# APPLYING LEAN TECHNIQUES IN DELIVERY OF TRANSPORTATION INFRASTRUCTURE PROJECTS

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## ABSTRACT

The use of Lean techniques for the delivery of large complex capital projects is quickly growing throughout the country. Lean techniques allow for project delivery in less time, at lower costs, and with improved quality. However, Lean techniques are currently not being used by State Highway Agencies (SHA). Lean project delivery can be the new way for future projects to achieve these higher quality, quicker, and more efficient projects. To attain this, the transportation industry, as a whole, needs to work closely together using non-traditional approaches to achieve the necessary improvement.

To reach this goal, this project looks at the benefits of Lean techniques in the delivery of transportation projects, along with potential impediments to adoption. The transportation industry provides a unique challenge in implementing Lean techniques by being in the public sector. Due to this fact, special care is needed in identifying any impediments to implementation when going forth with Lean. Once promising techniques and impediments are properly identified, a successful management plan can be created to help SHA's begin their Lean journey.

## KEY WORDS

Lean Construction, Lean techniques, Transportation, Project delivery

## INTRODUCTION

Lean techniques describe a set of non-traditional project delivery approaches to managing the multitude of collaborative relationships that exist on a project. Companies and projects that utilize lean techniques are better able to integrate management components. As a result, they are able to deliver high-quality products in less time and at lower costs.

Lean techniques first emerged in manufacturing, where Toyota developed a revolutionary set of techniques to minimize waste during automotive production (Liker, 2004). These Lean techniques streamlined the manufacturing process and proved to be effective at production management. Today, Lean techniques are

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successfully used in industries throughout the world. Lean techniques are being adopted by the construction industry and are currently used in general construction and other non-transportation projects throughout the United States.

"Lean techniques" is a broad term that encompasses a variety of tools, strategies and technologies. Taken as a whole, Lean techniques provide continuous assistance and support at all stages of the project. During the design and development process, Lean techniques result in an increased quality of design through constructability and design reviews. During construction, Lean techniques enhance collaboration between project parties and foster a culture of continuous improvement. Projects that utilize Lean techniques can be completed in less time and with fewer costs than typically required.

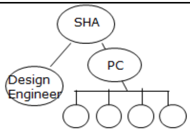
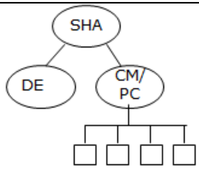
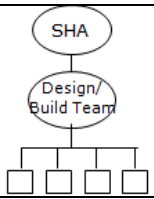
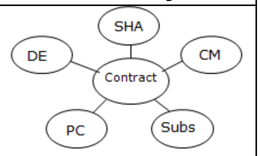
Lean techniques improve work flow and productivity by systematically identifying and minimizing waste. Waste is defined here as activities that do not add value to the project. When implemented, Lean techniques can produce the following results:

- The facility and its construction processes are designed together to better achieve customer needs.
- Construction activities are structured to remove obstacles so that work is ready to be done when it needs to be done.
- Waste is reduced because work flow is more predictable and productivity improves.
- Management efforts are aimed at improving total construction project performance rather than focusing on the speed of any one activity.
- Project control focuses on "making things happen" rather than "monitoring results".
- The project team's owners, designers, contractors and suppliers are linked together with common goals and a planning system.

Transportation agencies have implemented different project delivery systems to achieve some of these same goals. Traditionally, State Highway Agencies (SHA) use the design-bid-build (DBB) project delivery method to complete transportation infrastructure projects. DBB requires that the owner first contract with a design entity for complete design documents. Once the design is complete, the owner then solicits bids from contractors to perform the work. The owner then selects a contractor based on their bid. Other commonly used delivery methods include Construction Manager at Risk (CM at Risk) and Design-Build (DB) (Konchar and Sanvido, 1999)

Lean techniques foster a fundamentally different approach to project delivery. Lean project delivery involves using Lean techniques to increase levels of integration and cooperation on construction projects while improving quality, shortening project duration and reducing costs. Table 1 shows a comparison between the traditional project delivery methods used in transportation projects and lean project delivery.

