

Sustainability Strategies for Highway Construction: A Case Study of ADOT's Piestewa SR51 HOV Widening Project

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Highway construction contractors are starting to adopt measures to address sustainability issues. These measures address environmental aspects but they also result in economic benefits while reducing the social costs that result from highway construction. Conventional highway construction methods offer many opportunities that can be modified to make the construction process more sustainable. This case study documented sustainability strategies employed in the construction of Arizona Department of Transportation's (ADOT) Piestewa State Route 51 (SR51) High Occupancy Vehicle (HOV) widening project. The project employed sustainable strategies that reduced natural resource consumption, construction waste, traffic congestion and transportation necessitated by the project. The case study documents the strategies employed and specific gains that were realized in this project, which were financially, socially and environmentally beneficial.

Key Words: Highway Construction, Sustainability, Waste Reduction, Transportation

Introduction

Sustainable development has been defined by the United Nations as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). When applying this definition of sustainability, it expands beyond environmental issues but also considers economic and social aspects of sustainability. In recent years there has been a trend to incorporate sustainability principles into construction projects. The development of sustainability rating systems is one indicator of the increased focus to address sustainability within the built environment. There are two rating systems that have been developed specifically for highway construction projects. The Green Highways Partnership and GreenRoads Sustainability Performance Metric are both measurement systems that provide guidance specific to building more sustainable transportation projects. The Green Highways Partnership (GHP) was initiated by the US Environmental Protection Agency (EPA) and the Federal Highway Administration (FHWA) to address the need for sustainable infrastructure projects. Similar to the GHP, Greenroads is another rating system available for designing and constructing sustainable infrastructure projects. Greenroads is a collection of sustainability best practices which can be applied to any roadway project, including new, reconstruction and rehabilitation, and bridges. Programs like these have assisted in raising awareness of the importance of incorporating sustainability principles into infrastructure development projects. This awareness has resulted in more projects considering and incorporating sustainability objectives.

Literature Review

Conventional highway construction operations offer many opportunities that can be seized in order to make the construction process more sustainable. These projects have a significant impact on the amount of natural resources utilized, the amount of waste generated and social and environmental impacts due to increased traffic congestion.

Natural Resource Consumption

Highway construction requires large quantities of materials, such as natural aggregates (which include sand, gravel and crushed stone), asphalt, cement and steel. As of 2006, there was approximately 4 million miles of roadway in the US requiring repairs every 2-5 years and replacement every 20-40 years. The 4 million miles of roadway is estimated to include 1.5 billion metric tons (Gt) of natural aggregates, 48 million metric tons (Mt) of concrete, 35 Mt of asphalt and 6 Mt of steel (USGS, 2006). These figures illustrate the large amount of natural resources that are consumed by roadway construction projects.

As infrastructure development continues and maintenance of existing infrastructure is required, the demand for more aggregates will continue to increase. The Federal Highway Administration reports that natural aggregates used for road base and mixed in with concrete and asphalt account for 94% of the material used in highway construction (USGS, 2006). The demand for natural aggregates is expected to grow to 2.6 billion metric tons by the year 2020 (USGS 1997). Since natural aggregates are a finite resource, the availability continues to diminish as we use virgin aggregates. In addition, availability of aggregates where they are needed most, in developing areas, is also decreasing due to increased demand, zoning regulations and alternative land uses restricting mining. Today over 50% of the aggregates produced are in only 10 states (USGS, 2010). As availability of aggregates decreases and the demand remains, the distance to haul the material will increase resulting in higher financial costs and increased environmental impacts.

Waste Production

One way to reduce the demand on the amount of natural aggregates required is to recycle or reuse highway construction materials. Recycled concrete has been identified as a suitable replacement for natural aggregates as base material in highway construction. Ranajendran and Gambatese (2007) found that for every 1% replacement of natural aggregate with recycled aggregate, there was a decrease of 8 tons in the total waste.

Recycling concrete for onsite use limits the amount of waste that is diverted to landfills. Christensen (1994) estimated in Canada that 63% of all construction and demolition waste is generated from road and bridge construction. The study showed the two largest contributors to waste were asphalt, accounting 39% or 5.9 million tons, and concrete, accounting for 23% or 3.6 million tons of waste. A similar study conducted in the US concluded that road and bridge construction and demolition waste were the primary contributor to the 123 million tons of building related waste generated (USEPA, 1998).

