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Improving Sustainability of Work-zones by Implementing Lean Construction Techniques

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Abstract: *Pavement construction, maintenance and rehabilitation have considerable impacts on environment, society, and economy. These impacts can be minimized by implementing lean construction strategies that focus on reducing wastes and improving performance, as well as increasing the overall value of the facility to the end users. The objective of this study is to identify the adverse effects of work-zones activities for pavement projects, and demonstrate how lean construction techniques can provide sustainable solutions. For example, 5S's can help reducing the waste which is a cause of environmental degradation. The last planner technique can be used to prevent schedule delays and to accelerate the construction process, and assist in reducing the excess emissions due to unstable traffic around the work-zones and from heavy equipment. It can also minimize vehicle operating costs due to congestion and improve the mobility of work-zone. Increased visualization approaches such as speed advisories, delay advisories; regulatory speed limit changes merge control and alternate route guidance, can further enhance safety and mobility. Other impacts such as noise pollution; and reduced accessibility to businesses and emergency facilities can be minimized using phased scheduling which allows the selection of construction time and duration suitable for the surrounding community.*

Keywords: *lean construction, sustainability, work-zone, pavement maintenance*

1. Introduction

The 2013 Report Card for America's Infrastructure published by ASCE indicates that US road network includes more than 4 million miles of public roadways, and 32% of these major roads are in poor or mediocre condition. According to the US Department of Transportation, traffic volumes and congestion are increasing on national roads, but there is very small growth in road miles. Furthermore, highways are approaching middle age, requiring more construction and repair, which results in more work-zones.

Work-zones have considerable impacts on environment, society and economy. Pavement construction, maintenance, and rehabilitation activities have adverse impacts on the environment through generating construction wastes, emissions caused by construction equipment, increased emissions from traffic congestions and excess noise (Mallela and Sadavisam 2011). Some of the economic impacts caused by work-zones include travel delay cost; vehicle operating cost; crash cost; as well as impacts on local businesses. Work-zones also have significant social impacts on adjacent routes and transportation networks, as well as; public and private properties in the vicinity. A sustainable work-zone should satisfy the triple bottom line of sustainability. Lean construction techniques can help in eliminating non value-adding works. (Salem et al. 2005)

Lean principles are applied to the construction process in order to minimize waste, increase the value of service, and to improve performance. Implementing lean techniques on construction projects can also optimize the schedule, budget, and improve safety (Salem et al. 2006). However, implementing lean construction techniques on highways and road are very different from lean application in building sites. For example, the main priority of work-zone workers is to cause minimal disruption to traveling public, and the working space is allowed by traffic management instead of contractors to minimize the disruption.

Therefore, it is important to adapt lean techniques in a proper way to utilize their full potential in road construction. (Ansell et al. 2007)

The objective of this study is to identify the impacts of pavement construction, maintenance and rehabilitation activities, and demonstrate how implementation of lean construction techniques in work-zones, can benefit the triple bottom lines of sustainability. This paper explains the impacts of work-zone activities on the environment, economy and community, and discusses suitable lean construction techniques that can help in reducing the negative impacts of these activities.

2. Literature Review

Lean construction is the implementation of Toyota motor company lean production principles to construction process. Although construction and manufacturing are significantly different in their features and products, Koskela (1992), introduced the idea of applying lean manufacturing techniques to construction industry (Bertelsen 2004). Huovila and Koskela (1998) recommended considering the challenges of sustainable development in life cycle process of buildings. The benefits of lean on sustainable development include minimizing wastes; reducing resource depletion and pollution, adding value to the customer, and achieving business and environmental excellence. Lean construction offers the conceptual basis and potential for sustainable construction (Huovila and Koskela 1998).

2.1 Lean Techniques

The 5S process has five steps that can help in eliminating wastes and reducing process inefficiencies in a workplace. The 5 S's of lean are sort, straighten, sweep, standardize, and sustain.

