



# Applying Lean Techniques in the Delivery of Transportation Infrastructure Construction Projects

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## **Abstract**

It is well documented that construction productivity has been declining since the 1960's. Additionally, studies have shown that only 40% of construction workers' time is considered to be value-added work. Interest in the use of Lean techniques for the delivery of large complex capital projects is quickly growing throughout the country. Manufacturing and vertical construction have shown that a project using Lean techniques can be delivered in less time, at lower costs, and with improved quality. However, Lean techniques are not currently being used by State Transportation Agencies (STAs). The implementation of Lean techniques with a Lean Project Delivery (LPD) can be a way for future projects to achieve higher quality, faster completion, and more efficient delivery. To attain this goal, the transportation industry, as a whole, needs to work closely together using non-traditional approaches to achieve the necessary improvement.

This study looks at the benefits of Lean techniques in the delivery of transportation projects, along with potential impediments to adoption. Case studies are provided which document the successful use of Lean techniques in the infrastructure industry. The transportation industry provides a unique challenge in implementing Lean techniques due to public sector constraints. Special care is needed in identifying obstacles to implementation when going forward with Lean. The most effective application of Lean techniques is in the design-build procurement process, but many of the Lean concepts are applicable in the traditional design-bid-build system, as well. Once these promising techniques and barriers are properly identified, a successful management plan can be created to help STA's begin their Lean journey.

## Executive Summary

Construction productivity has been declining since the 1960's, and studies have shown that only 40% of construction workers' time is considered to be value-added work. Lean Techniques are being used successfully on general construction and other non-transportation projects throughout this country, and their use is growing. Manufacturing and vertical construction have shown that a project using Lean techniques can be delivered in less time, at lower costs, and with improved quality. The implementation of Lean techniques with a Lean Project Delivery (LPD) method can lead to higher quality projects, faster project completion, and more efficient delivery. However, Lean techniques are not currently being used by State Transportation Agencies (STAs). To implement these techniques, the transportation industry as a whole needs to work closely together using non-traditional approaches to achieve the necessary improvements. This study focuses on the benefits of Lean techniques in the delivery of public infrastructure projects, along with potential impediments to adoption. Case studies are provided which document the successful use of Lean techniques in the infrastructure industry. The transportation industry provides unique challenges in implementing Lean techniques due to public sector constraints. Special care is needed in identifying obstacles to implementation when moving forward with Lean.

Lean Project Delivery uses a holistic, non-traditional project delivery approach to managing the various collaborative relationships that exist on a project for better integration of the individual management components to maximize project benefits. Lean Techniques systematically identify and minimize waste (non-value-added activities) through continuous improvement.

Two of the most popular forms of LPD in the transportation industry are the use of a Design Build (DB) or Construction Manager at Risk (CM@R) contracting method. Two of the newer transitions into Lean are Project Alliancing and Public-Private Partnerships (P3s).

A work sampling study was conducted on a county highway bridge project to observe the actual tasks being performed and help identify wasteful activities within the process. The work sampling study found that the rebar installation task consisted of only 32% direct work, with 29% of all activities consisting of pure waste. Asphalt paving work was found to include only 35% direct work, with 51% of all activities consisting of pure waste.

Case studies of public projects were performed to learn more about the application of Lean techniques in foreign markets. Lean techniques used in the case studies included an improvement team, strategic gap analysis, pareto charts, standard work, fishbone diagrams, process mapping, workflow simulation, 5-S strategies, value stream mapping, system diagnosis, process simulation, pull operations, standard work, improved supply chain logistics, the Define-Measure-Analyze-Design-Verify (DMADV) process, and a voice of the customer study.

Promising lean techniques for transportation projects were identified. Many best practices currently being used by STAs are similar to Lean techniques. Because some of these practices already exist, it will be easier for the transportation industry to implement certain tools before others. It may be appropriate to focus first on Lean techniques that match up well with current STA practices, before moving on to apply some of the other types of Lean techniques. These techniques were ranked according to their ease of implementation in the transportation industry, and the amount of agreement between the technique and the current STA delivery process, including the overall delivery system, individual resistance to change, and legal issues. Techniques ranked highly included: (1) Collaborative Planning, which is the process of involving all stakeholders in a project at the same time in order to ensure that all players are on the same page; (2) Daily Huddle Meetings (Pre-Task Planning), which is a short 5-10 minute meeting to give updates on the project progress as well as identify any issues that may need to be

addressed; (3) Last Planner System, which is a scheduling tool where work is scheduled by the person who is closest to the work actually being done; (4) Pull Schedules, which are a tool where a project is planned in reverse from the end to the start in order to understand which work tasks are impacted by a particular trade; (5) Simulation and Modeling, which covers a number of ways to virtually plan and construct a project before breaking ground, including BIM (Building Information Modeling) and IPD (Integrated Project Delivery); (6) Standard Work, which is the process of creating standard items and tasks in order to take methods and products produced or used on one project and apply them to another; and (7) Value Stream Mapping (VSM), which is the process of identifying all of the steps in a particular process and listing the value-added time and total time of each task.

Specific barriers to implementation of Lean techniques in public transportation projects were also identified. For public construction contracts, there are often restrictive laws governing the selection of contractors through competitive bidding. Lean relies on the careful selection of contractors and subcontractors early in the project cycle, which conflicts with several of the characteristics of a competitive bidding process. The working and management philosophies of STAs were designed to complete projects using the DBB (design-bid-build) delivery system. Many STA scheduling and review systems may contribute to difficulties in developing a holistic review of the project and in promoting early and extensive collaboration among project participants. In most cases, an organization will initially lack some of the resources, including budget, knowledge and experience to successfully implement a new delivery system. There are not currently any insurance products that align with the no-fault environment of LPD. Insurers are struggling to create policies that cover the project instead of the individual parties involved. LPD multiparty agreements also do not include a guaranteed price. Without a guaranteed price, it may be difficult for public entities budget, or to defend how or why a particular team was selected over another.

A management plan for adoption of Lean techniques within an STA was developed as an outcome of this research. To implement an LPD system, an STA must overcome the inertia of long-standing traditions and procedures to improve processes, establish a guiding core philosophy that is compatible with LPD, designate a change agent to become the resident LPD expert, find a “lever” to help move forward with the implementation process, initiate the changes, choose appropriate Lean techniques, determine whether there are significant legal barriers to implementation, work with the state legislature to address any barriers identified, map the value streams within the STA, create incentives to involve the workforce, create a pilot program, recognize small accomplishments, build momentum by capitalizing on these accomplishments, expand the scope of the LPD within the organization, and work for continuous improvement.

By creating an in-house improvement process, it is possible for STAs to improve projects by implementing some Lean techniques within the current delivery methods. With Lean principles in place and with continuous improvement in mind, industry-wide productivity should improve as the use of Lean techniques spreads. Utilizing Lean delivery methods, construction industry productivity will be more likely to mirror the productivity increases seen in other industries.

Implementation of lean techniques requires a significant shift in the organization’s core philosophy. How large this shift will be is one of the key questions. Without a major shift in core philosophy, lean techniques cannot be applied on public transportation projects in a transformative manner. Even with a major shift in philosophy, it may only be possible to apply incremental lean techniques to public transportation projects. Generally, the level of implementation of lean techniques within an SHA will depend, at least initially, on the level of acceptance of lean techniques by the state legislature. If current trends continue, putting increased stress on state and SHA budgets, state governments may become increasingly open

to innovative ways of saving time and money, improving quality, and increasing the efficiency of project delivery.

Incremental implementation of any of the lean techniques discussed in this report does not constitute a true LPD system. Development of a true LPD system requires integration of a coherent lean philosophy, implemented through the systematic application of appropriate lean techniques discussed in this report within an integrated project delivery framework. While many lean techniques and tools can be implemented in isolation, utilization of the IPD framework seems to be an important baseline requirement for development of a truly lean project delivery system.

# 1. Introduction

As the United States' transportation infrastructure continues to age and replacement and rehabilitation efforts grow, State Transportation Agencies (STAs) must continuously find ways to successfully complete projects faster and at a high level of quality. A potential candidate tool for accomplishing these goals is the use of Lean techniques and Lean delivery methods, which are currently being used successfully in vertical construction.

Lean Construction is defined by the Lean Construction Institute (LCI) as a production management-based approach to project delivery (LCI, 2010). Lean Project Delivery (LPD) seeks to align interests, objectives, and practices through a team based approach where the primary team members are the owner, design professionals, prime contractor, and key subcontractors (trades partners). 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, and as a result, they are able to deliver high-quality projects in less time and at lower costs.

Traditionally, STA's use the design-bid-build (DBB) project delivery method for transportation infrastructure projects. The basics of the DBB delivery system include the STA contracting first with a design entity for 100% complete design documents. Once the design is complete the STA then solicits bids from contractors to perform the work. The owner then selects a contractor based upon their bid. The structure of this delivery method is seen in Figure 1.

