Economic Impact Analysis of Accelerated Bridge Construction

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Abstract Traffic disruption due to bridge construction has been reduced to several hours with the development of methods characterized as Accelerated Bridge Construction. Associated risks, and additional work involved with the accelerated construction for a site result in increased initial project cost is assumed to be balanced by reduced risk for traffic within work zone, cost for maintenance of traffic, life cycle cost, construction duration, user cost during construction. This article presents a comprehensive cost model for accelerated bridge construction that incorporates the economic impact on the surrounding communities and businesses considering not only user costs but also, environmental costs and economic activity costs.

1 Introduction

Economic impact of a roadway closure and safety within construction zone are two major parameters considered when evaluating bridge construction methods for a specific site. The roadway closure duration is called the 'Mobility Impact Time'. Accelerated bridge construction (ABC) methods are implemented over conventional construction (CC) techniques to reduce the mobility impact time. ABC procedures are recent, and highway agencies and contractors are gaining experience through implementations and demonstrations. Site complexities, time constraints, and perceived risks increase the project cost of ABC by 6% to 21% over CC [1]. Nonetheless, as shown in Table 1, ABC incorporates immediate benefits of reduced mobility impact time and improved durability of the new bridge [1].

A comprehensive list of benefit parameters for ABC is shown in Table 1. Some of these benefit parameters can be quantified while the others are accounted for qualitatively. As an example, Aktan and Attanayake [1] quantified the economic impact on surrounding communities using a numerical county economic activity multiplier. But the economic impact on surrounding businesses was evaluated qualitatively.

This article presents a comprehensive quantitative model for evaluating economic impact on surrounding communities and businesses. For calculating the economic impact on surrounding communities (i) user cost of passenger car driver and occupants and (ii) environmental costs due to air pollution, water contamination, and climate change are calculated replacing the county multiplier.

Economic impact on surrounding businesses is also quantified by calculating user costs for commercial trucks and economic activity costs due to loss of access to the businesses from road closure.

Table 1. ABC Benefit Parameters

		Benefit Parameter
Quantitative Parameters	1.	Maintenance of traffic (MOT) cost
	2.	Life-cycle cost
	3.	User cost during construction
	4.	Economic impact on surrounding communities
	5.	Risk for traffic within work zone
	6.	Construction duration
Qualitative Parameters	1.	Stakeholder's limitations
	2.	Seasonal limitations
	3.	Site condition complexities
	4.	Environmental protection near and within the site
	5.	Economic impact on surrounding businesses

3. Cost Categories

The primary objective of this article is to quantify the economic impact of road closure on surrounding communities and businesses. After a comprehensive literature review, Fig 1 was developed summarizing the associated cost categories for economic impact analysis. As shown in the figure, user costs and environmental costs contribute to the economic impact on surrounding communities. Similarly, user costs and economic activity costs contribute to the economic impact on surround businesses.

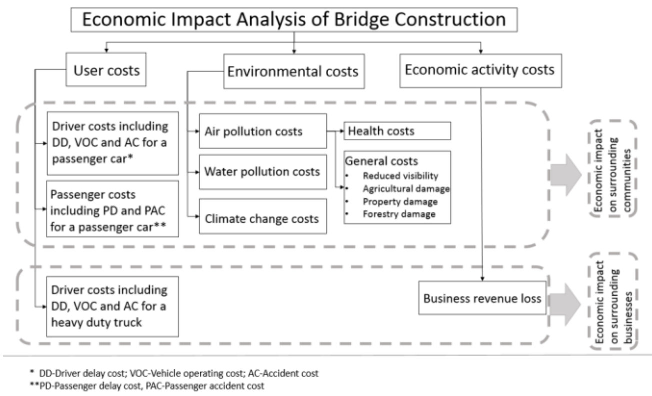

Fig 1. The cost categories for economic impact analysis of bridge construction

3.1 User Costs

User costs represent driver delay cost (DD) (Eqn. 1), vehicle operating cost (VOC) (Eqn. 2), and accident costs (AC) (Eqn. 3) as shown below [1]:

$$DD = \left[\frac{L}{S_a} - \frac{L}{S_n}\right] \cdot ADT \cdot N \cdot w \quad (1)$$

$$VOC = \left[\frac{L}{S_a} - \frac{L}{S_n}\right] \cdot ADT \cdot N \cdot r \quad (2)$$

$$AC = L \cdot ADT \cdot N \cdot (A_a - A_n) \cdot C_a \quad (3)$$

where, 'L' is length of the affected roadway due to bridge construction (i.e., work zone length); 'S_a' is speed limit within the work-zone; 'S_n' is normal speed limit of the roadway; 'ADT' is average daily traffic of the roadway; 'N' is duration of construction in days affecting the work zone; 'w' is weighted-average cost per hour for the passenger car drivers and truck drivers; 'r' is weighted-average vehicle cost per hour for passenger cars; 'A_a' is accident rate per vehicle-mile due to work zone; 'A_n' is normal accident rate; and 'C_a' is cost per accident (includes damage to the driver and the vehicle).