The last planner system was developed by Glenn Ballard and Greg Howell in 1980s to improve the predictability and reliability of construction production (Mossman 2010). According to Ballard (2000), the last planner system is a technique that manages the construction flows and addresses project variability. Last planner replaces optimistic planning with realistic planning by evaluating the performance of workers based on their ability and reliability to achieve their commitments (Ballard 2000). Some of the last planner techniques that help minimizing impacts and improving sustainability are Master Schedule, Reverse Phase Scheduling (RPS), and Six Week Lookahead (SWLA), Weekly Work Plan (WWP), and Percent Plan Complete (PPC).

Increased visualization technique can be implemented on projects by posting signs and labels such as project milestone, safety, quality, and schedule signs around the construction site, can help in creating awareness of action plans on a job site. (Salem et al. 2005)

First run studies and using a "Plan, Do, Check, Act" cycle can help with the continuous improvement of the project. Brief daily meetings for team members to provide status updates of their work can also assist in increasing employee involvement and satisfaction (Salem et al. 2005).

2.2 Implementation of Lean in Construction

This section summarizes some of the research studies on the benefits of implementing lean techniques in construction projects. Salem, et al. (2006) compared lean construction techniques with lean manufacturing techniques using a parking garage project in Ohio over a period of six months as a case study. After using lean techniques such as the last planner, increased visualization, huddle meetings, first run studies, and five S's the project was under budget and three weeks ahead of schedule, the average PPC value increased 20 points, subcontractors were more satisfied, and incident rates were below that of similar non-lean projects completed by the same company (Salem et al. 2006).

Peng and Sui (2012) discussed how to improve sustainability in precast concrete factories by utilizing lean principles. The paper stated that many lean techniques have been applied on precast concrete production which addresses specific problems rather than the fundamental problems. The results showed that implementing lean techniques in precast concrete factories can improve the value chain and reduce carbon emissions (Peng and Sui Pheng 2011). Patel (2012) discussed implementing the last planner system on a commercial construction project. The study presented significant improvement in PPC ratios after implementing LPS without which there might have been longer schedule delays (Patel 2012). Ballard (2000) discussed a case study on a $2.1 billion refinery expansion for a national oil company. Because of the poor productivity, contractors wanted to increase the workforce which was not a viable solution. Thus the LPS was used which included six week lookahead schedules, screening processes for creating workable assignments, sizing assignments to crew capacity, and charting and acting on reasons for not doing planned work. This resulted in 30% to 90% improvements in PPC of different subcontractors, more than1% increase in annual productivity factor, and 50% to 700% improvement in first run studies (Ballard 2000).

Introducing lean process to highway and pavement construction engineering is challenging since most of the previous lean construction studies came from building industry and there are few examples to show the applicability of lean techniques in pavement construction industry (Ansell et al. 2007). Ansell et al. (2007) discussed the differences between lean application in building sites and highway construction and showed the importance of how to adapt lean techniques to achieve full potential in a highway project. The team framed a lean program to reduce the duration of each activity by performing constraints analysis, delay analysis, and buffer analysis on a highway renewal project and bridge repair projects which required structural strengthening of bridge piers (Ansell et al. 2007).

Ahuja (2013) studied lean methods that help improve sustainable impacts. According to this paper three key impacts of lean construction methods can help achieving sustainability. Economic values can be achieved by reducing cost, saving resources, minimizing operation cost, and maximizing the productivity. Social values can be achieved by making the workplace safe, being loyal among team members and stakeholders, and by keeping in mind the community welfare and happiness. Environmental values can be achieved by minimizing the resource depletion, saving the resources, removal of waste, and preventing pollution. Lean techniques used in this research are the use of the integrated product teams, set based design, design build operate maintain integrated design, design for maintainability, value stream mapping, and 5Ss (Ahuja 2013).