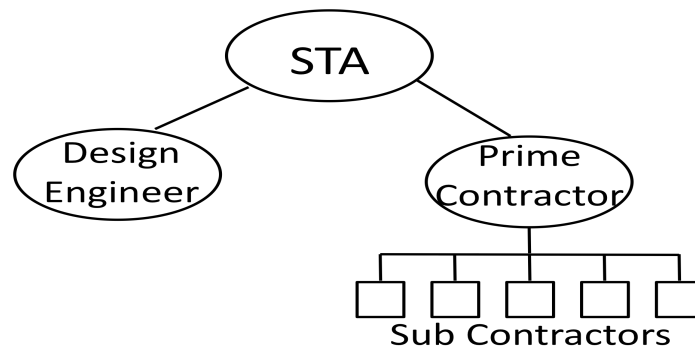


Figure 1. Traditional Design Bid Build Organization

With this traditional approach, the construction industry has not improved productivity since the 1960's. As seen in Figure 2, all nonfarm U.S. industries have more than doubled productivity, but the construction industry's productivity has actually decreased.

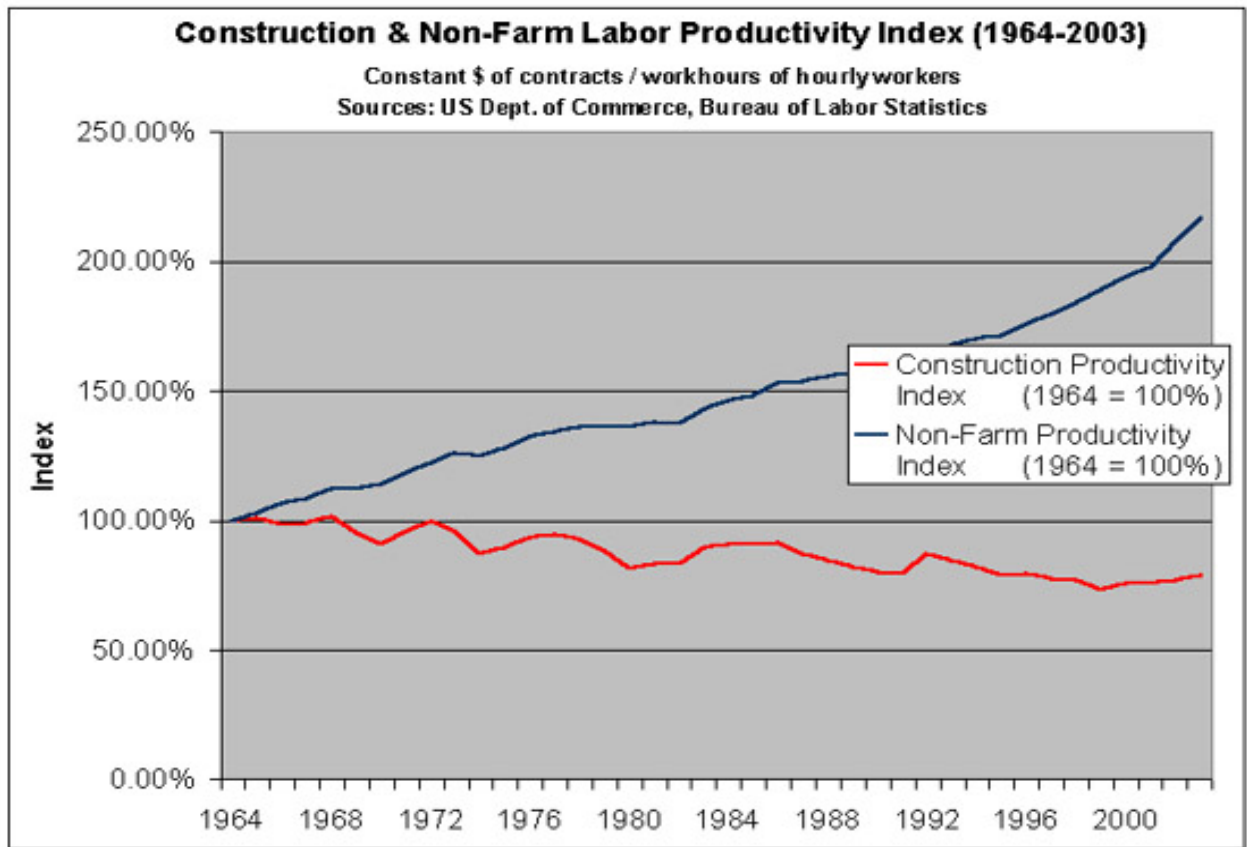


Figure 2. Productivity Index (1964-1998) (Teicholz, 2004)

Recent productivity studies have shown that workers are currently only about 40% productive while on site. This continuing existence of non-value added work can be attributed to improper management of projects (Hanna, Fall 2009). As most infrastructure projects are based on this traditional DBB delivery, huge opportunities for improvement exist because of the current practice only being 40% productive.

This information is pertinent to the economic future of the United States because currently in the United States trucks move 78 percent of the nation's domestic freight tonnage. Long range projections indicate continued growth and dependency on the use of trucks in this country. The Federal Highway Administration (FHWA) estimates that freight bottlenecks cost the trucking industry \$8 billion in economic loss annually. Adding to the problem is the increasing age of the facilities. The impact on the national economy created by the disruption of freight transportation due to bottlenecks created during infrastructure construction projects is tremendous. It is critical that new infrastructure and the repair/replacement of existing infrastructure projects be accomplished much more rapidly than is currently being done. In addition, projects must be done with minimal disruption to the community and produce facilities that are long-lasting. Rapid or accelerated projects typically involve complex logistical requirements, unique designs, and difficult construction conditions. The transportation industry, STA's, contractors and consulting engineers will need to work closely together using non-traditional approaches to achieve the needed improvements.

LPD can be part of the "new approach" to transportation project delivery to meet these demands. Lean techniques are being used successfully on general construction and other non-transportation projects throughout this country, and their use is growing. Lean techniques use a



holistic, non-traditional project delivery approach to managing the various collaborative relationships that exist on a project for better integration of the individual management components to maximize project benefits. Lean techniques systematically identify and minimize waste (non-value-added activities) through continuous improvement, and when implemented 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, as shown in Figure 3.

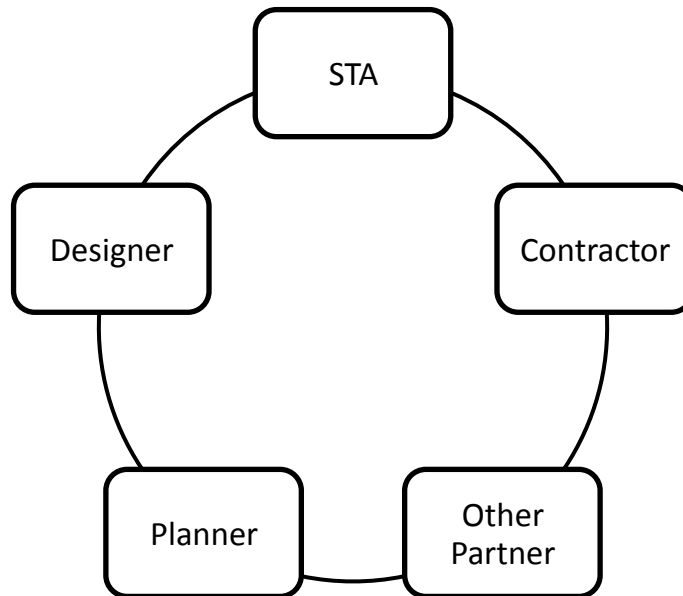


Figure 3. Lean Project Delivery System

Transportation projects could benefit greatly from the use of Lean techniques for delivering projects faster with higher quality. LPD is a project centric delivery in which the owner, engineers, and contractors sign a single contract for achieving project goals. LPD encompasses a number of Lean techniques where “Lean techniques” is a broad term that utilizes a variety of tools, strategies and technologies to increase levels of integration and cooperation on construction projects while improving quality, shortening project duration and reducing costs. LPD fosters a fundamentally different approach than the traditional DBB delivery. Figure 4 shows a comparison between the traditional project delivery methods used in transportation projects and LPD; notice how LPD creates early collaboration with early involvement versus the traditional linear method of handing off knowledge and responsibility. It should be noted that different terms are being used to represent Lean delivery; namely, (LPD) (Lichtig, 2005), Integrated Project Delivery (IPD) (Post, 2010) and Integrated Lean Project Delivery (ILPD) (Walker, 2009). These terms all focus on the concept of creating a project centric / team centric approach to achieve project goals.

