Little Ivy Creek Bridge Replacement Using Accelerated Bridge Construction Methods
(Technical Paper)

Estimating Societal Costs of Bridge Repair Options
(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction:

Infrastructure in the United States is in desperate need of repair. In 2017, the American Society of Civil Engineers (ASCE) gave an overall D+ grade to American infrastructure (p. 5). Repairing our infrastructure will cost trillions of dollars and require extraordinary manpower. One critical area of this infrastructure overhaul is bridge diagnosis, repair, rehabilitation, and replacement. According to the ASCE (2017, p. 28), roughly four out of ten bridges in the Unites States are 50 years or older. An additional 15% of bridges are between 40 and 49 years old. With a typical design life of 50 years, over half of bridges are past or quickly approaching the end of their design life. Further, one in eleven bridges in the US was designated structurally deficient in 2016 (American Society of Civil Engineers, 2017, p. 27). These bridges have degraded due to corrosion of steel reinforcement, concrete degradation, lack of maintenance such as protective painting, and simply the passage of time (Rehman, 2016, p. 59). Occasionally, drivers also exceed posted weight limits and force (typically older) bridges to carry loads they were never designed to carry. This can cause extra wear on the structure at best and partial or full collapse at worst. This damage is often hard to detect and most bridges are only inspected once every two years (Chang, 2003, p. 257). Given these dire assessments, it is almost a miracle that bridge collapses are rare occurrences. And because, on average, roughly 188 million trips are taken across structurally deficient bridges every single day, it is a fact that bridge collapses have the capacity to be devastating (American Society of Civil Engineers, 2017, p. 27). Unfortunately, there is currently not enough funding to repair or replace these bridges. If the status quo is maintained, it is only a matter of time before bridge collapses leading to catastrophic loss of life, limb, and property occur.

My group’s capstone project, the technical part of this prospectus, dealt with the mitigation of one such structurally compromised bridge: the Ivy Creek Bridge on Route 250 outside of Charlottesville. The Virginia Department of Transportation (VDOT) decided it needed to be replaced based on bridge inspections. Our job was to determine the best way to replace the existing bridge and then to submit designs for our replacement.

This led us to the question of what the “best” way to replace the bridge actually was. Should we look at only cost? How should we measure societal impacts such as traffic delays and increased emissions caused by them? It also led to the question of whether or not that money and manpower should be expended at Ivy Creek rather than somewhere else. Moving forward, civil engineers will need to create an intelligent and systematic approach to prioritize bridge repair based on need and minimization of societal impacts in light of a scarcity in human and capital resources. Quantifying these societal impacts will be the focus of the sociotechnical section of this prospectus.

Technical Topic – Little Ivy Creek Bridge Replacement Using Accelerated Bridge Construction Methods

My capstone group was tasked with determining the best method to replace the Ivy Creek Bridge on Route 250 outside of Charlottesville and then to supply a design using the chosen method. The existing bridge was built in 1936. VDOT rated it as being in poor condition and had it slated for replacement (Virginia Department of Transportation, 2017). Being so old, it was hard to determine even its dimensions from old drawings, let alone what kinds of loads it had been designed to withstand in its best days. It is a perfect example of our crumbling infrastructure. Had it not been addressed by VDOT, it could have easily led to injury or death despite being a small bridge over a small creek.

Two construction techniques were considered for the project. The first was simply to use conventional bridge construction (CBC) techniques to replace the bridge. Using conventional construction techniques, workers typical remove and replace one lane of a bridge at a time. VDOT estimated that conventional construction techniques would require three months with traffic restricted to one lane at a time using temporary traffic signals. Due to the long time it takes to replace a bridge using conventional construction methods, a technique known as Accelerated Bridge Construction (ABC) has been developed in recent years. This technique uses prefabricated bridge sections that are either shipped from off-site prefabricated concrete facilities or built on-site away from the existing structure as to not hinder traffic. When all of these sections have arrived or all of the on-site concrete has set properly, the original bridge is cut away and removed. Then the prefabricated sections are rolled into place on Self-Propelled Modular Transports (SPMTs) or placed with cranes and attached together. A road surface and all other necessities are then added to the top of the bridge as normal. VDOT estimated that a design based on this ABC technique would require only two weeks, but would cause total bridge closures during that time. This route had an Average Daily Traffic (ADT) of 11,500 vehicles that would now have to take a detour using I-64 if ABC methods were used. It should be noted that, for more critical thoroughfares with higher volumes of traffic, ABC techniques have been used to replace bridges and major bridge sections in as little as 48 to 72 hours (Federal Highway Administration, 2012, p. 1).

ABC methods are more expensive from a material standpoint. They typically require prefabrication and shipment of heavy, awkwardly shaped concrete structures from off-site. They usually require less on-site labor, however, so this increased cost is somewhat offset. Despite this, the true strength of ABC methods is the significantly reduced impact to the travelling public. This reduction of societal cost may well be worth the increased construction costs. The determination of these hard-to-measure externalities will be the subject of the sociotechnical section below.

