and volume for the year. Annual growth rate was selected for the present research. The traffic distribution options included AADT by the hour of the day and hours in a year.

4.4. Traffic and Geographical Information

Once the overall route data were entered, additional route information such as traffic and geometric information, was also inputted, as needed. In the traffic information section, initial AADT, growth rate, and traffic distribution during a 24-h time period were all specified. For geometric information, the widths of the medians, lanes, and shoulders could all be described.

4.5. Route Segment

The length of the segment and the number of lanes are decisive factors in the calculation of RUC for existing and proposed segments. The route segment data were specified in the traffic operation section. Here, design and posted speed were assigned based on the design of the road. Design speed was obtained from the typical section drawing in the construction documents. Work zone information includes details, such as the number of days the work zone is in place and the beginning/ending hours of the lane closure. Table 10 shows the input values for the SR-241 project as an example.

Table 10. Input Data for SR-241.

Data in Question	Value	Data in Question	Value
Area Type	Rural	Initial AADT	4558
Project Type	Pavement Rehabilitation	Growth Rate	10%
Total Construction Cost	$29,000,000	Lane Width	3.6 meter
Discount Rate	5%	Shoulder Width	1.2 meter
Year when Improvement Completed	2003	AADT (Base year)	6500
Road Classification	Minor Arterial	Segment Length	1.2 mile
Percent of Truck	10%	No. of Work Zone	1
Method of Editing Traffic Data	Volumes for each year	No. of Days Work Zone in Place	236
Type of Traffic Distribution	Hour of Day	Beginning/Ending hour of Lane Closure	7:00-18:00

4.6. Result from MicroBENCOST

Table 11 shows the results of the MicroBENCOST analysis. As mentioned, cost benefit was calculated by subtracting the RUC after construction from the cost during construction. The amount of cost benefit was then converted to the daily RUC.

Table 11. Result of MicroBENCOST.

Projects	During Construction ($)	After Construction ($)	Cost Benefit ($/Year)	RUC ($/Day)
SR-241	2,731,000	1,578,000	1,153,000	3159.90
SR-121	1,495,000	798,000	697,000	1910.59
SR-100	1,624,000	867,000	757,000	2073.97
SR-129	1,656,000	884,000	772,000	2115.07

5. Data Analysis

Table 12 is a summary of the RUC values for the four projects, based on the information presented in Table 9. In both methods, AADT was a determining factor in the RUC calculation because the delay cost per car was multiplied by the AADT to calculate the total daily delay cost. Figure 3 illustrates how AADT is related to RUC, using the FDOT method. It was observed that the volume of AADT is related to the amount of RUC. However, the RUC of SR-121 was higher than that of SR-100, in spite of the lower AADT. The reason is that the length of the lane closure on the SR-100 project was only 0.4 miles for four of the 10 days when data were gathered. Shorter distances cause smaller delays, resulting in a lower RUC.

Table 12. Summary of RUC.

Projects	AADT Adjusted	Average Distance	Average Work Zone Speed	Posted Speed	RUC by FDOT (TTI Method)	RUC by MicroBENCOST
SR-121	2782	1.37	15.40	54	$2397.49	$1910.59
SR-100	3019	1.07	13.42	56	$2175.54	$2073.97
SR-129	3078	1.58	13.65	52	$3403.24	$2115.07
SR-241	4558	0.85	10.85	52	$3932.97	$3159.90

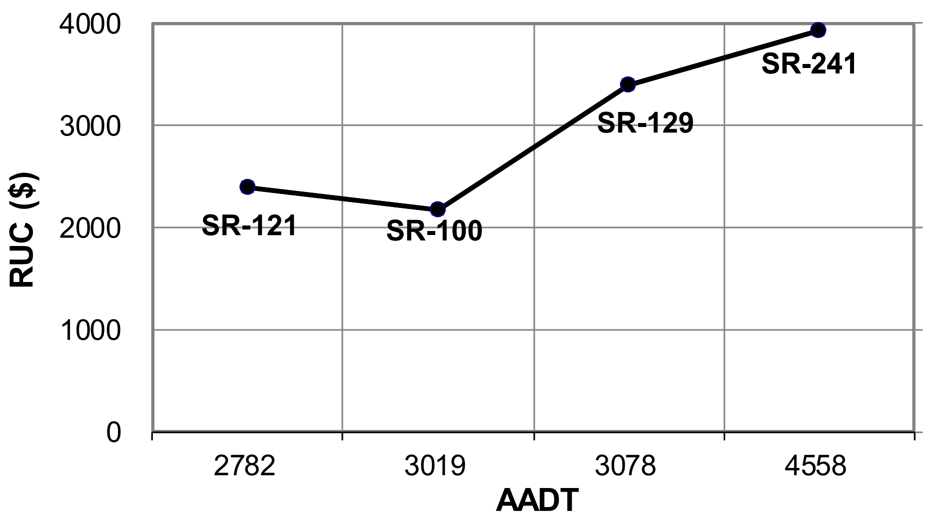

Figure 3. RUC and AADT by FDOT method.