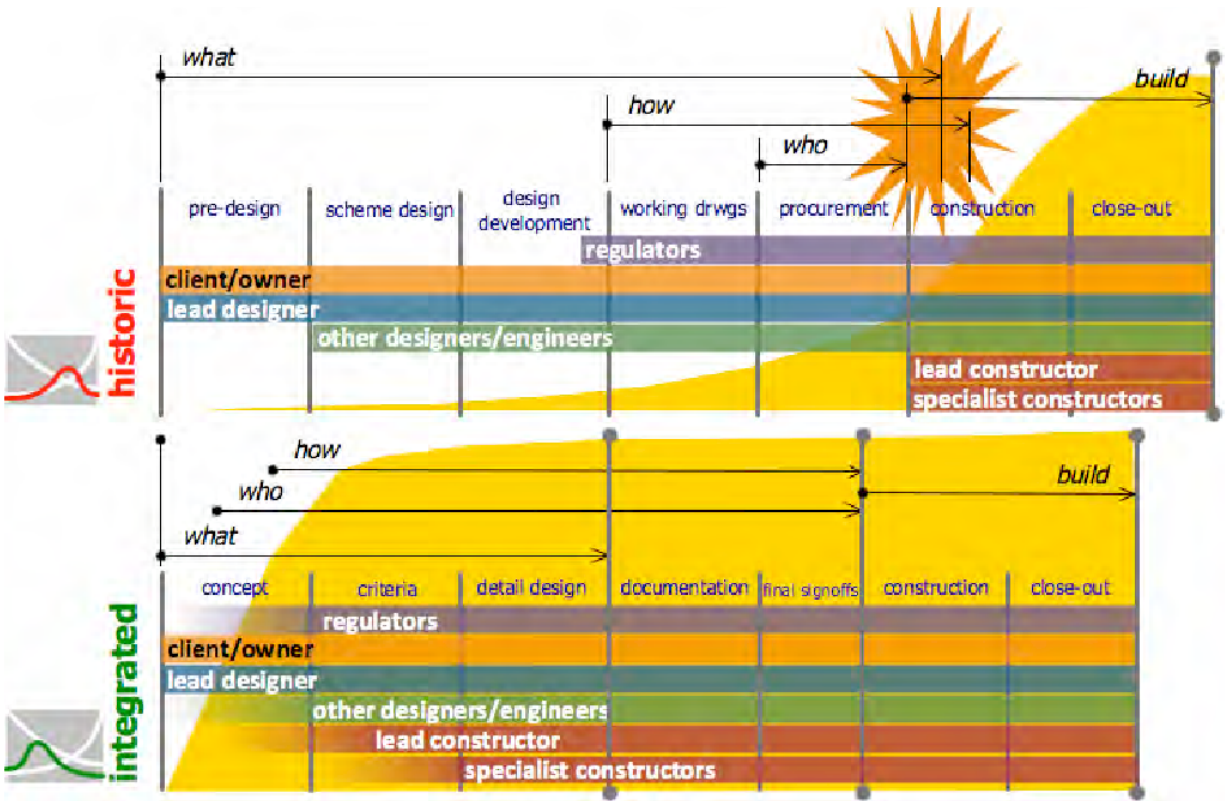


Figure 4. Comparison Between an Integrated Lean Project Delivery and Historic (DBB) Delivery (Mossman, 2008)

### 1.1. Project Delivery Types

While the traditional type of project delivery is DBB, two other delivery methods have been gaining in popularity recently: (1) Design-Build Delivery Methods (DB); and (2) Construction Manager at Risk (CM at Risk). Table 1 presents a comparison of these methods with the traditional DBB and the new LPD systems based on the project participants and the system structure that organizes these participants.

Table 1: Project Delivery Systems (The Boldt Company , 2009)

	<b>Design-Bid-Build</b>	<b>CM at Risk</b>	<b>Design-Build</b>	<b>Lean Project Delivery</b>
<b>Management Structure</b>				

<b>Contract</b>	STA has separate contracts with DE and PC. PC selects subcontractors	STA has separate contract with DE and CM/PC. CM/PC then contracts with subcontractors	STA contracts with Design/Build Team, who then designs and constructs the facility.	STA, 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
<b>Construction Contracts Held By:</b>	Owner	CM	Design/Build Team	Core group of integrated team
<b>Change Orders:</b>	Increased risk due to the bid environment using the lowest responsive bid	Reduced because of increased team collaboration during design phase	Greater risk, related to locking in prices early in design.	Minimized due to increased collaboration during the design phase.
<b>Collaboration</b>	Minimal because design is complete before selection of PC	Increased because of early selection of CM	Collaboration within the DB team is maximized, but STA has less involvement	Maximized due to the nature of the contract.
<b>Project Schedule</b>	Linear project schedule without project phase overlap	Fast-track schedule with emphasis on up-front planning with project phase overlap	Fast-track schedule with emphasis on up-front planning with project phase overlap	Similar to DB, but the project team has greater control over the schedule

(DE = Design Engineer, STA = State Transportation Agency, PC = Prime Contractor, CM = Construction Manager)

Each of these delivery methods provide unique benefits to a project, however LPD is the only method of the four to provide for a true collaborative effort. This way all parties are subject to one contract where risk is shared and collaboration is required. The transportation infrastructure industry needs to evaluate the LPD approach as a way to ensure greater quality, lower costs, and quicker time to market for future projects.

## 1.2. Identifying Waste

Waste is inherent in any process, and one of the key principles of the Lean approach is in identifying these wastes. According to Professor Jeffrey Liker there are eight types of waste in any process. These wastes are (Liker, 2004):

1. Overproduction;

2. Waiting;
3. Unnecessary transport or conveyance;
4. Over or incorrect processing;
5. Excess inventory;
6. Unnecessary movement;
7. Defects / Rework; and
8. Unused employee creativity.

It may not be immediately clear how each of these wastes relate to the transportation industry. By looking at the root cause of many construction delays and issues it is evident that many of these wastes are a common occurrence and are even considered best practices in some situations. The main problem with these wastes in the construction industry is that usually wastes are compounded and several are observed in a single process. An example of this may be the mass delivery of storm sewer pipe on day one of the project, as shown in Figure 5.



Figure 5. Example of Storm Sewer Waste

First of all, this scenario will create excess inventory since a location will need to be created for storage of the pipe. As a result, there will be unnecessary movement of the material since it will have to be moved from the storage area to the installation area instead of just coming straight off the delivery truck and into place. By having inventory sitting out in the open in harm's way there is also the potential for defects to occur since it is harder to protect the materials on hand. Conversely this could be looked at as overproduction of storm-pipe if it is delivered on day one. The reason behind this is that there may be design changes throughout the project which could change the size and quantity of pipe necessary for the project. If the supplier thinks that they are done once everything is delivered there will be extra difficulties to get more material later on in the project instead of just changing a weekly/daily order. This can lead directly to an increase in excess inventory since pipes will be on site that will not be used for this project due to changes.

A second example of waste common on a construction site can be illustrated using Figure 6. This large pile of basecourse could represent multiple forms of waste including excess inventory and unnecessary transportation of materials. If the pile had been delivered to this spot, and would then need to be moved a second time in order to be placed into its final spot, this would be an example of unnecessary transportation of materials. Additionally, this pile is at the far end of the project and will require maximum movement in order to get the material to the other end. As seen in Figure 6 the pile is taller than a car and obstructs the views of local businesses. The Lean approach would be to deliver the material onsite as necessary so that it could be dumped in place and used immediately instead of stored in one large pile at the far end of the project. This would reduce double handling of the material and would save time and equipment use.

Another approach would be to determine if the material can be crushed in place and then the whole process of crushing and placing the material could be done in one pass.



Figure 6. Illustration of Waste in Road Construction

Lean delivery allows identification of wastes early on in the process and provides a way to streamline value-adding processes.

## 2. Literature Review

### 2.1. History of Lean

Lean production can be traced back to the Toyota Production System (TPS). Japan's economy by 1974 had entered a state of zero growth following a recession in 1973. At this point many companies were suffering and Japanese businesses could no longer function based off of the American mass production system. As a result of the crisis a need for a new production process was born. Toyota saw this as a time of opportunity and was led by Taiichi Ohno who looked at how Toyota could produce many different models in small quantities. Ohno defined the TPS as having two main principles: Just-in-time and Automation (Ohno, 1988). These were the leading principles that helped make Lean production mainstream. When observing the American form of manufacturing, Toyota noticed that only the worker on the assembly line was adding value and the striking feature of placing emphasis on continually running the production line seemed to only compound and multiply errors (Ohno, 1988). This has led to the bottom up approach for process improvement which is a staple of the Lean theory.

In the late 1980's a Massachusetts Institute of Technology (MIT) study conducted by a research group in the International Motor Vehicle Program (IMVP) coined the term "Lean". The IMVP definition of Lean is:

half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products (Womack, et al., 1990)

The theory of Lean was expanded later when the book "Lean Thinking" came out in 1996. This book defines the five main principles of Lean as: 1) define customer value; 2) define the value stream; 3) make it "flow"; 4) "pull" from the customer back toward the company; and 5) strive for excellence (Womack, et al., 1996). These main principles can define the entire process from beginning to end. It is necessary to focus on the end customer's value as they are the ones who will be buying the product. Thus, identifying the value stream according to the customer is necessary.

