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SOCIAL RETURN ON INVESTMENT AS A METRIC TO PRIORITIZE USE OF ACCELERATED BRIDGE CONSTRUCTION IN RURAL REGIONS

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ABSTRACT

Accelerated Bridge Construction (ABC) techniques have a great potential to minimize the traffic disruptions during the bridge repairs/replacements, promote traffic and worker safety, and improve the overall quality of the built bridges. Despite the major advances in design and construction of ABC techniques, transportation agencies are still hesitant about using ABC techniques largely due to perceived risks during construction and higher initial costs. Furthermore, the current decision process used to prioritize the candidate bridges for this type of construction is oftentimes solely based on metrics such as the average annual daily traffic (AADT). This paper proposes to use a metric employed by the World Bank to prioritize funding for aid in developing countries: social return on investment (SROI). SROI will measure the value of investment in ABC techniques to reduce social, economic, and environmental impacts to the road network users. The Missouri Department of Transportation (MoDOT) completed the replacement of more than 500 bridges as part of the "Safe and Sound" project using the ABC techniques. This paper considers five counties, mostly with agricultural demographics in the state of Missouri, as the case study and estimates the SROI of the utilization of ABC. The results show that SROI provides a holistic measure to incorporate the socioeconomic aspects in the prioritization of the bridges that could benefit from ABC techniques.

INTRODUCTION

Transportation networks are an important component of the civil infrastructure system. They provide a means of commute to the users to conduct their everyday activities, allow for emergency vehicles to perform timely critical duties, and provide businesses, industries, and agricultural entities with a means to transport goods among other important functions. The socio-economic impact of any dysfunctionality in the network could ripple down to the community and go beyond the borders of the town, county, or possibly even the state (*1*). User costs are a major factor as the disruption in typical flow of traffic around the project area results in longer wait times, additional mileage traveled to detour around the work zone, and inefficient movement of goods and services. This underlines the importance of implementing an effective strategy to repair/replace the structurally deficient bridges in the shortest possible time. Accelerated Bridge Construction (ABC) is a technique that uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce the onsite construction time when building new or replacing existing bridges (*2*). Oftentimes long detours present opportunities where the use of ABC methods can provide more practical and economical solutions to those available with conventional construction methods. However, ABC techniques are perceived to add a cost premium to replacement of bridges in the rural US (*3*). As such it's important to not only consider the initial costs (cost of material and labor required to design and construct the structure) but also the societal costs associated with the construction activities and attendant traffic disruptions (*4*).

Prioritization of the construction funding to replace deficient low volume bridges is challenging (*5*). Oftentimes, transportation agencies use metrics such as the average annual daily average traffic (AADT) as a measure for prioritization. However, one should note that AADT alone ignores the value of the goods travelling and its financial impact to the businesses, industries, or agricultural entities (*6*). A study by Furtado and Alipour showed that in the context of rapid restoration after extreme events, although the initial cost of ABC implementation was high, it resulted in lower socio economic costs in the long run by decreasing the downtime in the system (*4*). Another good example is the study conducted by Miller et al. (*5*) that used a metric introduced by the World Bank to prioritize funding for the bridge replacement projects in rural Iowa. The metric is called social return on investment (SROI) and it monetizes the social benefits and costs relative to the financial costs based on the net present value in dollar terms (*7-8*). The SROI analysis helps estimate the amount of social value created or destroyed during an activity.

The Missouri Department of Transportation (MoDOT) replaced 554 structurally deficient bridges statewide under a single design-build contract in 2009-2012 called the Safe and Sound Project (S&S). ABC techniques were utilized during the replacement of these structurally deficient bridges in an effort to minimize the impact to the traveling public in Missouri. Five of the 111 counties comprising of 70 of the 554 replacement bridges were selected for evaluation of how ABC techniques impact the SROI in rural Missouri. These counties are Caldwell, Daviess, Harrison, Lafayette, and Ray and are all located in Northern Missouri which is identified to have a heavy agricultural industry. Figure 1 shows the locations of each of these 70 bridges. Missouri DOT manages many farm to market roads that are the lifeblood for farmers needing to transport their crops from their farms to the markets they serve. The five counties selected for this study comprise of 5,621 individual farms producing over $400M in annual crop market sales per year in 2012, with over 60% or $250M annually of this crop production being either corn or soybean (*9*). The road network enables the farmers to deliver their crop to market to be sold to consumers. It has been recognized for over 50 years the poor condition of roads and transportation disruption and delays can lead to inefficiencies in other industries such as agriculture. SROI can provide a socio-economic metric to quantify the impact of this transportation disruption and delay to the road users. ABC reduces the disruption and delay to the road user and using SROI will help quantify and compare the benefits of ABC investment with the costs of traditional construction.