3. Application of Lean on Work-Zones

Pavement construction and rehabilitation have considerable impacts on environment, society, and economy, such as emissions, waste, travel delay cost, vehicle operation cost, and impacts on nearby businesses and residences. Although evaluating the triple bottom lines of sustainability in pavement construction is of great importance, not enough studies have been done in this area. Federal Highway Administration (FHWA) indicates that several agencies have adopted strategies that minimize the impacts of work-zones during construction and maintenance and operation activities. Lean techniques can be implemented on different construction projects to help increasing the system’s value while minimizing environmental, economic, and social impacts caused by construction process (Mallela and Sadavisam 2011).

3.1 Environmental Impacts

Environmental impacts caused by work-zones are mostly due to emissions from construction equipment, emission due to unstable traffic, construction dust, work-zone waste, and noise pollution. State and local transportation agencies are motivated to investigate strategies to reduce air pollution caused by work-zones. In urban areas, traffic emissions around work-zones increases due to frequent acceleration and deceleration, reduced speed and queuing. Unstable traffic caused by work-zones can be avoided to some extent by implementing proper work-zone management techniques. Using the last planner and scheduling the construction process accurately accelerates the process of construction and reducing the emissions caused by work-zone. In addition, having a master schedule and weekly work plan helps scheduling the closures during off peak and night time, and times that causes less disruption in traffic.

Another environmental impact caused by highway construction and maintenance is wastes produced in work-zones which can be eliminated by implementing the 5S process. Keeping the work-zone neat and organized during the whole construction phase, will help minimizing the waste and pollution produced in the work-zones. Wastes can be reduced by optimization of construction processes, just in time delivery of material, avoiding double handling and unnecessary movement of equipment, and minimizing defects in construction material (Gao and Low 2014).

FHWA proposes techniques for controlling dust nuisance. Dust screens should be kept until the construction of permanent ground cover. FHWA recommends uniform application of water using pressure-type tank truck equipped with spray system, pipe, hose, or spray apparatus. Dust should be monitored until at least 60 days after final project acceptance (FHWA 2005).

Excessive noise is very common in work-zone construction projects, but the impacts can be minimized by utilizing management techniques. The last planner techniques allow scheduling the best work hours depending on the area of the work-zone. In residential areas, noise emitting construction processes can be minimized during afterhours at night. In business areas, which are usually more populated during the daytime, noise should be prevented during the work hours. In addition, FHWA recommends different noise control techniques such as using modern equipment with better engine insulation, moving equipment farther away from the receiver, enclosing noisy activities and stationary equipment, erecting noise barriers, or using landscaping as a shield (Sankar et al. 2006).

3.2 Social Impacts

Social impacts of work-zones include accidents, impacts on adjacent transportation network, public properties and private properties. Work-zones affect the transportation system at both the corridor and network levels including parallel corridors, and alternate routes. They also have impacts on nearby transportation infrastructure such as key intersections and interchanges, railroad crossings, public transit junctions, and other junctions in the transportation network. Work-zones affect public properties including parks, recreational facilities, fire stations, police stations, and hospitals, as well as private properties including businesses and residences (Mallela and Sadavisam 2011).

Work-zones are hazardous for both construction workers and motorists who drive through the work-zones with unorganized barrels and equipment and various complex signs around them. Increasing visualization is a lean technique that can help improving safety. Using signs indicating work-zone speed limits, and using detour signs in proper distances from work-zone can result in less accidents and safer work-zones. These signs should be visible for everyone and updated regularly (Gao and Low 2014). Furthermore, injuries caused by motor vehicles outside the work-zone and construction equipment within the work-zone can be avoided by increasing the visibility of workers and vehicles with high visibility apparel, paying attention to blind spots, and proper lighting (Hinze and Teizer 2011).

The 5S process can help increasing safety and minimizing incidents in work-zones, by sorting, keeping tools and equipment organized and in order regularly. In addition, having brief daily meetings for construction team members and employees helps discussing and resolving work place problems and increases their awareness to create and maintain a safer workplace.