Pull scheduling was derived from the U.S. supermarket system. This system was able to provide the customer with what they needed, when they needed it, in the amount they needed it. This philosophy in relation to manufacturing is that the customer is buying any product at any time, in the amount they want. Manufacturers are no longer pushing the customer to purchase the goods they have pre-produced, but instead are basing their needs on the customers' demand. This relates to the new form of management and scheduling seen in construction.

Jeffrey Liker contributed to the spread of Lean information by publishing his book "The Toyota Way." In this book Liker defines the 14 principles by which Toyota operates and outlines the culture of the company. Liker has a unique take on Lean in that he created the 4P Model, in the form of a triangle as can be seen in Figure 7. This model has a long term philosophy on the bottom, which then supports a process, people and partners, with problem solving on top. Liker went on to identify the seven major types of non-value-adding wastes in business or manufacturing processes as noted by Toyota and he additionally included an eighth waste which he saw as important, as described earlier in Section 1.2.

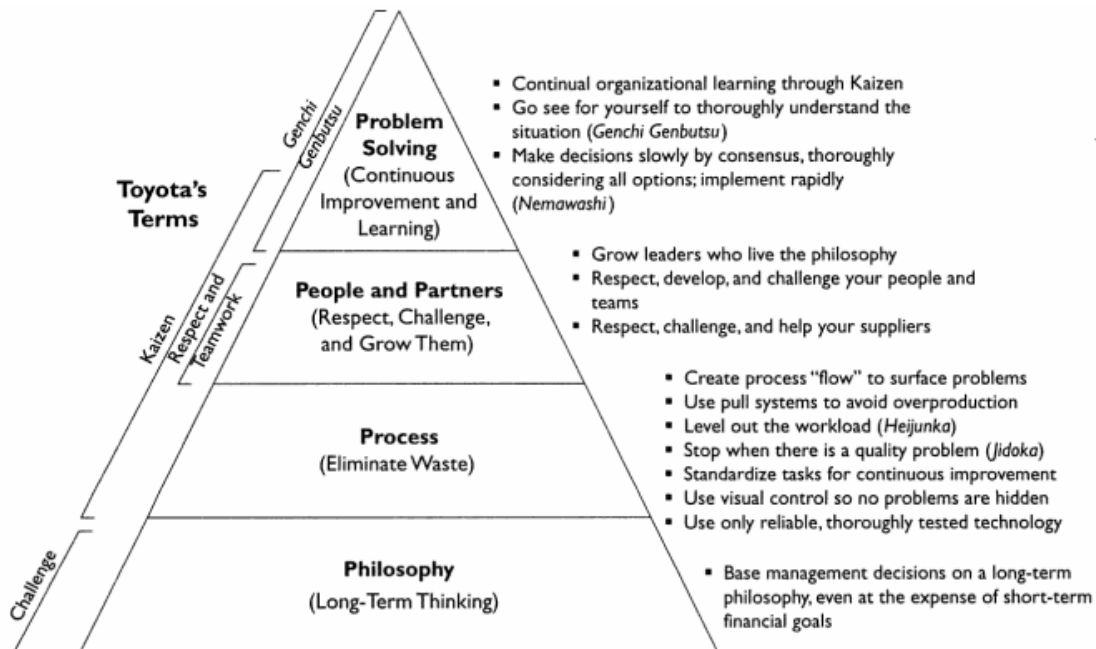


Figure 7. Liker Triangle (Liker, 2004)

Ohno considered the fundamental waste to be overproduction since it is the root cause of most other wastes. These ideas of waste have been transferred to the construction industry where many of the same inefficiencies can be found.

## 2.2. Lean in Construction

According to Koskela, planning and control are often replaced by chaos and improvisation in design (Koskela, et al., 1997). This issue was noted in the mid 1960's in the Tavistock report on communication in construction:

Sufficient thought and time does not seem to be given to ensuring, either as a design team brief or during the designing process, that all who must contribute understand the common objective similarly and fully. There is seldom a full awareness of all the steps necessary to realize an optimum overall outcome without loss of time, and the means of ensuring coordination is often not clear. (Higgin, et al., 1965)

Planning is important to any construction project and even though this problem was identified over 40 years ago, it still remains an issue. In the mid 1990's interest in this topic of increasing planning and communication in construction to improve productivity appeared to be catching on.

Koskela originated the idea that construction processes must be viewed as systems of Transformations, Flows and Value-adding actions, the so-called TFV model (Koskela, 1992). Bertelsen expanded the manufacturing model of Lean to include the ideas of construction as one-of-a-kind production, construction as a complex system and construction as cooperation (Bertelsen 2002).

In the United States, Glenn Ballard and Greg Howell founded the Lean Construction Institute (LCI) in August 1997 (Lean Construction Institute, 2010). LCI's goal is to develop, through research, knowledge regarding project-based production management in the design, engineering, and construction of capital facilities.



Greg Howell noted that managing construction as a Lean process is different from the traditional practice because it (Howell, 1999):

- has a clear set of objectives for the delivery process;
- is aimed at maximizing performance for the customer at the project level;
- designs concurrently product and process; and
- applies production control throughout the life of the project.

In contrast, the traditional form of construction management is based on an activity-centered approach not found in mass production. This activity-centered approach aims at optimizing the project activity by activity.

Howell and Ballard's studies about the "Last Planner" technique showed that the use of formal and flexible production planning procedures is the first step to keep the production environment stable. It emphasizes the use of the Daily Production Plans, Constraint Analyses, Lookahead, and the Percentage of Planned and Concluded items (PPC) as tools for immediate implementation on any jobsite (Ballard, et al., 1994). This created commitments at a personal level where individuals were now responsible for specific work items and allowed for any variances to the schedule to be analyzed because a specific reason for not completing the work became identifiable. Since individual tasks were being tracked, the PPC of each task could easily be measured and any problem could be addressed immediately instead of reoccurring throughout the project.

The initial results of the Last Planner™ implementation of increasing PPC levels close to 100% on projects translates to an increased confidence in short-term planning processes. When PPC is first measured on a project, only 50% of activities are completed when first stated. By bringing the reliability of commitments up to 100% project planning can become extremely effective.

One major boost in Lean Construction in the U.S. industry can be attributed to the 1994 Northridge earthquake, which caused significant damage to healthcare facilities in Southern California. As a result of the damages, the California Legislature enacted SB 1953 – the Hospital Facilities Seismic Safety Act. This act required significant structural seismic upgrades to be accomplished by January 1, 2013 (Lichtig, 2005). One healthcare company that this greatly impacted was Sutter Health, who, in response to this act, looked to implement LPD on their projects. Sutter Health categorized the delivery system into five big ideas as shown in Figure 8.

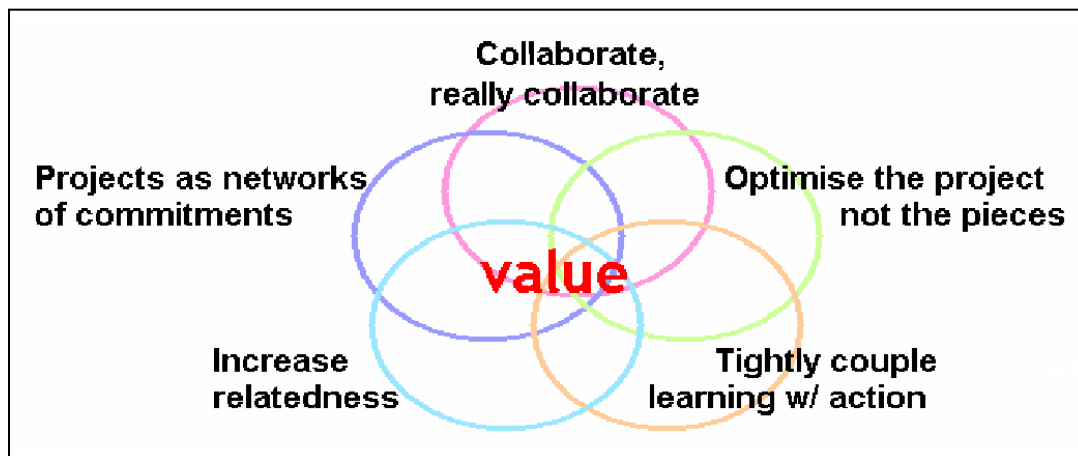


Figure 8. Sutter Health's Five Big Ideas (Lichtig, 2005)

These five big ideas are: (Lichtig, 2005)



1. Collaborate; really collaborate, throughout design, planning and execution.
2. Increase relatedness among all project participants.
3. Projects are networks of commitments.
4. Optimize the project not the pieces.
5. Tightly couple action with learning.