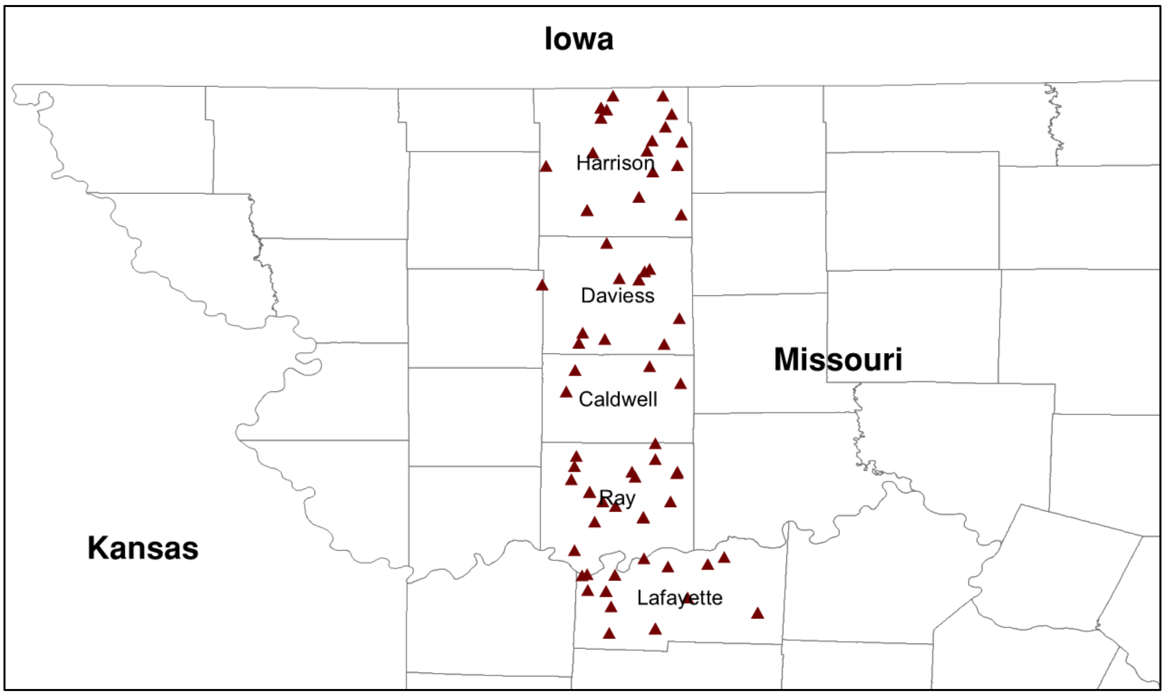

FIGURE 1 Map of 70 bridge locations of the S&S project in 5 counties of Missouri.

METHODOLOGY

Reduction of road closure times, traffic disruption and user costs, in addition to improvements in construction quality and utilizing prefabricated elements, are all attractive qualities of the implementation of ABC techniques that encourage the transportation agencies to use the technique for repair and replacement projects. ABC would help minimize onsite construction activities, result in decreasing the long-term presence of contractor related equipment, labor, and staging areas and consequently can decrease driver distractions and traffic disruptions that reduce the safety and mobility efficiencies of the transportation network (*2*). According to FHWA, two time metrics are used when determining the amount of impact to the road user: i) Onsite construction time, which is the period of time when a contractor alters the project site location until all construction related activities are removed. This includes, but is not limited to, the removal of Maintenance of Traffic items, construction materials, equipment, and personnel. And ii) mobility impact time which is any period of time the traffic flow of the transportation network is reduced due to onsite construction activities. This study will focus on quantifying the effects of the mobility impact time to the road users of the rural road network of the bridges that are located in the specified counties of Missouri. For this specific study, the on-site construction time and mobility impact time are equivalent and measured in average schedule bridge closure time.