Although the popularity of recycling on highway construction projects has increased in recent years, the frequency that it is applied is still limited. In 2009, the amount of material reported to be recycled increased by 45% compared to the previous year (USGS 2010). When recycling material is chosen over disposal, the environmental impacts from mining and manufacturing natural aggregate, hauling of virgin material to the site and transportation for hauling material off site are reduced. This reduces the impact of the End of Life stage of a life cycle assessment, which is reported to be the largest contributor to the environmental impact of highway construction (Ranajendran & Gambatese, 2007).

Transportation

Transportation that results from construction activity has a significant impact on the overall sustainability of highway construction. The transportation sector consumes over 13 million barrels of petroleum each day, of which heavy trucks used in construction account for approximately 380,000 barrels each day (Davis, Diegel, & Boundy, 2010). In 2002, 4.5 million construction trucks traveled 75.9 billion miles. Concrete mixer trucks alone traveled 1.2 billion miles, averaging 15,600 miles per truck annually (US Census Bureau, 2004).

Transport of the concrete to the site and the return of the concrete truck to the plant is one of the largest environmental impacts of highway construction projects. A case study of an onsite batch plant documented the reduction of the environmental impact when compared to hauling concrete from an offsite batch plant. The study documented a saving of 7.9 million lbs of CO^2 over the course of the project that resulted only from the reduced need to transport the concrete (Edwardsen, 2010). Depending on the location, an onsite batch plant can be a strategy to significantly reduce the environmental impact of highway construction.

In spite of the statistics for heavy truck emissions, there is no data available to understand the total impact of construction transportation activity. A research study completed for the American Association of State Highway and Transportation Officials identified three areas needed for further research, of which developing simple methods to analyze the direct impacts of transportation infrastructure construction and maintenance on GHG emissions was a top priority for further research (ICF Consulting, 2006).

Traffic Congestion

Typically highway construction crews must share the roadway with day to day travelers when lane closures are required. These closures cause traffic to slow, frequently to stop and go conditions which result in traffic congestion. Congestion increases the social and environmental costs of highway construction.

Social costs are measured by the cost to travelers, both individual and commercial, that result from roadway use. These costs are measured by lost time due to delays, increased vehicle operation costs, and increased risk for accidents in a construction zone. Kendal et al (2008) found that the highest user costs resulted from lost time to private and commercial users delayed by construction related congestion. It is estimated that the average user costs resulting from construction related congestion is $757.00 per traveler per year (Schrank & Lomax, 2009).

There are several environmental impacts that result from construction related traffic congestion as well. The primary sources of the environmental impact are caused by increase fuel usage and related combustion emissions. The result is increased air pollutants and green house gas emissions (Huang, 2009; Kendall et. al. 2008; Keoleian et. al. 2005). In a life cycle analysis, Keoleian et al (2005) found that the largest contributor to the total energy consumed and green house gas (GHG) emissions were generated from construction traffic congestion when comparing two bridge systems. Kendal et al (2008) estimated that traffic related energy consumption accounts for 85% of the total primary energy costs.

Methodology

A case study methodology was employed for this analysis. The case study evaluated the HOV widening project on Arizona Department of Transportation's Piestewa SR51 freeway in Phoenix, AZ. The contract was awarded to Meadow Valley Contractors Inc. (MVCI) for the amount of 45 million dollars. The project began in 2007 and was completed in early 2009. The project included construction of three concrete girder HOV bridges connecting SR51 to the Loop 101, earthwork and excavation, concrete pavement, asphaltic concrete pavement, rubberized asphalt and retaining walls. The total project spanned the course of 7.3 miles.

The general contractor, MVCI, provided the data used in the analysis. The data utilized included contract documents, change orders, value engineering proposals, construction documents and interviews with onsite construction personnel. Quantity and cost values were extracted from these documents for the calculations presented.