These main ideas helped to visualize the efforts by Sutter and showed where value exists in the process. Additionally, Sutter Health implemented an incentive program to encourage superior performance based upon Sutter Health's goals for LPD. This incentive program also served to reward the design and construction team for successfully achieving superior performance and successfully exceeding the project expectations and benchmarks.

In 2004, the Construction Industry Institute (CII) published a report showing how Lean principles in the manufacturing industry can be used in the construction industry (Diekmann, et al., 2004). Additionally, CII published a report that investigated what makes a Lean project successful and created a road map for implementation (Ballard, et al., 2007).

## **2.3. Variations of Lean**

The transition to a more LPD-like method has taken many forms in transportation infrastructure construction throughout the years. Two of the most popular forms of moving away from DBB are the use of a Design Build (DB) or Construction Manager at Risk (CM@R) contracting method. Both of these have been heavily researched and described in the past. Two of the newer transitions toward Lean are Project Alliancing and Public-Private Partnerships (P3s), which will be discussed further in this section.

### **2.3.1. Project Alliancing**

In Australia since the early 1990's project alliancing has become more and more popular in the public sector. From 2004 to 2009 \$32 billion or 29% of the total infrastructure projects for road, rail and water sectors used an alliancing approach. An alliance is defined by the Victorian Department of Treasury and Finance as:

a commercial/legal framework between an owner (the "owner participant") and one or more "non-owner participants" (NOPs) for delivering a capital works project, characterized by:

- Collective sharing of (nearly) all project risks
- No fault, no blame and no dispute between the alliance participants (except in very limited cases of default)
- Payment of NOPs for their services under a "3-limb" compensation model comprising:
  - Reimbursement of NOPs' project costs on 100% open book basis
  - A fee to cover corporate overheads and normal profit, and
  - A gainshare/painshare regime where the rewards of outstanding performance and the pain of poor performance are shared equitably among all alliance participants
- Unanimous principle-based decision-making on all key project issues
- An integrated project team selected on the basis of best person for each position. (Victorian Government, 2006)

The motivation for the alliance system in Australia stemmed from the traditional problem of risk being shifted to the parties who are not in the best position to manage those risks. The alliance system is an attempt to allocate the risks to appropriate parties who are best able to manage the risk on the project (Ross, 2009).

### 2.3.2. Public-Private Partnerships (P3s)

Public-Private Partnerships (P3s) are contractual agreements formed between a public agency and a private sector entity that allow for greater private sector participation in the delivery and financing of transportation projects. The early involvement of the private sector can bring creativity, efficiency, and capital to address complex transportation problems. Currently there are 23 U.S. States and one U.S. territory that have active statutes that enable the use of various P3 approaches for the development of transportation infrastructure. These states are highlighted in Figure 9 below (Federal Highway Administration, 2010).

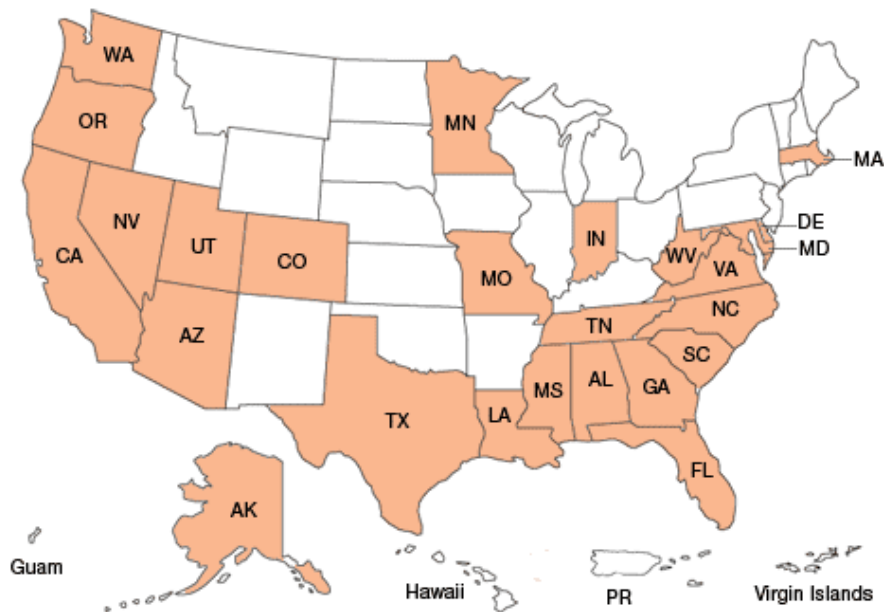


Figure 9. U.S. States and Territories with Active P3 Statutes (Federal Highway Administration, 2010)

The main benefits of using a P3 to deliver a transportation project include (Federal Highway Administration, 2010):

- Expedited completion compared to conventional delivery methods;
- Project cost savings;
- Improved quality and system performance from the use of innovative materials and management techniques;
- Substitution of private resources and personnel for constrained public resources; and
- Access to new sources of private capital.

One of the main ways that P3s shift delivery toward LPD is the allocation of project risk to the party that is best equipped to manage the risk instead of just passing the risk to the next contractor in line. Incentives are also included in P3s to reward parties for taking on the risk of the project (Federal Highway Administration, 2010).

P3s are becoming more and more popular and are helping to ease a transition into a true LPD. In 2010, two projects in Texas used a P3 contract, two projects in Florida are underway with a P3, and a transit P3 contract has been awarded in Denver (Cho, et al., 2010). Additionally, Virginia is using a P3 for the \$1.35 billion reconstruction of the Capital Beltway which includes the construction of four new 14 mile long lanes, 58 new bridges and 900,000 sq ft of retaining wall (Cho, 2010).

P3s are a growing trend in the United States and greater use of P3s will lead to greater collaboration and move the transportation industry closer to creating a true LPD.

### **3. Work Sampling Example Study**

In order to successfully understand and characterize the implementation of Lean tools, the productivity problem had to be defined. As stated earlier, construction productivity has been decreasing since the mid 1960's. As an example of the applicability of this statistic to transportation infrastructure construction, a work sampling study was conducted on a county highway bridge project to observe the wastes that existed in the construction process.

#### **3.1. Work Sampling Example Study**

The work sampling study was conducted to exemplify the industry trend that less than 50% of time spent on the construction site is value-added work. There seems to be a misconception in the construction industry that if a worker is moving then they are being productive. The work sampling study helps in identifying the actual tasks being performed and can help identify wasteful activities within a process.

##### **3.1.1. Work Sampling Study Definition**

Work sampling is a management tool which consists of making a large number of random observations and using the theory of probability to identify the activities where waste exists. Work sampling groups the activities into one of three categories: value-added, essential but non value-added, and non-value-added. The value-added activity was anything that was directly contributing to the construction of the bridge (i.e. rebar installation, formwork, paving), the essential but non-value-added ("contributory") work was that which was necessary to be done, but did not directly add to the construction of the bridge (i.e. measuring/layout, moving materials/equipment/tools within a short distance ~25 ft.) and non-value-added ("ineffective") activity, was any activity that was done which did not directly add to the final project's value (talking, walking around empty handed, moving tools/materials/equipment further than 30 feet). By creating these three categories it was possible to determine which activities took the most time during the construction process and allowed for the identification of leverage areas to determine where the major wastes occur.

To successfully conduct a work sampling study the following seven steps must be followed:

1. Establish the study objective;
2. Define the population to be studied;
3. Define the study period;
4. Select and train persons to gather the samples;
5. Formulate the activity categories (value-added, essential but non-value-added, non-value-added);
6. Establish confidence limits and number of observations; and
7. Develop random observation times.

Once these steps are complete the observers then need to actually go out and observe the work until the appropriate number of samples has been observed. From this a Labor Utilization Factor (LUF) can be developed which is the value-added-work plus one quarter of the essential but non- value-added work. This factor can be used to determine how effectively the crew is performing a specific task. Observation sheets and calculations for the work sampling study can be found in Appendix A.

### 3.1.2. Work Sampling Background

The work sampling study was conducted on the reconstruction of two county highway bridges in southwest Wisconsin which are approximately 1.25 miles apart. On this project, there was one contractor and one construction manager. However, each bridge had a different designer. Therefore, even though these were two almost identical bridges, there were slight differences in the design of each bridge. An example of differences is that the eastern bridge was designed with asphaltic flumes, whereas the western bridge did not have flumes, but instead had the rip-rap brought up closer to the bridge deck. These small design differences led to extra change orders because the contractor wanted to be able to use the same materials and methods on each bridge. Thus, looking at the project as a whole, it is easy to see that the project would have benefited from having the same design engineer so that the two bridges would have had consistent designs, and it would have allowed for one specific contact. Additionally, had there only been a single design engineering firm, there could have been time and money saved by using the knowledge gained from the design of one bridge to help design the other. Alternatively, if it was not possible to utilize the same designer, a constructability review of the total project could have identified these differences and improved the consistency of the design by allowing design modifications to be made prior to bid.