Temporary traffic control strategies can be used to facilitate the traffic flow near work-zones. Phase scheduling helps having a detailed schedule for each phase of the project, and reverse scheduling helps to find the best way to meet the milestones stated in master schedule. Knowing the exact start and finish time of each phase of the project makes it easier to plan the construction process to decrease the social impacts as much as possible. The Washington state department of transportation requires maintenance crews to use work hour charts. These charts are used to determine the most suitable time to perform construction or maintenance activities on a corridor to minimize the impact on traffic (Sankar et al. 2006).

FHWA suggests various strategies for minimizing work-zone impacts on transportation network such as sequencing and phasing different aspects of project, reducing lane or shoulder width to maintain number of lanes, and using two-way traffic on one lane. (Sankar et al. 2006).

Implementing the transparency techniques and increasing visualization also helps reducing the impacts on nearby transportation network and properties. For example using detour signs, temporary pavement markings, changeable message signs, and informing people about future detours in each phase of the construction can make their transportation through work-zones easier. However, these signals should be kept organized and fixed so that they don't cause any disruption in traffic and construction work. FHWA indicates public awareness strategies such as signs, brochures, mails, websites, paid advertisements, and other public information systems can also help minimizing work-zone impacts (Sankar et al. 2006). Some other strategies suggested by FHWA to minimize the impacts on nearby transportation infrastructures include improvement of streets and intersections by roadway and shoulder widening and additional through and turn lanes. Construction of bus stop areas that are recessed from travel lanes, restriction and elimination of parking in work-zones, truck and heavy vehicle restrictions and separate truck lanes can reduce congestions. Controlling railroad crossings located in work-zones by signs, pavement markings, flashing lights, gate arms, flaggers or police officers can improve safety besides minimizing traffic impacts (Sankar et al. 2006).

Work-zones have negative impacts on businesses, recreational facilities, hospitals, police centers, fire stations and other public and private properties. These impacts include customer access, delivery access, and parking issues. To minimize the work-zone effects, all the relevant stakeholders should be involved early in the process. Proper estimation of construction duration of each phase is necessary for providing accurate information to daily commuters about the work-zones near specific businesses which will allow them to plan accordingly in advance. In addition, to improve the accessibility to these businesses during the construction, signs and information to direct people to those businesses or their relocation of access can be used. Arizona uses an information program to send weekly newsletters to the media, businesses, and local residents. The newsletters provide information on project status, lane restrictions, ramp closures, detours, access to area businesses, and other work-zone restrictions (FHWA 2005).

3.3 Economic Impacts

Economic impacts of work-zones are crash cost, travel delay costs, and vehicle operation cost. Highway work-zones are hazardous roadway environment for drivers and workers. To reduce the fatalities, injuries, and crash cost different strategies can be utilized. Crashes can be reduced by increasing visualization such as using signs related to speed limits and detours in proper distance from work-zone. FHWA suggests keeping the work-zone clean and in order, and arranging tools and equipment will result in significant cost reduction.

Delay time is the additional time necessary to reduce the speed from upstream speed to the work-zone speed, as well as, the additional time needed to pass the work-zone in lower posted speed. Detours cause delay time due to the extra distance of the detour route. Vehicle operating cost increases due to speed change, stopping, queue idling and detours. These costs include fuel consumption, engine oil consumption, tire-wear, repair and maintenance, and mileage-related depreciation costs (Mallela and Sadavisam 2011). FHWA indicates if there are multiple rehabilitation tasks that can be done on one area, those should be scheduled in one work-zone instead of multiple construction periods which will result in a considerable budget saving. In addition, improving maintenance and construction practices to reduce number and duration of work-zones will help reducing travel delay and vehicle operation costs.

First run studies and using a "Plan, Do, Check, Act" cycle can help with the continuous improvement of the project. By studying and analyzing all the impacts in each phase of the project, we can eliminate them in the next step and improve the three bottom lines of sustainability in the project.

4. ITS and Innovative Technologies

Various intelligent transportation systems (ITS) and innovative technologies have been employed by different state departments of transportations. These practices can be used extensively in work-zones to decrease the impacts of work-zones on workers and road users (FHWA, 2013).