The use of prefabricated bridge elements and systems (PBES) is one strategy that can meet the objectives of accelerated bridge construction. Prefabricated elements are a category of PBES which comprise a single structural component of a bridge, and can reduce or eliminate the onsite construction time that is needed to build a similar structural component using conventional construction methods (2). Examples of ABC prefabricated elements include; deck elements, beam elements, pier elements, abutment and wall elements, and other miscellaneous elements. Other ABC methods utilized consist of alternative project delivery, contract time incentives, and bundling multiple bridges under one contract agreement (*10*). This paper will determine the specific ABC prefabricated elements that were used in S&S project and will identify any other ABC methods that were used in replacement of the rural bridges in Missouri.

SROI places a monetary value on the social impact of an activity and compares this with the cost incurred in creating the benefit (*11*). Following the recommendation by the Cabinet Office (*12*), carrying out an SROI analysis involves six stages: i) establishing scope and identifying key stakeholders, ii) mapping outcomes, iii) evidencing outcomes and giving them a value, iv) establishing impact, v) calculating the SROI, and vi) reporting, using, and embedding. In the context of replacing the rural bridges in Missouri using ABC technique, the social impact is the reduced bridge closure time that could cause delays to the road users, and the investment is the use of ABC to replace the bridge. The outcome is the reduced delay time and associated monetary value which results in reduced road user costs (RUC) with the price of an additional initial cost that needs to be invested through the application of ABC. Road user costs (RUC) here are defined as the estimated incremental daily costs to the traveling public resulting from the construction work being performed (*13*). These costs are primarily time lost because of conditions such as detours/rerouting that add to travel time, reduced roadway capacity that slows travel speed and increases travel time, or a delay in the opening of a new or improved facility that prevents users from gaining travel time benefits. The fundamental components of RUC to be considered here are; vehicle operating costs, accident costs, and time costs (*14*).

Collecting quantitative data to complete the SROI analysis consisted of review of project documents to obtain: overall cost of each bridge, schedule days of bridge closure time, location of each bridge, contract time incentives per bridge, detour length, and AADT. Following data collection, the results were analyzed and the output was used to conduct the SROI analysis. Figure 2 illustrates the methodology used to complete this study.

CASE STUDY CONTEXT

The Safe and Sound Project (S&S) replaced 554 structurally deficient bridges located in 111 counties in rural Missouri from 2009 to 2012. This study took a sample of 70 of the total 554 S&S bridges. The scope of the S&S project included small two-lane rural bridges with predominant designs utilizing core slabs and box beam systems. The sample set consists of replacement bridges located in five counties; Caldwell, Daviess, Harrison, Lafayette, and Ray to evaluate the extent which the SROI was affected by the use of ABC techniques in replacing the bridges in these selected counties. Table 1 provides contextual information of the S&S project and the sample bridges selected for this study. The table illustrates that the sample taken for the study is a good representative sample of the overall project with average schedule days and cost per bridge very similar to the overall S&S project.