Before even looking at the productivity onsite, one can see how systems thinking could be applied for the entire project to enable better flow. This idea of systems thinking needs to be used by STA's as they are in the unique position of being able to let all projects during the year. STA's should use location and contractor workload in identifying when projects should be let as well as when they should be designed in order to eliminate waste and increase flow.

### 3.1.3. Work Sampling Rebar Installation

The work sampling study was conducted by physically going to the jobsite and observing the workflow of the contractor. Observations were taken periodically and identified the work being done as: value-added, essential but non-value-added, and non-value-added. Further, workers, foremen, the site engineer, and the project manager were interviewed during the process to help aid in the understanding of the project. This allowed for invaluable insight as looks can be deceiving. The two major work areas that were observed were the rebar installation for the structural deck, and then the asphalt pavement of the bridge approaches. Figure 10 depicts the installation of the rebar for the structural deck.



Figure 10. Rebar Installation of Structural Deck

The following is the equation used for calculating the sample size:

$$N = \frac{K^2 P(1 - P)}{S^2}$$

Where:

N = Number of Observations

P = Decimal Equivalent of Percentage in Category

K = Number of Standard Deviations

S = Sample Percentage

$$N = \frac{(1.88)^2(0.28)(1 - 0.28)}{(0.06)^2} = 198$$

Utilizing 1.88 standard deviations to give a 94% confidence limit (6% limit of error) and an estimate of 28% value-added work as the category percentage, a total of 198 samples was required for this project to allow assumption of a normal distribution for the observations. These samples were taken at random time intervals and utilized the observation sheet shown in Appendix A. All of these observations were recorded in one day, as all the work for the rebar was performed in one day. As shown in Figures 11 and 12 rebar installation consisted of only 32% direct work and 29% pure waste.

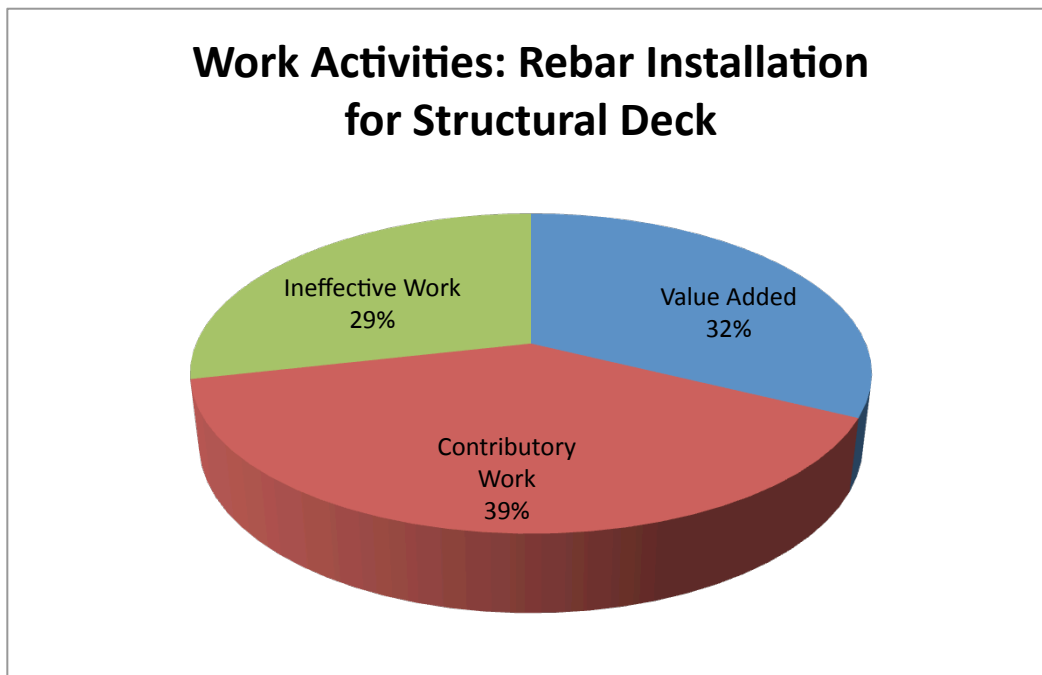


Figure 11. Summary Breakdown of Rebar Installation

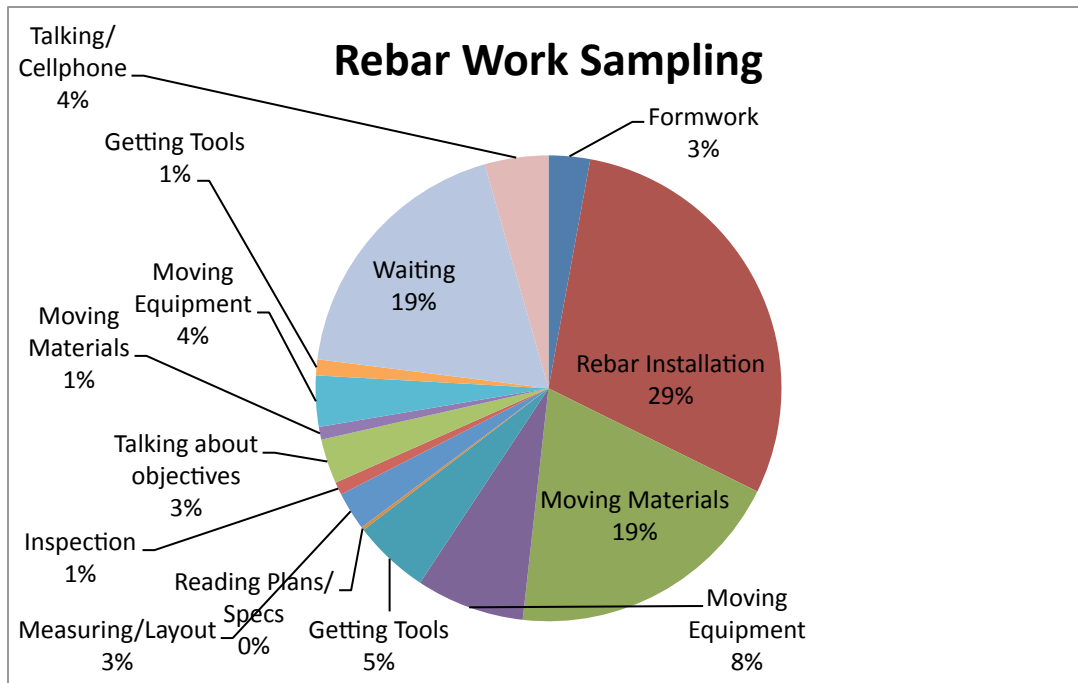


Figure 12. All Observed Rebar Activities as a Percentage of All Activities Observed

The work activity data from rebar installation was summarized and evaluated using a variation of the Pareto analysis. The Pareto analysis is used to prioritize and focus on the potential benefits for the customer based on the process problems and causes (Finster, 2010). The Pareto principle states that most comes from a few. Often the principle is stated as “80% is caused by 20%.” Looking at the analysis between the two forms of non-value added work (i.e. contributory and ineffective work) the analysis was performed to help target the major areas of inefficiency on a construction site.

First, analyzing the contributory work as seen in Figure 13, about 80% of the activities adding to contributory work were associated with moving materials, equipment and obtaining tools. By focusing in on these three categories the construction team can work on minimizing these tasks so that they take less time and can better utilize their time on site with value added work. These tasks are all necessary, but can be improved and/or reduced. For instance, tools could be better arranged or located so that they are found more quickly and accessed more easily. The materials could be directly delivered instead of having small stock piles around the site that then need to be transported in the interim. This category mainly focuses on the jobsite logistics and how the contributory work can be reduced.

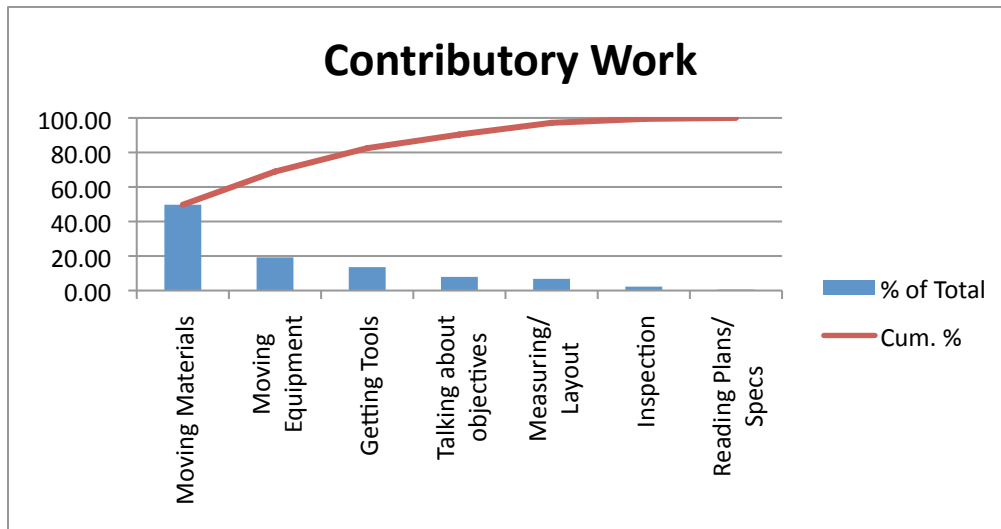


Figure 13. Pareto Analysis of Contributory Work

The second Pareto analysis was conducted on the ineffective work onsite. Focusing on the rebar installation for the structural deck it can be observed from Figure 14 that about 18.5% of the time the workforce being observed was waiting. This correlates to 65% of the ineffective work. Therefore, for every dollar spent on rebar installation, \$0.18 was being wasted because of waiting. This can quickly add up and shows a major area that needs to be improved. It was observed that the majority of waiting seemed to occur when others were moving materials. The crew had a system in place where two to three workers were always doing the direct work of installing the rebar and then the other two or three workers were obtaining the materials. However, the deliveries were not spaced out correctly and as a result there was a significant amount of waiting by both groups depending on whether the load was being received or not.