Table 1: Project Delivery Systems (DE = Design Engineer, SHA = State Highway Agency, PC = Prime Contractor, CM = Construction Manager) (Format from Boldt, 2009)

| | **Design-Bid-Build** | **CM at Risk** | **Design-Build** | **Lean Project Delivery** |
|---|---|---|---|---|
| **Management Structure** |   |   |   |   |
| **Contract** | SHA has separate contracts with DE and PC. PC selects subcontractors | SHA has separate contract with DE and CM/PC. CM/PC then contracts with subcontractors. | SHA contracts with Design/Build Team, who then designs and constructs the facility. | SHA, DE, CM, PC and key trades partners are party to single contract; additional construction and design partners join the team through Joining Agreements to the Contract |
| **Construction Contracts Held By:** | Owner | CM At Risk | Design-Builder | Core group of integrated team |
| **Change Orders:** | Increased risk due to the bid environment using the lowest acceptable bid | Reduced because of increased total team collaboration during design phase | Risk is directly related to timing of costs being locked in | Should be kept to a minimum because of high degree of total team collaboration during design phase. |
| **Collaboration** | Limited because design is complete before selection of PC | Early selection of CM provides for improved collaboration | Collaboration with the DB team is maximized, but SHA has less involvement | Maximum collaboration because of contract structure; co-location of entire team is possible. |
| **Project Schedule** | Linear project schedule without any overlap of project phases | Fast-track Schedule with emphasis on up-front planning to accelerate groundbreaking and completion | Fast-track Schedule with emphasis on up-front planning to accelerate groundbreaking and completion | Similar to Design-Build, but the project team has greater control over the schedule |

Lean project delivery results in all parties being subject to a single contract where risk is shared and collaboration is required. Future transportation infrastructure projects will need to look to the lean approach to ensure greater quality, lower costs and quicker time to market.

### LEAN TECHNIQUES IN THE TRANSPORTATION INDUSTRY

Construction of new infrastructure projects is a major cause of traffic bottlenecks. It is critical that the addition of new infrastructure or the repair/replacement of existing projects be completed as quickly as possible. Projects must be long-lasting and completed with minimal disruption to the community. According to their current mantra, SHAs must "get in, get out, and stay out".

Lean techniques are a way for future projects to achieve these goals. Rapid or accelerated projects typically involve complex logistical requirements, unique designs and difficult construction conditions in which Lean techniques are ideal.

Using Lean techniques, future projects can be completed faster, more efficiently and with higher quality. The transportation industry, SHAs, contractors and consulting engineers must work together using non-traditional approaches, such as Lean techniques, to produce the necessary improvements in transportation infrastructure.

## CHALLENGES OF LEAN CONSTRUCTION IN PUBLIC SETTING

The benefits of Lean techniques are well-documented in many industries, ranging from manufacturing to construction. However, public transportation projects present particular challenges to the implementation of lean techniques. Listed below are the most common barriers to implementing an Integrated Lean Project Delivery (ILPD) that an owner may face.

### LEGAL ISSUES

For public construction contracts, there are often restrictive laws governing the selection of contractors. In particular, low-bid competitive bidding is often mandated or strongly suggested. This creates a challenge when implementing a Lean project delivery system. Lean relies on the careful selection of contractors and subcontractors, which conflicts with several of the characteristics of a competitive bidding process. With Lean, contractors are selected early in the project cycle, allowing for strong collaboration between project parties from the design stage onward. This is at odds with traditional bid award processes that require that the design be completed for bidders to evaluate. Furthermore, a Lean project delivery system selects the "best" contractor for the project, while competitive bidding selects contractors according to the lowest bid.

The relevant laws vary from state to state; however, there is often a plethora of laws governing the selection of contractors, subcontractors and design professions. These legal issues must be investigated and adequately resolved before an effective Lean project delivery system may be implemented.

### FEAR OF CHANGE

Since the start of the modern construction era, the main delivery system has been design-bid-build. Until the last few decades, it was essentially the only delivery system (Federal Highway Administration, 2006). The working and management philosophies of SHAs were designed to complete projects using the DBB delivery system.