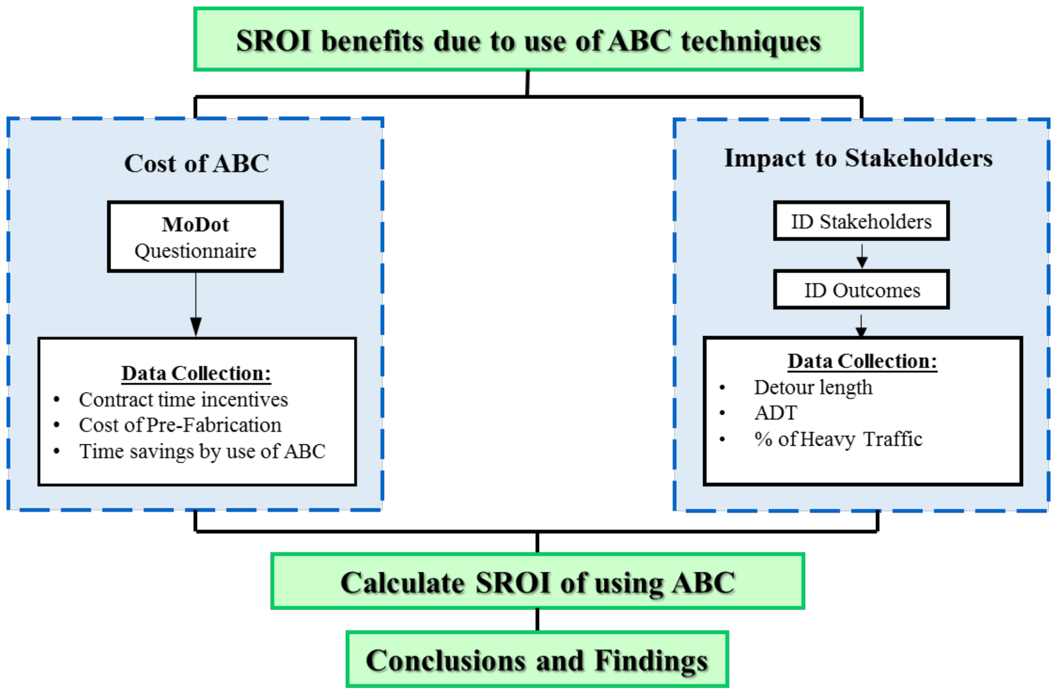

FIGURE 2 Case Study Methodology.

TABLE 1 Safe and Sound Project vs. the case study area.

Case Study Description		
Description	**Safe and Sound Project**	**ABC/SROI Case Study**
Agency	Missouri DOT	Missouri DOT
Project Type	Structurally Deficient Bridge Replacement	Structurally Deficient Bridge Replacement
Project Location	Statewide - Rural	5 Counties - Rural
Number of Bridges	554	70
Number of Counties	111	5
Project Cost	$487,000,000	$57,911,381
$ per Bridge (S&S)	$879,062	$827,305
$ per Bridge (Conventional)	$1,024,433	$1,024,433
Average Schedule Days per Bridge (S&S)	43 Days	40 Days
Average Schedule Days per Bridge (Conventional)	90-120 Days	90-120 Days
Life Expectancy of Bridges (S&S)	50 years	50 years
Life Expectancy of Bridges (Conventional)	75 years	75 years

SROI PROCESS

The first step of the SROI process is to identify the stakeholders who are impacted socially, economically, or environmentally. In the case of this study, the predominant stakeholders are the road users. In addition to general road users using these routes for general transportation, this particular region is home to much agriculture. Crop production is a primary source of economy for this region and transporting of crops from the farms to market is a vital component of this industry. Therefore, a major stakeholder of the bridge replacement process is the crop producers who use these roads to transport their goods. Due to necessary detours during replacement of the bridges, additional mileage and time is incurred during construction of the replacement bridges. Use of ABC technique is meant to reduce the overall time taken to complete the construction of a bridge and consequently reducing the overall delay in travel time.

The next steps are mapping outcomes and giving them a value. The outcome of replacing a bridge on a state highway is creating a detour route around the bridge which results in additional delay time and miles traveled to the users of the particular section of the road network, thus impacting the road users socially, economically, and environmentally. The valuation of this outcome is quantified using road user costs impacting the users' vehicle operating costs (*VOC*), vehicle owners time (C_T), and environmental impact (C_E).

The investment made to reduce the impact to the road users is the use of ABC techniques. The use of ABC techniques accelerates the completion of the bridge replacements thus reducing the amount of time for each bridge closure, consequently increasing the social return through adding value socially, economically, and environmentally. Knowing the road user cost (*RUC*) and the ABC costs (C_{ABC}), SROI can be calculated using Equation 1:

$$SROI = RUC/C_{ABC} \quad (1)$$

where *RUC* typically include costs related to the value of the travel time spent by the driver and passenger, expenses of operating the vehicle, and costs of possible additional accidents (*14*).

Figure 3 displays the process used to conduct the SROI analysis in this study.