The results of the Pareto analysis provide an effective tool for analyzing where the focus should be placed on a particular site. Generally, it can be difficult to get a firm grasp on an improvement process because it is hard to quantify. The Pareto analysis allows for quantification because it directly tracks the work being done and allows for the measurement of progress based on observations.

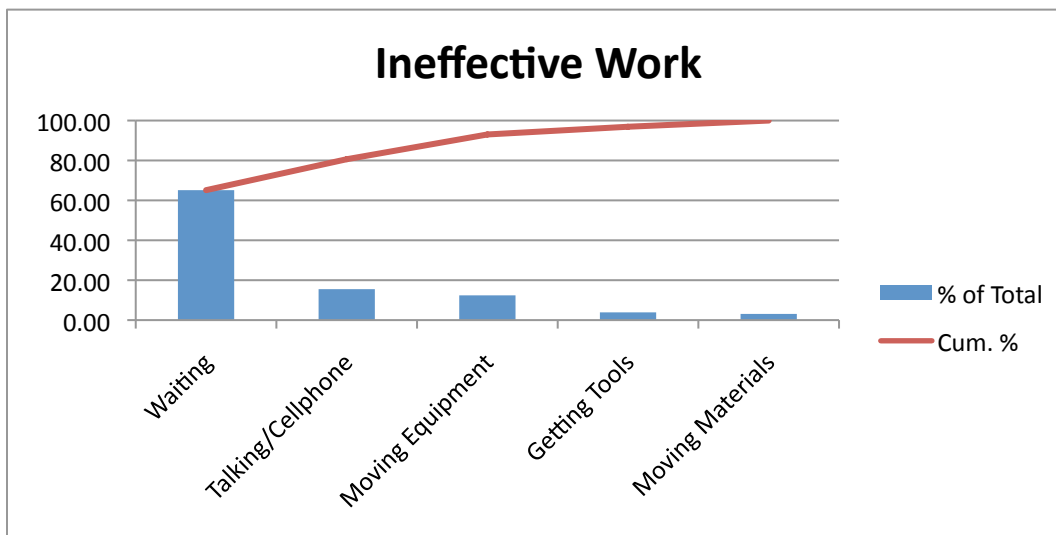


Figure 14. Pareto Analysis of Ineffective Work



The work sampling study is an important way to understand inefficiency problems and should be done prior to implementing any Lean initiatives on a project because it is important to ensure that the improvement effort is focused on the most important aspects of the project. It is also important to note that not every situation may present clear cut problems on a site and thus, further analysis may have to be conducted in order to determine where improvement implementation should start.

#### **3.1.3.1. Site Layout for Rebar Installation**

One way to better understand the rebar process is to have a graphical representation of the site. Figure 15 depicts the current state of the site at the time of the work sampling study. This shows visually where some of the improvements could have been made in order to reduce double handling, waiting, and other wastes which were included in the process.

Based on Figure 15, a few observations can be made immediately as to how the site could become more efficient. The main one is that the job trailer is located about 60 feet from the nearest abutment. During the rebar installation the crew spent the majority of their time either on the bridge deck or by the crane. This meant that any trip to the trailer would take a significant amount of time. Additionally, the rock pile was located near the road to make it easier to load and unload, however this location made the rock pile an obstacle for persons trying to access the trailer. Because of this, more time was used to walk around the rock pile versus just walking directly to the job trailer. This could have been improved by either waiting to deliver the rock until it was needed on site, or the pile could have been placed further from the road in order to provide a clearer walking path for the workers. This location may have been easiest for delivery of the rock, but it negatively affected other site activities. The third major site logistic issue is the location of the Porta Potty. The location across the road and opposite of the job trailer made quick access impossible. Unless it is only used during break times, this location could hinder performance and create a waste of excess walking.

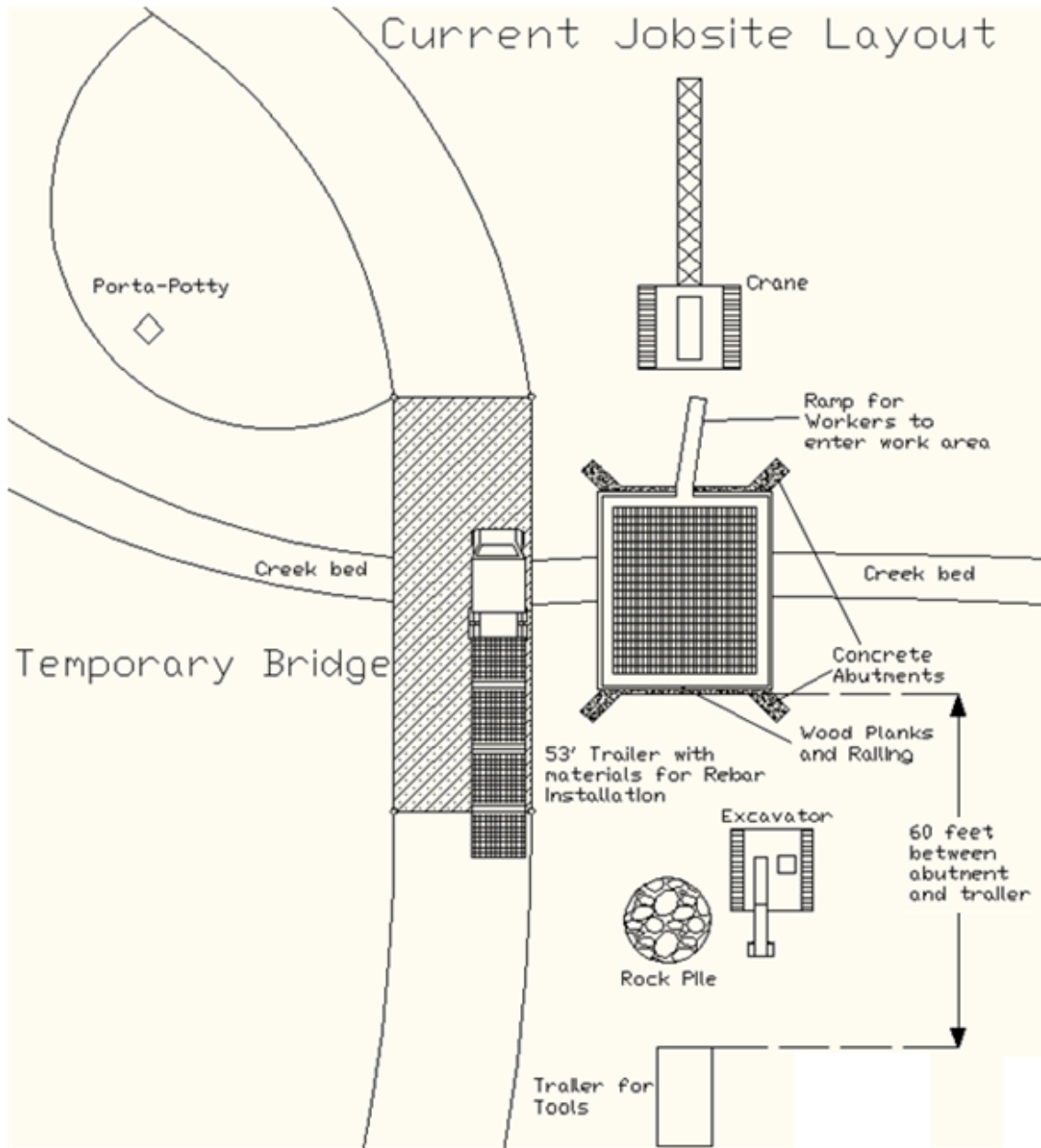


Figure 15. Current State Site Map for Rebar Installation

By relocating these three items into a more manageable site, the crew could save time accessing their tools, information, etc. These improvements alone will not generate a Lean process, but will aid in creating better flow. By making many small adjustments and looking at the site as a whole it will become possible to create a Lean site layout.