Leadership and training is needed to overcome the fear of change. In a survey response concerning innovative delivery systems, the Minnesota Department of Transportation wrote:

> "*With any organization, culture changes need to occur with any shifts in delivery or modifications in a system. With an organization as large as a DOT, perceptions of change are going to vary greatly (i.e. some people are willing to accept new ideas, others are not). With any change, champions are needed to implement new technology and practices."*(Hanna et al, 2008)

Detailed training on the system of Lean project delivery is an effective way to familiarize staff with the new delivery method processes.

### LACK OF RESOURCES

In most cases, an organization will initially lack some of the resources to successfully implement a new delivery system. Resources may include budget, knowledge and experience.

Knowledge and experience is gained over time, as Lean techniques are applied to more projects. Formal training and communication with others who have implemented Lean techniques can help overcome the "knowledge gap" that may exist during the early Lean projects. Formal training may include university courses, attending Lean workshops or conferences or hiring a consultant with expertise in Lean delivery systems. Communication can occur with anyone involved on a construction project that utilizes Lean techniques; many of the lessons learned in other construction industries are applicable to transportation infrastructure.

### RISK MANAGEMENT

Risk is an inherent part of the construction industry and is present on every project, Lean or otherwise. Risk management is defined by the Project Management Institute as "the art and science of identifying and responding to risk factors throughout the life of a project and in the best interests of its objectives." In general, there are three strategies involved in risk management – eliminating risk, transferring risk, or accepting risk. The fundamentals of risk management according to the Construction Industry Institute (Hanna, 2007) are as follows:

- Risks belong with those parties best able to evaluate, control, bear the cost, and benefit from the assumption of risks.
- Many risks and liabilities are not to be totally assigned but may be shared.
- Every risk has an associated, unavoidable cost which must be assumed in the planning, designing, bidding, or construction of the work.

### LEAN TOOLS AND TECHNIQUES

Many Lean techniques have been successfully used in non-transportation projects. Through the research the team has identified those techniques that can be used on any project independent of delivery type. These techniques include but are not limited to:

- Value-stream mapping
- Supply chain management
- Just-In-Time Delivery
- Last Planner$^{TM}$ concept "culture"
- 6 sigma

Each technique is summarized below, along with information on how they may be implemented to improve the construction process.

### VALUE-STREAM MAPPING

Value stream mapping (VSM) is a Lean technique used to improve existing work activities or processes. The purpose of VSM is to ensure that each process or activity adds value to the project. It involves analyzing a process or activity, identifying problem areas, and then creating an improved plan, known as a future state map, for that process.

The future state map shows the ideal steps in completing a process in the most efficient way possible. The future state map may improve on the current process by eliminating double handling, excess materials, obtaining information more quickly, etc, and functions as a goal for the team to works towards (Rother and Shook, 2009).

The value stream map is used eliminate or minimize the non-value adding activities which allows the process to be streamlined. This helps to reduce the cycle time of the process and allows for everyone involved to have a better understanding of what activities are involved in a process.

### SUPPLY CHAIN MANAGEMENT

Supply chain management views product production as a joint, coordinated effort between a network of interconnected businesses (Harland, 1996). On any project, multiple suppliers of services and materials are all involved in producing the finished product. Supply chain management is a system for coordinating and managing the complex logistics within a project.

Supply chain management may be divided into five categories or business processes: planning, procurement, production, distribution and customer interface.

Supply chain management views the relationships between suppliers, vendors and customers as a holistic system. Improvements in one area can create a "ripple effect", causing positive change throughout the system.

To effectively use your supply chain management on a construction project it may help to first create a value stream map. This will help to identify where and when each product needs to be delivered. It is then up to the management team to work with the appropriate suppliers to ensure that the necessary supplies will be available. This concept is closely tied to the Just-In-Time (JIT) delivery technique.

### JUST-IN-TIME DELIVERY

Just-in-time delivery is an inventory strategy that reduces in-process inventory and reduces carrying costs. Materials are delivered when they are needed, rather than being stockpiled on site. This minimizes double handling, reducing the chance of misplaced or damaged materials and cuts back on storage costs and set-up times.

Just-in-time delivery has particular application to sites where there is very little space for on-site storage or where theft and weather damage of materials are a problem. This concept must be integrated with supply chain management to ensure that the necessary materials are delivered on time. Detailed planning and coordination are required to implement a just-in-time delivery system, as any delay in deliveries can affect the operations of the entire project.