VOC for trucks, is also calculated from Eqn. 2 by replacing 'r' with associated value for trucks and ADT with average daily truck traffic (ADTT).

The user cost also includes passenger costs calculated from average vehicle occupancy (AVO) data which represents the number of people in a passenger car [9]. To detach the passengers, AVO is reduced by one representing the driver. With this, Eqn. 1 and Eqn. 3 are modified, as shown in Eqn. 4 and Eqn. 5, by incorporating the number of passengers to calculate the passenger delay cost (PD) and passenger accident cost (PAC). Since VOC is already considered in driver costs, it is not included in passenger costs calculation.

$$PD = \left[\frac{L}{S_a} - \frac{L}{S_n}\right] \cdot ADT \cdot N \cdot w \cdot (AVO - 1) \quad (4)$$

$$PAC = L \cdot ADT \cdot N \cdot (A_a - A_n) \cdot C_a \cdot (AVO - 1) \quad (5)$$

where, 'C_a' is average medical cost per accident per person (i.e., accident cost without considering cost of damage to the vehicle).

During bridge construction when the road is closed to traffic, a detour route is designated. The user costs from the detour route are described by Eqn. 6, Eqn. 7, and Eqn. 8 for drivers, and Eqn. 9, and Eqn. 10 for passengers.

$$DD = (T_D - T_{Br}) \cdot V_T \cdot T_M \cdot w \quad 6$$

$$VOC = (T_D - T_{Br}) \cdot V_T \cdot T_M \cdot r \quad 7$$

$$AC = (L_D - L_{Br}) \cdot ADT \cdot N \cdot A_n \cdot C_a \quad 8$$

$$PD = (T_D - T_{Br}) \cdot V_T \cdot T_M \cdot w \cdot (AVO - 1) \quad 9$$

$$PAC = (L_D - L_{Br}) \cdot ADT \cdot N \cdot A_n \cdot C_a \cdot (AVO - 1) \quad 10$$

where 'T_D' is time to travel via detour; 'T_{Br}' is time to travel on the bridge for facility carried (FC) user cost or under the bridge for feature intersected (FI) user cost; 'V_T' is volume of traffic on the roadway to be impacted during construction; 'L_D' is the length of detour; 'L_{Br}' is the length of closed section of the road.

3.2 Environmental costs

Air pollution, water pollution, and climate change costs are the three major categories considered for calculating the environmental costs as shown in Fig 1,. Even though a large number of parameters can contribute to air pollution, water pollution, and climate change, only the impact of ADT is considered during this study for environmental cost calculation.

Air pollution cost

Air pollution affects human health and results in many diseases. Hence, the health costs can be calculated by using treatment cost data for various air pollution related disorders.

The pollutants used in the analysis are carbon monoxide (CO); nitrogen dioxide (NO_2); ozone (O_3); and particulate matter (PM), including PM less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$), and PM between 2.5 microns and 10 microns (coarse PM_{10}). Eqn. 11 shows the formulation during construction while traffic is allowed in the work zone, and Eqn. 12 during traffic closure.

$$CP = UC_p \cdot E \cdot ADT \cdot N \cdot L \cdot (SCF_{Br} - SCF_{WZ}) \quad 11$$

$$CP = UC_p \cdot E \cdot ADT \cdot TM \cdot (L_D \cdot SCF_D - L_{Br} \cdot SCF_{Br}) \quad 12$$

where 'CP' is cost due to pollutant; 'UC_p' is unit cost of pollutant, 'E' is emission of the pollutant; 'SCF_{Br}' is the speed correction factor for speed limit before the construction; 'SCF_{WZ}' is the speed correction factor for speed limit during construction; 'SCF_D' is the speed correction factor for speed limit for detour road.

In addition to calculating the direct cost due to pollutant, the impact of pollution on visibility, property damage, agriculture, and forestry can be quantified as general costs. The reduced visibility cost is established by considering the asset value of homes. The agricultural damage cost is established by the crop shortfalls. The property damage cost is established based on discoloration and building facade damage. The forestry damage cost is established by the decline in timber growth due to air pollution [4], [5], [6]. As shown in Table 2, these general costs due to air pollution can be quantified with lower and upper bounds as a percentage of health costs [3].