Results

Strategies

Three strategies were implemented in the effort: reduce construction waste, reduce traffic congestion and increase the recycling/reuse of material. The first strategy, waste minimization, evaluated the requirements for removing a portion of the median in order to make room for the HOV lane and focused on excavation. The second strategy, traffic and transportation reduction, utilized a concrete pavement conveyor belt with an onsite batch plant. The third strategy, material recycling/reuse, applied was the reuse of asphaltic concrete to be utilized as an aggregate base course. Each of these strategies helped to reduce the environmental impact, reduce the social costs resulting from construction traffic congestion and ultimately reduce the contract scope of the project to save the state money and make the contractor more profitable. The total savings realized were just under 1 million dollars compared to the as-bid estimated costs.

Strategy 1: Waste Minimization

The State Route 51 (SR51) originally consisted of three northbound and three southbound lanes that were separated by a forty-foot wide center median. The expansion included reducing the size of the median in order to make room for the HOV lane. The plans called for removal of the dirt median which included the aggregate base course (ABC) and asphalt base adjacent to the existing structural roadway section. The plans called for a three foot depth excavation of the existing sub grade. This would have required the excavated sub grade to be hauled off to the landfill. It was originally specified that the sub grade be replaced with borrow from an offsite source. The original contract estimated this to be 89,328 CY of over excavation which would be replaced with 35,738 CY of borrow to be hauled, placed and compacted.

The goal of this strategy was to reduce construction waste by limiting the amount of over excavation and in turn reduce the amount of borrow that would be necessary. This would not only limit the amount of new material necessary but also reduce the transportation impact of hauling off excavated material and transportation of new materials to the site. In a review of the as built plans from the original phases of the highway, the contractor identified that the asphalt base in the median was previously constructed to support the HOV lane. Therefore, there was no need to remove and replace the material since ADOT had already accepted a majority of the sub grade material placed during the previous phase that was slated for removal. This resulted in significant savings for both the contractor and ADOT. The removal of 14,811 s.y. of existing asphaltic concrete pavement was eliminated. One thousand seven hundred and seventy eight cubic yards of roadway excavation was also eliminated. Material savings were also realized by reducing 165 tons of asphaltic binder and 31 tons of mineral admixture. The over excavation quantity was reduced by almost 50%, from 89,328 to 46,816 CY, while the borrow required went from 35,738 CY to only 5,315 CY. Not all of the excavation and borrow was able to be eliminated due to slight changes in the roadway design from the original phases but overall there was a significant reduction in the amount of material needed.

A majority of the cost savings were seen from the reduction in the requirement of over excavation and the need for additional borrow. An estimated savings of $600,827 was gained from eliminating portions of the over excavation and a savings of $450,919 for the reduction in borrow needed. This resulted in a total savings of approximately $1,051,746. There were a few additional costs that the contractor incurred from administrative costs and clearing and grubbing the roadway area which totaled $273,254. Therefore, the waste minimization strategy resulted in $778,492 cost savings for the project.

Strategy 2: Traffic and Transportation Reduction

As part of the HOV expansion, the contractor sub contracted the placement of the portland cement concrete pavement (PCCP). The original scope included getting the concrete from an off-site batch plant. This would have necessitated concrete mixer trucks to continuously travel to and from the batch plant to the site.

In addition to the transportation required for each truck, an offsite batch plant requires daily lane closures in order for trucks to safely enter and exit the median. The lane closures remain in place until the placement of the PCCP is complete, an estimated 48 days. In addition, the lane closures also increase the risk of accidents; therefore increasing the liability of the project.

The sub contractor proposed utilizing an onsite batch plant with a conveyor system, therefore eliminating the need for the mixer trucks and lane closures. The proposed batch plant was adjacent to the outside of the highway and a bridge conveyance system was used to transport the concrete to a hopper system located in the median. Five 10-wheel trucks operated in the median within the construction area and away from live traffic to place the concrete.

Overall implementation of the conveyance system was more costly for the sub contractor. In order to compensate for the lost profit, the contractor created a Lane Rental Fund. This was calculated to be $2,675 per day therefore the contractor recovered $143,292 for the 48 days required for paving and concrete production. Ultimately, the Lane Rental Fund was not lucrative for the contractor but did cover the lost profit from labor associated with setting up and removing the traffic control devises. Additional benefits for the contractor were reduction in exposure from missing the schedule and liability from accident risk of lane closures.