Figure 4 shows that the MicroBENCOST application calculated an increasing RUC as the AADT increased. This result validates the FDOT method because the RUC values calculated by the two methods were very comparable.

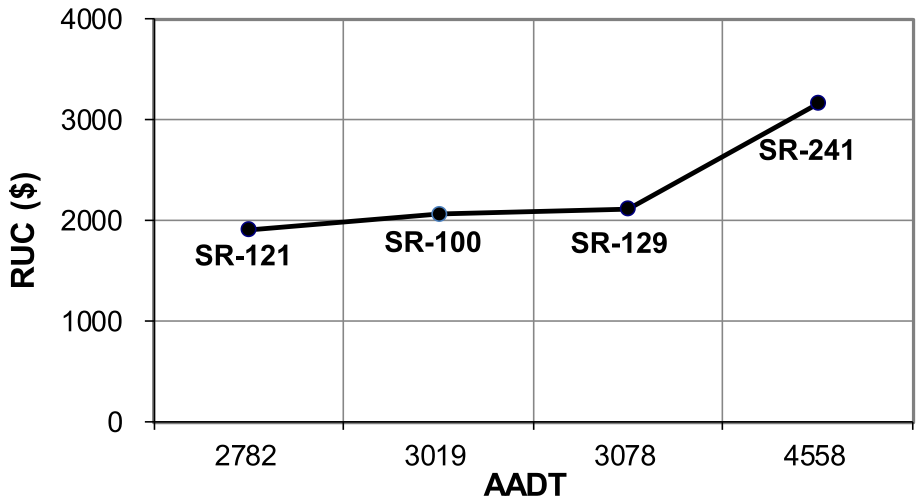

Figure 4. RUC and AADT by MicroBENCOST.

Work zone speed seemed not to be directly related to RUC. Even though vehicle waiting time depends mainly upon the length of a lane closure, long waiting time does not necessarily mean slow work zone speeds. There are many factors that could affect the speed of traffic through a work zone that have no relationship with the length of the lane closure. Figure 5 compares work zone speed to RUC. Thus, AADT is a more important factor than work zone speed when calculating RUC using either method, either that of the TTI manual (used by FDOT) or MicroBENCOST.

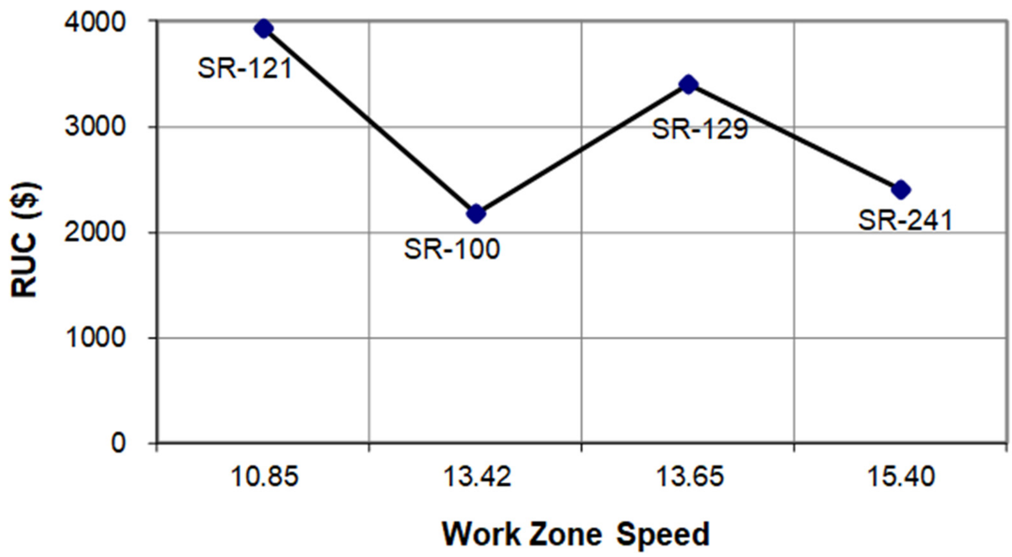

Figure 5. Relation between work zone speed and RUC.

6. Conclusions and Future Work

This research presented case study projects for the purpose of reporting RUC calculations for projects with lane closures in the work zone and comparing two popular methods of conducting such calculations. There are several factors that contribute to the RUC of any construction project involving lane closure, including AADT, work zone speed, and length of the lane closed. The most important factor is AADT. The results show that RUC values are consistently high, where a high traffic volume (i.e., AADT) exists.

Since all four projects were rehabilitation projects in rural areas with less than 10,000 AADT, relatively small RUC values (less than $4000 per day) were calculated by both methods (i.e., FDOT and MicroBENCOST). Using the same methods, the results could be completely different if the project analyzed was located in an urban area with a high AADT. However, since the two methods employed here yielded similar results, either will provide satisfactory conclusions when calculating RUC for a highway construction project.

The RUC calculations in this research were conducted under critical factors, including geographic area, traffic volume, and value of time. The implemented RUC calculations represent the meaningful comparison results between two accepted methods focusing on lane closures in the work zone. Our future research direction demonstrates RUC calculations by applying them to diverse construction projects in urban and rural areas.

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