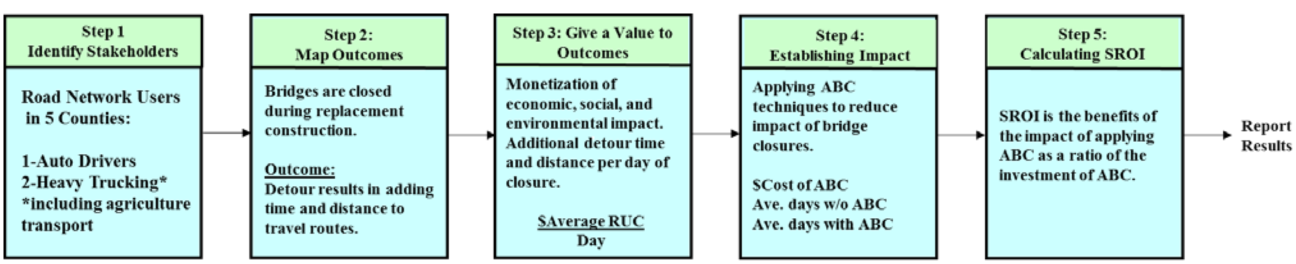

FIGURE 3 SROI process diagram.

CASE STUDY RESULTS

Identifying and Evaluating the Impact to the Stakeholders

Bridges are a vital component to any road network and can act as a bottleneck in case of any disruptions. When the bridges are closed due to repair or replacement, the users are forced to take alternate routes that will make the travel time longer due to the length of detour, quality and condition of the detour, and its capacity. S&S replaced 554 bridges statewide causing the traveling public to use alternate routes that most often times increased both the travel time and distance for the road user. The impact to the road user is directly related to the amount of time the bridge is closed. In the case of the S&S project, the average time each of the 554 bridges were closed was 43 total days, meaning the traveling public was impacted for a total of 43 days on average. Conventional bridge replacement projects similar to the bridges comprised in the S&S project that do not utilize ABC techniques, are completed in 90-120 days on average. As such the use of ABC techniques allowed the S&S project bridges to be closed for only half the time a conventional construction would take, saving the users approximately 60 days in average.

The specific impact to the road user of each bridge closure is unique to the location of the specific bridge. The detour distance and time varies from one bridge location to another as does the amount and type of traffic using the specific route. By increasing the amount of travel time and distance for the road users, there are impacts economically, socially, and environmentally for the traveling public using the road network. Figure 4 presents detour distances for each of the 70 bridges replaced for the S&S project in the selected 5 counties.

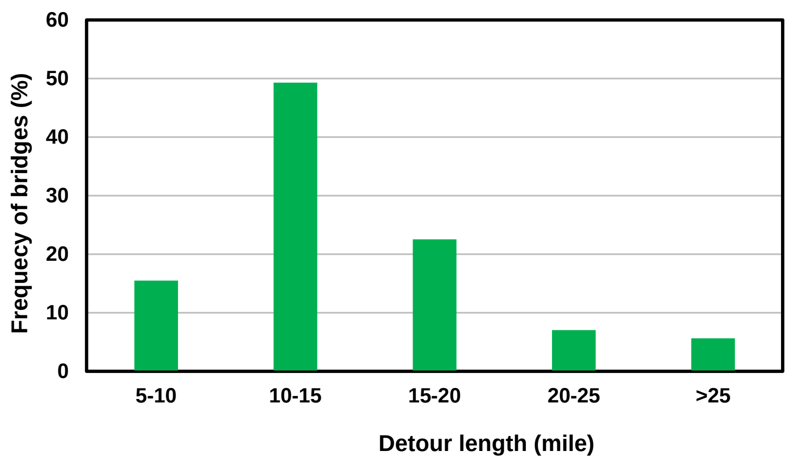

FIGURE 4 Distribution of detour lengths for the 70 bridges.

Estimation of Road User Cost due to Detours

The fundamental components of RUC are: vehicle operating costs (*VOC*), accident costs (C_A), driver time costs (C_T), and emissions costs (C_E) (*15*):

$$RUC = VOC + C_A + C_T + C_E \quad (2)$$

Accident costs are not included in this study as data was not furnished to include in the SROI calculation. The inputs for the RUC calculations for vehicle operating costs and vehicle owner time for automobiles and trucks were derived from published information by Michigan Department of Transportation (MDOT) (*16*). The Highway Development and Management Model (HDM-4) developed by the World Bank was used to calculate the environmental impact of the detours (*17*). Table 2 represents the statistical results of the RUC calculated for the 70 bridges described in terms of average, median, and standard deviation. As the results show, the use of ABC resulted in an average saving of 64% in road user costs

TABLE 2 RUC savings statistics for 70 bridges replaced using ABC.