Just-in-time delivery is essential in creating a productive construction site because if the correct tools and materials are not available, there will be excess waiting on site as well as any excess of movement due to mobilizing to a part of the site that is ready to be worked on. In order to know when and where these deliveries take place, a tool such as the Last Planner™ should be used.

## LAST PLANNER CONCEPT "CULTURE"

The Last Planner™ concept culture is a collaborative method of scheduling work activities. In traditional scheduling practices, the person who makes the schedule is separate from the person who completes the work. Last Planner™ combines these roles, ensuring that the person with the greatest ability to complete an activity is also responsible for setting the corresponding schedule.

The Last Planner™ is the person who has the most control over an activity and knows best when the task will be completed (Ballard, 2000). Last Planners are assigned responsibility for the tasks they directly control, which creates accountability within the system. Group meetings at the end of the week allow people to present their needs to the other team members, fostering collaboration. These meetings allow for schedule constraints and conflicts to be proactively identified and resolved. This also allows for specific delivery dates to be identified so that the necessary supplies are onsite only when needed.

Last Planner™ concept culture results in cost savings by streamlining the scheduling process. Reliable commitments allow for work to be completed sequentially during the project, increasing productivity and reducing float and uncertainty. These processes can be monitored using a Six Sigma approach in order to keep processes in statistical control.

## SIX SIGMA (6σ)

Six Sigma (6σ) is a business management strategy, originally developed by Motorola, focusing on quality control. Six Sigma improves quality by identifying and removing the causes of defects and variability in the production process (Antony, 2008).

To achieve Six Sigma, a process must produce no more than 3.4 defects per million opportunities. Six Sigma defines a defect as anything outside of consumer specifications. The Six Sigma approach to reducing defects varies depending on whether the process is new or already established.

For already established projects, the DMAIC methodology is used. DMAIC stands for Define, Measure, Analyze, Improve and Control.

- **D**efine project goals and the current process.
- **M**easure key aspect of the current process and collect relevant data.

- **A**nalyze the data to determine relationships and identify relevant factors.
- **I**mprove or optimized the process based upon data analysis.
- **C**ontrol to ensure that any deviations from the target are corrected before they results in defects.

For projects aimed at creating new products or designs, the DMADV methodology is used. DMADV stands for Define, Measure, Analyze, Design and Verify.

- **D**efine design goals that are consistent with customer demands and the enterprise strategy.
- **M**easure and identify CTQs (characteristics that are Critical To Quality), product capabilities, production process capability and risks.
- **A**nalyze to develop and design alternatives, create a high-level design and evaluate design capability to select the best design.
- **D**esign details, optimize the design, and plan for design verification.
- **V**erify the design, set up pilot runs, implement the production process and hand it over to the process owners.

Six Sigma is related to, but distinct from Lean manufacturing. Lean can be seen as a proactive approach to project management, while Six Sigma is a reactive approach, specialized for quality control. The system produces cost savings by controlling and improving the quality of work completed on site. An example of how Six Sigma and Lean can be joined on a public transportation project is described in the following case study.

## MOTORWAY CASE STUDY[4]

In October 2006, work began on the Albanian Motorway Project under a fixed unit rate contract with the Albanian Government. For the project Bechtel is constructing a 61km motorway which includes a 5.5km twin bore tunnel (Bechtel Corporation, 2008). This was the largest project ever undertaken in Albania and the re-election of the Government at the time was in part dependent on the successful opening of the project by June 2009.

During construction Bechtel discovered that the quality of rock in the tunnel was significantly worse than the quality stated in the plans. This finding created an initial schedule delay of five months due to the fact that productivity was slower in the poorer rock grade (from class II to class IV) and because the critical path of the schedule went through the tunnelling process it was known that any delay in tunnelling would delay the project. However, due to the high profile nature of the project Bechtel knew that they had to have the tunnel open by June 2009.

### THE IMPROVEMENT PROCESS

Initially, Bechtel was expecting class II rock which they would have been able to excavate at 5.55m/day, whereas productivity in the class IV rock was initially at 3.07m/day. In order to complete the project on time, Bechtel implemented a Strategic Gap Analysis on the tunnelling process to identify where improvement efforts should be focused.