STS Topic – Estimating Societal Costs of Bridge Repair Options

When attempting to determine the best way to mitigate the structurally deficient bridge over Ivy Creek, we had to define what we meant by the "best" solution. We settled on two options for comparison: conventional construction methods versus Accelerated Bridge Construction methods. We knew that, based on construction costs alone, the best solution would always be to use conventional construction methods as they are cheaper. However, construction costs are far from the only societal costs of bridge construction. While hard to measure concretely, these externalities include time wasted in traffic, extra gasoline consumption in traffic or on detours, and increased pollution and corresponding reduction in air quality.

In order to quantify and monetize one societal cost, time wasted due to construction, of differing construction methods an example methodology follows for our specific problem. VDOT estimated Average Daily Traffic (ADT) of 11,500 vehicles for the bridge and that CBC methods would take roughly three months. CBC methods called for traffic to be reduced to one lane controlled by a temporary traffic light over this period. VDOT estimated that traffic backups in both directions would be roughly 2000 feet. They further estimated that drivers should expect to wait through several three-minute traffic signal cycles to get through this temporary light. Conversely, VDOT estimated that ABC methods would take two weeks and would result in a full shutdown of the bridge over the construction period. A "full detour" from one end of the bridge in construction to the other is approximately 24 miles. A "full detour" would be an uncommon occurrence as there are side roads opened to local traffic to bypass the construction

(Virginia Department of Transportation, 2017). If the object is to reduce delays caused by bridge construction on a daily basis, then CBC is the winner.

If we estimate that the average driver would have to wait through three traffic signal cycles for the CBC option and would have to add 12 miles to their trip for the ABC option, we can get an estimate for the amount of time added to trips over the respective construction periods. For the CBC option, this corresponds to waiting for roughly nine minutes. For the ABC option, travelling at 45 miles per hour, 12 miles corresponds to 16 minutes. Over the lifetime of the respective projects, these correspond to 810 minutes per car for the CBC option and 224 minutes per car for the ABC option. With an ADT of 11,500 cars per day, this corresponds to a total of 9,315,000 minutes for the CBC option and 2,576,000 minutes for the ABC option. These are rough estimates, but the ABC option saves a ton of total time over the CBC option. In fact, with all other assumptions the same, the average detour would have to be more than 43 miles for the two methods to break even timewise. If the goal is to reduce delays caused by bridge construction over the course of the project, ABC is the clear winner.

Using this, we can also get an estimate of the total societal costs due to wasted time of each option. The median personal income in 2019 was $34,248 (Social Security Administration, 2020). This works out to $16.47 per hour. Therefore, the societal costs due to wasted time are $2,556,284 for the CBC option and $706,923 for the ABC option. These are significant sums, not the least of which because the costs of construction were estimated at $3 million (Virginia Department of Transportation, 2017). In the CBC case, the societal costs due to wasted time are eighty-five percent of the construction costs of the bridge. In the ABC case, the societal costs due to wasted time are about a quarter of the construction costs of the bridge.

In our scenario, we only had two options. In reality, there was a third option – to do nothing. Failing to mitigate the structural deficiency of the Ivy Creek Bridge could have led to death, injury, and destruction of property. Despite this, perhaps critical capital and human resources would have been better served on another bridge. Perhaps there was another bridge at greater risk of failure. Perhaps there was a bridge at less risk whose collapse would cause greater harm. Therefore, civil engineers will have to determine ways to quantify risk to prioritize bridge repair properly. Additionally, there are other societal costs to bridge repair besides time spent in traffic. The goal of my STS research project is to determine ways to prioritize, or triage, bridge replacement and ways to quantify the societal costs of different bridge construction methods beyond the “sticker price” of the bridge itself.

Conclusion:

My capstone group turned in our capstone project in April 2020. It included declarations of the problem statement, project scope, existing conditions at the site, and design constraints. It also included a cost-benefit analysis comparing conventional construction methods to Accelerated Bridge Construction methods and explanations for why the later was chosen. The remainder and vast majority of the capstone paper dealt with the actual design of the chosen replacement bridge: the structural design and geotechnical design, a constructability assessment, and a cost estimate. If the capstone project deliverables were successfully completed and appropriately implemented, they would lead to resolution of the bridge quality problem on Ivy Road. In fact, although our design was not actually used by VDOT, we independently arrived at a solution that was extremely similar to the one implemented.

If the systematic approach for determining the societal costs of traffic delays due to bridge construction were applied to every significant aspect of every project, engineers would have a better way to compare alternatives quantitatively. I plan to further explore ways to quantify the societal costs of repairing bridge infrastructure as well as ways of quantifying risk to prioritize those bridges in the most need of repair.

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