	ADT	Detour Length (mile)	Daily RUC Savings	Total RUC Savings	Total Cost of Bridge	Total RUC Savings as a Percent of Cost of Bridge
Average	728	14.23	$10,283	$532,243	$827,305	64.3%
Median	379	13.90	$5,374	$269,383	$726,631	37.1%
STDEV	869	4.83	$12,715	$707,577	$352,184	-

Evaluating the Cost of ABC Techniques

A structured questionnaire was administered to the Missouri Department of Transportation on the S&S project. The guidelines proposed by Harris and Brown (*18*) were used in structuring a questionnaire to maximize the likelihood the questionnaire and the data will align. The purpose of the questionnaire was to identify and quantify the ABC techniques that were used and their impact on the bridge closure time and cost to each bridge replaced. According to the responses from the questionnaire, the main ABC elements used in execution of the S&S project were:

- Prefabricated Beams and Girders
- Standardized Design
- Bundling of Contract with multiple bridges under one agreement
- Contract time incentives

Following identification of the ABC elements used during construction, the amount of impact was determined for each element in i) reduction in bridge closure time and ii) additional cost to the project. Each of these elements greatly impacted the overall reduction of the bridge closure time ranked in the following order of impact;

1. Standardized Design
2. Bundling of Contract
3. Contract Time Incentives
4. Prefabricated Beams and Girders

Only two of the ABC elements were identified to increase cost of the S&S project.

1. Contract Time Incentives
2. Prefabricated Beams and Girders

Due to the fact there were 554 bridges to be replaced under one contract for the entire S&S project, economies of scale efficiencies gained through both standardized design and sub-bundling of bridges under different subcontracts offset any additional costs, therefore standardized design and bundling of contract were determined to not add any cost under this scenario. In fact, due to the scale of the S&S project, the efficiencies gained through standardized design caused a reduction in overall cost. These two elements (bundling of contract and standardized design) were considered to have zero net increase to the overall cost of bridge construction of the 70 bridges included in this study.

The contract time incentives were written into the S&S project design build agreement and were defined specifically for each bridge. The bridges' time incentives were classified into two categories of monetary time incentives;

- $1000 per day of completing and opening bridge early
- Specified amount determined for the specific bridge based on traffic disruption

Data was collected for the total amount of time incentive paid for each bridge. The cost of the use of a pre-fabricated beam and girder system was based on input given from MoDOT. It was determined the cost of using this pre-fabricated system on the S&S project added roughly a 30% increase in cost due to typical bridge construction in the state. Historical bid tabs were reviewed from January of 2014 to November of 2015 to determine a baseline cost for beam and girder systems used for conventional bridge construction in the state allowing for a cost to be determined for each bridge included in this study using the PBES ABC technique. Table 3 represents the statistical results of the ABC costs calculated for the 70 bridges described in terms of average, median, and standard deviation. As the results show, use of ABC results only in an average of 4.4% increase in the cost of bridge compared to conventional construction.

TABLE 3 Cost of ABC statistics for 70 bridges.

	Cost of PBES	Cost of Time Incentives	Total Cost of ABC	Total Cost of Bridge	Total Cost of ABC as a Percent of Cost of Bridge
Average	$24,819	$11,471	$36,290	$827,305	4.4%
Median	$21,799	$6,000	$29,665	$726,631	4.1%
STDEV	$10,566	$25,155	$27,147	$352,184	-

Calculating Social Return on Investment

The reduced impact of the road network users is quantified as RUC savings per day due to the reduced amount of bridge closure time of each bridge. The average bridge closure time for a similar rural bridge replaced in Missouri using the conventional construction techniques is 90-120 days while the bridges included in this study utilizing ABC techniques had an average bridge closure time of 40 days per bridge. For the RUC savings calculation, the typical bridge closure time used as a baseline ($T_{\text{No ABC}}$=90 days). The average RUC per day ($RUC_{\text{avg.}}$), the bridge closure time (T_{ABC}) in days, and the cost of ABC techniques were determined per bridge. The overall SROI equation used was:

$$\text{SROI} = \frac{RUC_{avg.} \cdot (T_{No\ ABC} - T_{ABC})}{C_{ABC}} \qquad (3)$$

SROI, or in this case can be referred to as the benefit to cost ratio, was calculated for all 70 bridges included in this study. The results varied from a low SROI of 1.63 to a high of 118.38 with a median ratio of 9.65. The results indicate the benefits to the road users of Missouri are greater than the costs of implementing ABC techniques by a factor of approximately 10 on average. There were no instances when the costs were greater than the benefits of using ABC techniques. The histogram in Figure 5 shows the number of bridges with the corresponding SROI ratio.