Table 2. The cost of non-health impacts of motor vehicle air pollution as a percentage of the cost of the health impacts

General costs	Low	High
Reduced visibility cost	10%	19%
Agricultural damage cost	2%	17%
Property damage cost	3%	1%
Forestry damage cost	1%	1%

Water pollution cost

Fuel and chemical spills contaminate the watershed. The impact of contamination is harmful to human health, and can harm or kill wildlife [3]. Eqn. 13 shows the quantification of water pollution cost (WPC) from a bridge construction project. WPC is measured in terms of extra miles that a vehicle has to travel due to a detour.

$$WPC = UC_w \cdot ADT \cdot TM \cdot (L_D - L_{Br}) \quad 13$$

where 'UC_w' is the unit cost of water pollution due to passenger car, and truck.

Climate change cost

Emissions from transportation activities contribute to climate change. The pollutants are called greenhouse gases (GHG) and consist of CO_2, CH_4, N_2O, and CFCs. To express the global warming contributions of different GHG, global warming potential (GWP) concept is developed. It is measured in terms of equivalent unit CO_2 emission.

To quantify climate change cost (CCC), emissions of all GHG due to transportation activities are considered and converted into equivalent CO_2 values.

This is because CCC is calculated using the equivalent amount of total CO_2 emissions (E) and the unit social cost of CO_2 (SC_{CO2}) [7]. Eqn. 14 below shows the formulation to calculate climate change cost:

$$CCC = SC_{CO2} \cdot E \cdot ADT \cdot TM \cdot (L_D - L_{Br}) \qquad 14$$

3.3 Economic Activity Costs

Business revenue loss during the road closure is used to evaluate the economic impact on surrounding businesses. The change in business revenue (ΔR) is calculated using Eqn. **5** as a function of change in number of customers (ΔC); average money spend by household (AMS), and mobility impact time (TM)**.** ΔC is a function of the number of houses without direct access (HWA) during the mobility impact time, percent of households without direct access avoiding the area influenced by the project (P), and the frequency of going to a specific establishment in a given period of time (F).

A map with a road network of the surrounding area will help define HWA. The commercial area influenced by the bridge construction project is established by either utilizing traffic demand models or with a simple evaluation of the road network, depending on the complexity of the road network [8]. The affected area is described as the influence area of a bridge construction project. The area without direct access to the influence area also needs to be established. This is achieved by unifying the mid-point of shortest distances to the closest commercial centers and identifying areas without direct access. The number of households in the area without direct access is calculated manually using city maps. The change in business revenue due to road closure is calculated using Eqn. 15.

$$\Delta R = AMS \cdot \Delta C \cdot TM \qquad 15$$

$$\Delta C = P \cdot HWA \cdot F \qquad 16$$

The change in business revenue is calculated by assuming that households without direct access do not travel to the area influenced by the project (i.e., P = 100%). However, more rational quantification of business revenue loss requires determining site specific P and F. Hence a community survey can be conducted and the following questions or similar ones can be used to collect necessary data to determine site specific P and F:

- If the bridge is closed to traffic for _____ days, would you still travel to the area influenced by the construction and continue your weekend routine (shopping, eating, etc.)?
- If no, what type of business/store (gas station, party store, grocery store, pharmacy, auto repair, etc.) would you still make an effort to go to?

- How often do you go to the following businesses/stores?

Restaurants:____________ per week; Party/liquor Store:___________ per week;
Gas Stations:___________ per month; Pharmacy:__________ per quarter;
Auto Repair:____________ per quarter

6. Case Study- ABC in Potterville, MI

The M-100 over Canadian National railway in Potterville, Michigan, is the 3rd sliding project implemented by the Michigan Department of Transportation (MDOT). The bridge was slid in place during a weekend (November 14-15, 2015) with a mobility impact time of 2 days. The total duration of construction activities at the site was 237 days requiring reduced speed limits. For comparison purposes, conventional construction (CC) which requires mobility impact time of 180 days is considered. The detour length, road segment affected by construction activities, speed limits, ADT, and ADTT are obtained from project data. All monetary values are converted to 2015 values by incorporating relevant inflation rates.