Following the implementation of the conveyor system on this project, ADOT immediately adopted the same system in five other state projects for the specific purpose of reducing traffic congestion, eliminating closures and reducing the necessary trucks by 75%.

Strategy 3: Material Recycling/Reuse

There were three concrete girder bridges that spanned the traffic interchange between the SR51 and the Loop 101 to be constructed as a part of the project. This required a six and one-half inch asphalt paving section for a temporary traffic detour on the Loop 101. It was originally estimated that 4,685 tons of asphaltic concrete pavement would be used to construct the detour section. Once construction of the bridge was complete and the need for the detour eliminated, the temporary detour was to be removed.

Removal would have necessitated the material, asphalt and aggregate base course, to be hauled off and disposed of in the land fill. After completion of a cost analysis, the contractor proposed to mill and screen the asphaltic concrete for aggregate base course to be used on the final Loop 101 sections. After milling and screening, there was 4,865 CY of asphaltic concrete and 4,855 CY of ABC available for the new section of roadway. Roughly 35% of the milled asphalt was waste and did not meet requirements; therefore, this was used for fill in lieu of borrow. The new section required approximately 2,213 CY of the milled aggregate base course and the remaining base course was used for a section of the mainline SR51. This material was originally scheduled to utilize 13 belly dumps per day for two weeks. By limiting the portion of the ABS that needed to be hauled on site the contractor saved approximately $47,500. In addition, they also saved the cost to purchase $60,800 of new ABC. This resulted in a total savings of $108,300 from the material recycling/reuse strategy.

Conclusions

There is much debate as to whether it is economically feasible to incorporate sustainability into construction projects. This case study demonstrates that sustainability cannot only have positive environmental impact but also have significant economic benefits and social impacts.

Upon review of the as-built plans, the contractor was able to reduce the required over excavation by 50% and the need for replacement borrow was reduced by 30,000 CY Significant environmental benefits were realized from reduced transportation necessitated from removing the excavated material and to deliver new material to the site. This also reduced the need for virgin materials required for the project and therefore reduced the consumption of natural resources and the environmental effects for extracting that material. The amount of construction debris generated was also reduced and therefore was diverted from the landfill. The economic benefits for the project were shared between the contractor and ADOT. The financial savings realized by incorporating this strategy was $778,000. This demonstrates the need for proper review of as built plans to ensure that work that is not necessary is not included in the project scope.

The application of the onsite batch plant and incorporation of the conveyance system resulted in both environmental and social benefits. The onsite batch plant allowed for concrete to be mixed onsite and eliminated the need for concrete trucks to travel back and forth to the batch plant; therefore, eliminating the environmental impacts that would have resulted from the concrete trucks. The introduction of the conveyance system eliminated the need for lane closures. Lane closures have a significant impact on the environmental impact of the project that results from traffic congestion but there are also social benefits that are gained. These benefits primarily include the time required for travelers to sit in traffic. Although there was almost no economic benefit, this strategy did help to reduce the potential for future costs that could have resulted from schedule delay or the safety liability of the lane closures. Contractors often rely on traditional methods to deliver highway projects. This strategy demonstrates the benefits that can be gained by incorporating innovative construction practices on site.

Construction of a temporary detour was required for the project. Once there was no need for the detour, the contractor was able to recycle and reuse the material in other areas of the project. There was additional environmental impact and costs for the onsite milling of the material but these impacts were compensated for with the reduced transportation necessary for hauling off the material and transportation to the site for the new material. This decreases the need for virgin material decreasing the natural resource consumption and the environmental impact that results. Also the environmental impact was decreased by diverting construction debris from the landfill. The cost of the new material was also saved. Adoption of this strategy resulted in over $100,000 savings that were split equally between the contractor and ADOT. This shows that even though there are costs associated with onsite recycling material, it is financially feasible and environmental beneficial.

As highway contractors start to consider incorporating sustainability initiatives in their projects it is important to document the benefits that can be realized by the adoption of such strategies. This case study demonstrates that sustainability initiatives can be economically feasible, as well as environmentally and socially beneficial.

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