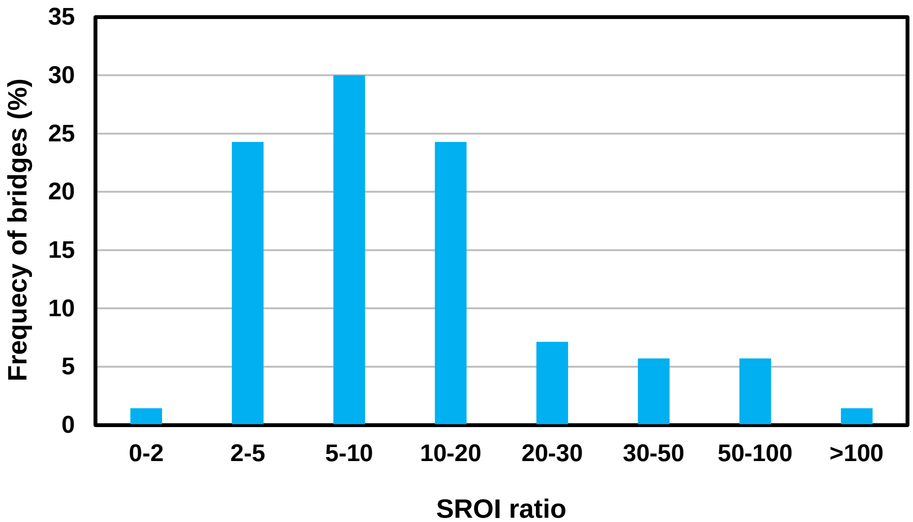

FIGURE 5 Histogram showing the percentage of bridges with the corresponding SROI ratio.

Prioritization of Contract Time Incentives

MoDOT used contract time incentives as an additional strategy to encourage earlier completion of the projects. Holistically from an overall project perspective, the daily time incentives were an effective technique used to improve the schedule as indicated by MoDOT survey responses and shown in the overall SROI ratio of benefits to costs of total ABC investment. The amount of incentive per day was equal to $1000 for all bridges except for four. Overall 54 bridges were completed earlier than schedule resulting in $802,950 were spent on contract time incentives, twelve bridges were completed as scheduled and 4 bridges were completed later than schedule resulting in $19,000 negative incentives to the contractor. The research investigated how well this time incentive investment made per bridge correlated to the road user impact benefits of each bridge location to determine if the prioritization of ABC investment was optimized to maximize the benefits to the project. For this purpose, the benefit of having incentive in place is calculated by estimating the number of days that a project was completed earlier (or later) than scheduled. The RUC was then estimated for those days. The ratio of the savings of (or lost in case of delays) RUC to the incentives spent (or disincentives charged) was calculated and presented in Figure 6. As could be seen there are three bridges with a high ratio of benefit of incentive, which had the largest number of ADT and associated user costs. In contrary there are three other bridges that received the most incentive for early completion but did not result in a whole lot of benefit considering their lower user costs. Considering the negative values (delayed projects) also shows that in some cases the penalties could not cover for the RUC lost to the public. Although the reason for the high investment in low benefit bridges may be other than just the RUC (political, regional, vicinity of critical facilities, etc,), this underscores the importance of using more detailed prioritization tools that would highlight the most critical components to the public so that more investment in their early completion could be made.