User costs of ABC and CC are calculated from Eqn. 1, Eqn. 2, Eqn. 3, Eqn. 4, Eqn. 5, Eqn. 6, Eqn. 7, Eqn. 8, Eqn. 9, Eqn. 10 and shown in Table 3. The primary databases used for user cost calculations are published by American Transportation Research Institute (ATRI), the National Highway Traffic Safety Administration (NHTSA), the Federal Highway Administration (FHWA), and the U.S. Department of Transportation (USDOT) and accessible from their websites.

The environmental costs of ABC and CC are calculated from Eqn. 11, Eqn. 12, Eqn. 13, Eqn. 14 and shown in Table 4. The average of the values of upper and lower bounds presented in Table 2 is used for reduced visibility, agricultural damage, forestry damage, and property damage cost calculations. The data for the environmental cost calculations are available through the Environmental Protection Agency (EPA), FHWA, and the U.S. Department of Energy (DoE) websites [2], [3].

Table 3. User costs

	ABC-SIBC	CC
Personal travel costs		
Driver	$194,142	$1,238,727
Passenger	$92,145	$586,760
Commercial travel costs		
Driver	$12,907	$63,110

Table 4. Environmental costs

	ABC-SIBC	CC
Air pollution cost		
Health	$3,288	$41,202
Reduced Visibility	$605	$7,582
Agricultural Damage	$526	$6,594
Forestry Damage	$4	$55
Property Damage	$160	$2,005
Water pollution cost	$3	$263
Climate change cost	$269	$24,210

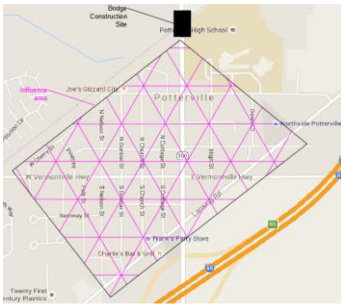

Fig 2.a. The bridge project influence area

Fig 2.b. The area wihout direct acces to Downtown, Potterville

Following the procedure described in section *3.3 Economic Activity Costs*, the influence area is established as shown in Fig 2.a. The number of households without direct access due to bridge project is also established as shown in Fig 2.b. The number of households without direct access to the influence area is extracted from the map as 250.

Other assumptions are: frequency of visits to restaurant and party/liquor store per household is once a week, gas station once a month; and a pharmacy and auto repair shops once every quarter. Another assumption is that households without direct access do not travel to the area of influence (i.e., P =100%). The required data required for AMS is obtained from *GALE Cengage Learning, DemographicsNow* tool. The database requires subscription and is accessed through the Western Michigan University (WMU) Library Services. The business revenue losses due to construction activities are shown in Table 5.

Table 5. Business revenue losses during bridge construction

Business revenue loss	ABC-SIBC	CC
Auto repair shop	$368	$33,125
Liquor Store	$198	$17,802
Restaurant	$1,621	$145,880
Gas Station	$4,878	$439,000
Pharmacy	$715	$64,375

7. Summary and Conclusions

Initial construction cost of ABC is 6% to 21% greater from CC due to site complexity, time constraints, and perceived risks. Accurate accounting for accelerated bridge construction (ABC) benefits and costs over conventional construction (CC) is essential to move the new technologies forward and in making accountable decisions. Economic impact on surrounding communities and business are two major parameters defined as ABC benefits. This article presents a comprehensive model for evaluating economic impact on surrounding communities and businesses due to bridge construction. User costs, environmental costs, and economic activity costs are defined as major parameter for economic impact analysis.

M-100 over Canadian National Railway bridge replacement project is the 3rd slide-in project completed by MDOT. Slide-in bridge construction (SIBC) is one of the ABC methods with the Michigan Department of Transportation has previously completed two bridge replacements. This project is showcased to demonstrate the application of economic impact analysis concepts and procedures. In order to perform a comparative analysis, SIBC is compared to bridge replacement with CC. Table 6 presents analysis results of the economic impact on surrounding communities, and businesses. The results show that the economic impact on surrounding communities with CC is 6.6 times greater than the impact with SIBC. Also, the economic impact on surrounding businesses by CC is almost 37 times greater than the impact by SIBC. The overall economic impact due to CC is 8.6 times greater than SIBC. Several assumptions are incorporated in the calculations due to lack of site specific data. As a future study, site specific data will be collected through a community survey to validate the process presented in this article and improve the accuracy of the analysis.

Table 6. Economic impact on surrounding communities and businesses

	ABC – SIBC (2015$)	**CC (2015$)**
Economic impact on surrounding communities	$291,143	$1,907,298
Economic impact on surrounding businesses	$20,687	$763,292
Total	**$311,830**	**$2,670,690**

Disclaimer

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