Queue length detector informs supervisor and workers when traffic has stopped or slowed. If the problem can be resolved on site, they can take action to increase the flow. Variable message signs, highway advisory radio, closed circuit TV, and smiley-face signs are some other portable ITS technologies that increase safety and help traffic move smoothly. Mobile surveillance technology can transmit traffic data and images from locations without surveillance infrastructure to traffic management center. 200 MHz radios can be used for data transmission up to the distance of 8-10 miles. These radios have been used in University of Cincinnati to develop travel time prediction rating systems. Another intelligent technology used in Indiana is the Indiana lane merge. In this system, depending on the capacity, different signs are automatically activated in work-zone upstream. The advanced traveler information system or Indiana expert system is used in work-zones to provide information to travelers. This system can be programmed to send messages from an incident or other information to travelers using highway advisory radio, variable message signs, and pagers at the same time. Real time traffic information system can also minimize travel delay and accidents caused by work-zones. These systems provide information of current traffic conditions to keep drivers informed of delay time or distance, the need to be cautious, or take different routes. Another innovative technology that can be used in highway construction projects is remotely operated auto flagger with stop/slow sign. This auto flagger can be used in low speed, low volume, 2-lane highways instead of human flagger to increase safety and mobility (FHWA, 2013).

5. Life Cycle Assessment

Life cycle assessment is a cradle-to-grave approach for assessing industrial systems. The term "life cycle" refers to activities done in life span of a process, including its manufacture, use, maintenance, and finally its disposal. LCA studies the total potential environmental impacts of all stages in the product's life cycle, and can help in selecting the process with the least impact to the environment (Hendrickson et al. 2006). Maintenance, repair and rehabilitation phase of pavement life cycle have considerable environmental impacts. It is important to consider routine maintenance procedures, such as crack sealing or other small activities. However, predicting the type and order of maintenance activities that happen during the life cycle of the pavement is a challenging task. In the end of the life phase, environmental impacts depend on the ultimate outcome of the pavement, whether it could be landfilled, recycled, or simply remain in place and serve as part of the underlying structure for another pavement layer. Recycling and reusing the material in work-zones minimizes waste.

In addition, to minimize environmental impacts of pavement maintenance, repair, and reconstruction, accelerated construction techniques can be employed. Some of these accelerated techniques are: precast concrete pavement systems, portland cement concrete pavement with admixture, rapid setting concrete, roller compacted concrete, ultra-thin white topping, warm mix asphalt, and foamed warm mix asphalt (Hendrickson et al. 2006).

6. The Limitations of Adopting Lean

Lean techniques have not been applied on construction projects widely due to several limitations; the nature of construction industry being a major cause. Many agencies are trying to change construction processes in order to use lean techniques, while, lean should be more project-oriented and cope with changes in the life cycle of the project (Demir et al. 2012). In addition, application of lean techniques in public sector has some barriers. Certain regulations in different states make it difficult for government agencies to implement lean practices in their projects. Initial implementation of lean by construction companies can be time consuming. Besides, lack of communications between project stakeholders may be a major hurdle for application of lean (Dettman et al. 2014). Salem et al. 2006 mentions that there is a lack of investment in research on lean construction techniques in the United States. Construction companies need to take more interest in research and development, and should train more staff to use lean techniques (Salem et al. 2006).

7. Conclusion

This paper reviews different lean construction tools that can be implemented to reduce environmental, social, and economic impacts of work-zones. The last planner techniques help reducing waste and emissions by accelerating the work process. The 5S techniques can reduce waste and minimize costs. Another technique to minimize waste and environmental impacts of work-zone is applying life cycle assessment in design and construction process. Increasing visualization can help to improve safety and reduce crash costs. It also minimizes the impacts on public and private properties considerably. Using intelligent transportation systems and innovative technologies in work-zones increases safety and mobility. Lean techniques have not been used considerably on road construction and maintenance projects. In order to increase the use of lean construction in work-zones and minimize the impacts of construction and maintenance processes, companies need to invest more on research and development, and train the workers and employers to use lean techniques effectively.

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