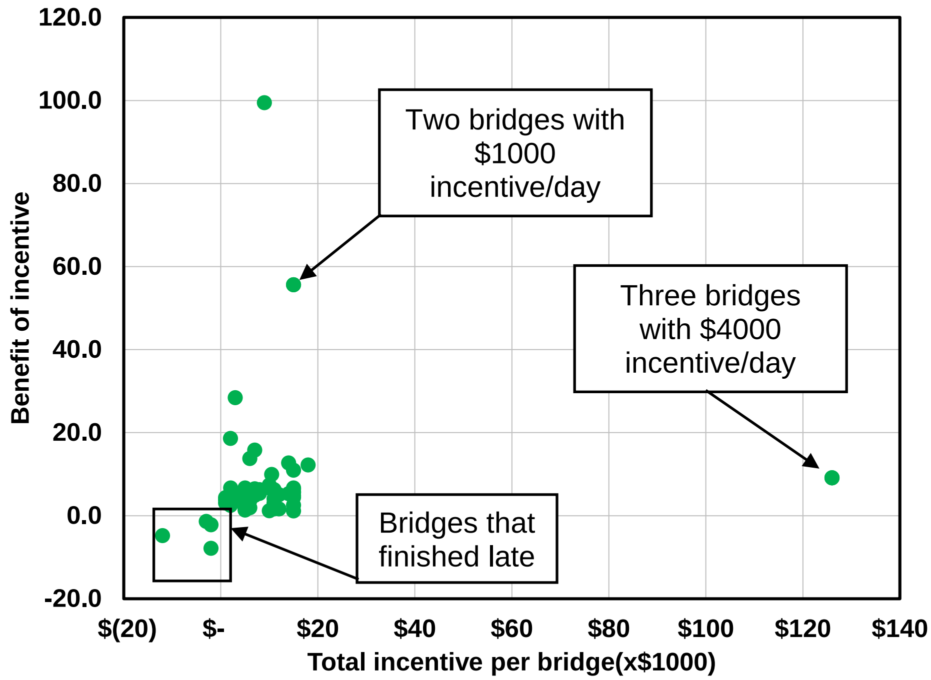

FIGURE 6 Benefits gained in RUC through early completion vs. the incentives per bridge

CONCLUSIONS AND DISCUSSIONS

The goal of this project is to understand the circumstances that would result in choosing ABC technique over conventional construction. For this purpose the data from a recently completed design-build project under the S&S project in Missouri was collected and five specific counties from this project were studied. A new measure called SROI was used to estimate the benefit of early project completion through ABC and incentives were used to assess the benefit to the public in this scenario. It was shown that a large benefit to the public with a median SROI of a factor of 10:1 was achieved. ABC techniques are highly effective in reducing the traffic disruptions during bridge replacements, promote traffic and worker safety, and improve quality and durability of bridges, however, the initial cost has prevented widespread and sustained implementation. The research here showed that implementing ABC on the 70 bridges resulted in an average 4.5% increase to the overall cost of the bridge, while there was a 64% increase in benefit for the road users of Missouri. It must be noted that the average total cost of the 70 bridges using ABC techniques included in this study was 20% less than typical conventional rural bridges of similar size and scope in Missouri. This overall construction cost reduction is due in part to efficiencies gained thru economies of scale due to bundling of 554 bridges under one agreement and standardized design.

SROI proved to be a useful metric in evaluation of the return on Missouri's investment of ABC techniques on the S&S project. Using the SROI metric as a means to prioritize the use of ABC investment in rural regions is a more appropriate method as it provides a more robust, holistic evaluation accounting for social, economic, and environmental impacts to the stakeholders in rural areas better than simply using AADT as the measure. The research illustrated that prioritizing the use of the ABC techniques on bridges that have the greatest SROI impact enables an agency to use their investment in ways that will bring the most value for money to the project.

The S&S project illustrated that by using multiple methods of ABC in conjunction, more overall benefit to the project could be achieved. Three out of the four methods did not involve concrete, steel, or any physical feature of the bridges. The S&S project benefited greatly from standardized design, bundling of multiple bridges under one-agreement, and the use of contract time incentives to reduce both cost and time of each bridge delivered. By leveraging these alternative concepts of ABC, the S&S project was able to take advantage of logistics, interchangeable components of bridge assembly, and schedule flexibility to optimize crew and equipment efficiency, all of which had a great impact on the cost and schedule savings. The S&S project proved how if applied correctly, ABC can be an effective strategy employed by transportation agencies to reduce the disruption of the road network users thereby increasing the overall value of public investment to the people of Missouri. MoDOT's use of ABC serves as a great example of how state agencies can continue to utilize alternative methods to meet the goals developed by the FHWA to reduce project delivery delays and expedite the movement of people and goods by accelerating project completion through eliminating delays (*19*).

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