[4] Information for the Motorway Case study is from (Silby, 2010) and (Bechtel Corporation, 2008)

The team started by conducting a process map of the tunnelling cycle. The map allowed the team to identify all of the necessary steps in completing the process as well as identify how long each process took. From the process map and conducting a Pareto analysis, the team found that the three processes with the longest cycle times were the shotcrete, drilling, and mucking operations.

For the shotcrete placement, the process improvement team walked through the process and used a fishbone diagram to identify forms of waste and improvement areas. An example is that there was excessive waiting in the process due to delays with mixer truck arrival times. This is a step that could use a Lean technique, for example supply chain management linked with JIT delivery in order to coordinate the mixer trucks on site better for arrival accuracy. By working through the shotcrete cycle, the process was improved by 30 minutes which improved the process by 18%.

The drilling process had the second highest cycle time. This process was improved from an average of 98 minutes down to 85 minutes. An example of improvement was the addition of an extra drilling jumbo to ensure that a spare was available at all times. It was found that the cost for the additional equipment was minimal compared to the benefits of the time saved. By looking at a mapped out process and understanding where the bottleneck may be, such as the case with downtime in the drilling process, it is easier to identify which activities are critical to the process productivity.

The third process analyzed was the mucking away process. There was significant waste in waiting time as the loader had to wait for trucks, due to the space constraints of the tunnel. A time motion study was used in order to optimize the process. Through traffic management improvements it was found that continuous productivity could be achieved. Additional side mucking was used where the spoil material was spread along the side of the tunnel away from the face which allowed the next process step to begin immediately. These improvements led a 14% (23 minute) reduction in mucking cycle time.

Through these improvement processes as well as others the team was able to improve the tunnelling productivity by 43% (3.07m/day to 4.45m/day) in type IV rock. As seen in just these three processes almost one hour was eliminated from the tunnelling process. Through these improvements there was a hard savings of $21 million and reduced the potential five month extension down to zero. This resulted in the tunnel opening in time and created new tunnelling processes which will be used in future tunnel work.

## CONCLUSION

The improvement processes used in the case study show the effect that Lean techniques can have on a public transportation project. This was a project that had a fixed rate unit contract and did not have a special integrated delivery method. It showed that many of the Lean techniques being used today can be implemented if the contractor is willing to take the time and make the effort. This project in particular had a set finish date with possible serious consequences if the motorway was not open on time. Thus, moving forward the first projects to implement these techniques may be those that have a tight schedule and need to complete a project in the allotted time with the most efficient processes.

When looking at the obstacles to implementing a Lean project many obstacles are related to the contractual obligations. By creating an in-house improvement process, it is possible to improve projects with the current delivery methods. This can help to alleviate any legal issues that may come up. Companies should find that improving productivity improves profits and this will help mitigate the fear of any change in project management. The more projects that are completed and utilize these tools the more individuals will learn the techniques and be able to spread the knowledge.

With these principles in place and with continuous improvement in mind, industry wide productivity should pick up as more and more contractors begin to utilize these Lean techniques. Construction productivity will therefore start to mirror the productivity increase as seen in other industries.

## FURTHER RESEARCH NEEDED

While there are many positive examples of using Lean techniques in manufacturing and private building construction, transferring those same concepts to publicly owned transportation infrastructure projects will be difficult. The institutional, cultural and legal barriers are sizeable, thus future research is planned to identify tools and techniques that are currently being successfully used in delivery of transportation projects, such as Partnering, that are similar to those used in Lean project delivery to ease the cultural fear of implementing Lean concepts. Research is underway to identify the barriers that exist for SHA's to implement the most commonly used Lean tools for both traditional design-bid-build and design-build procurement methods and how these can best be overcome. Research also needs to be done through work sampling studies to identify sources of waste and non-value adding activities, which can be directly applied to Value Stream Mapping techniques to improve the delivery time for transportation construction projects. Results of this and similar research will greatly speed up the adoption of Lean techniques by State Highway Agencies, contractors, and consultants involved in the delivery of transportation projects.

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