### 3.1.4. Work Sampling Asphalt Pavement

The second major task that was observed and documented was the paving of the approaches for the two bridges. There were many major wastes observed in this process that if apparent in other transportation projects should be addressed in order to greatly improve productivity in infrastructure construction. As seen below, over half of the time observations documented a non-value adding activity.

The following is the equation used for calculating the sample size:

$$N = \frac{K^2 P(1 - P)}{S^2}$$

Where:

N = Number of Observations

P = Decimal Equivalent of Percentage in Category

K = Number of Standard Deviations

S = Sample Percentage

$$N = \frac{(1.88)^2(0.28)(1 - 0.28)}{(0.06)^2} = 198$$

Utilizing 1.88 standard deviations to give a 94% confidence limit (6% limit of error) and an estimate of 28% value-added work as the category percentage, a total of 198 samples was required for this project to allow assumption of a normal distribution for the observations. These samples were taken at random time intervals and utilized the observation sheet shown in Appendix A. All of these observations were recorded in one day, as all the work for the rebar was performed in one day.

As shown in Figures 16 and 17, asphalt paving work consisted of only 35% direct work and 51% pure waste.

From this, the non-value-adding activities were broken out further in the pareto chart in Figure 18. As shown, waiting accounted for over 70% of the non-value adding time. For the project as a whole waiting accounted for 37% of the total time spent on the job.

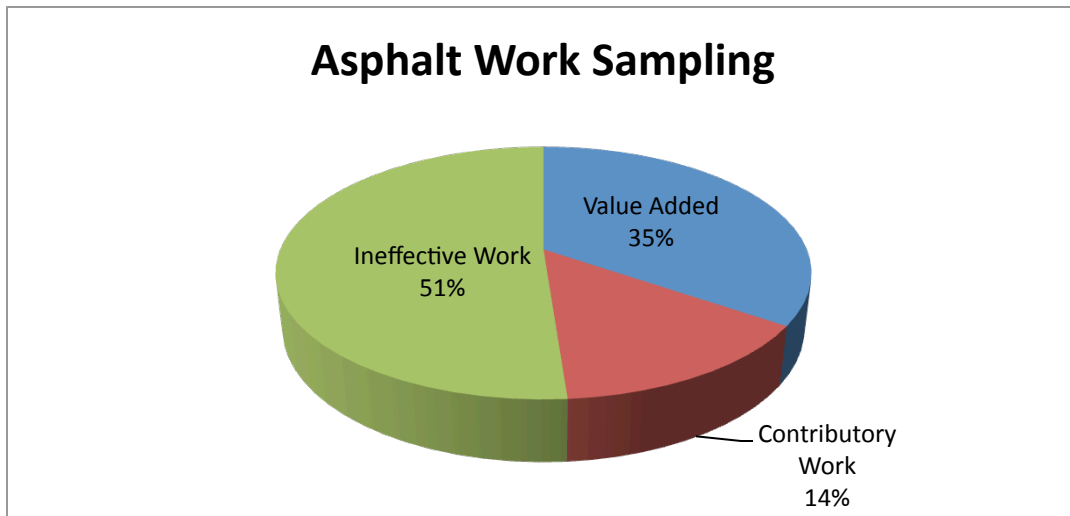


Figure 16. Summary Asphalt Work Sampling Pie Chart

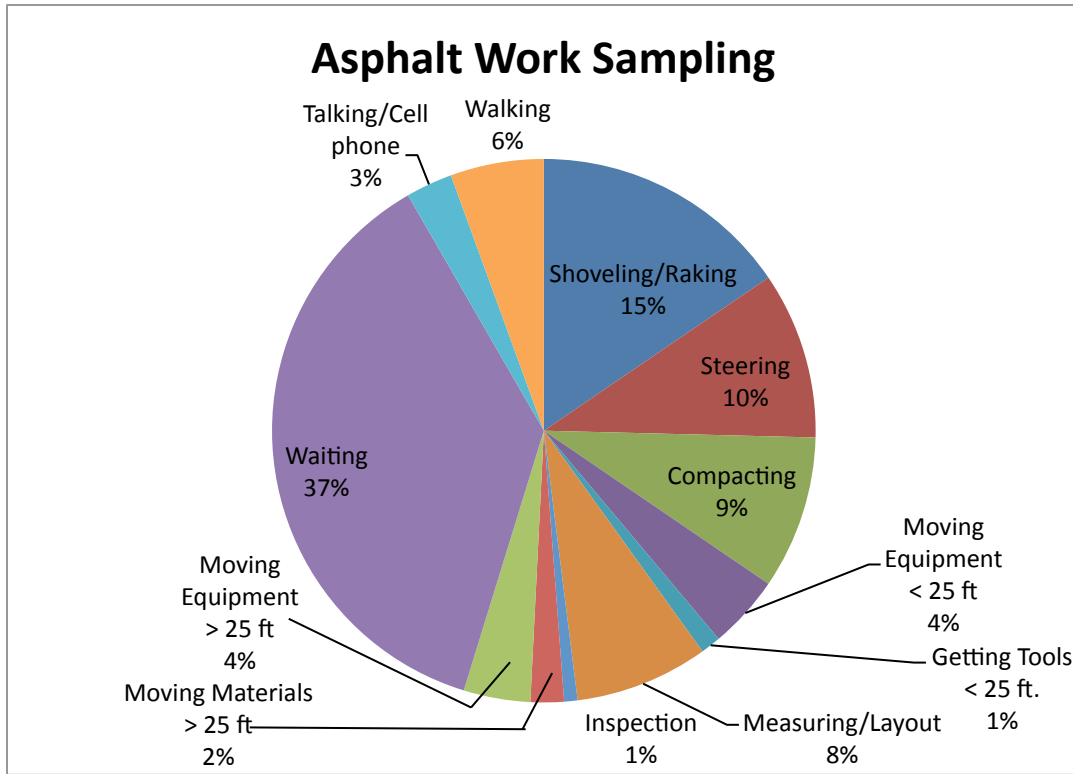


Figure 17. All Observed Asphalt Paving Related Activities

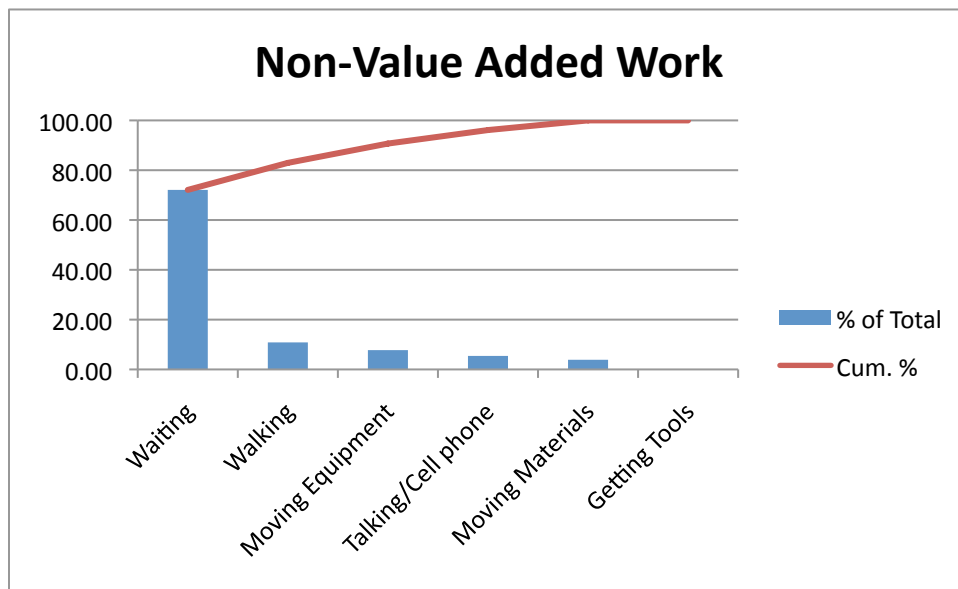


Figure 18. Non-Value Added Asphalt Pareto

By eliminating excess waiting and walking the non-value-adding activities can be almost completely eliminated. These are two of the easier activities to eliminate because root causes are easy to identify. In the asphalt example, the main reason so much waiting was observed was because there was not a steady supply of asphalt to the project. Because of this, the crew would have to wait for the next truck to show up as shown in Figure 19, where all seven crew members are waiting for the next truck to arrive.



Figure 19. Crewmembers Waiting for Asphalt Truck

Identifying the causes of waste is important because any improvement made can become instant profit for the contractor. In this case, 37% of the project went to paying a crew to wait. Any reduction in waiting relates to higher productivity and better profitability for the contractor.

The other interesting aspect of this particular project was that both bridges were being paved at the same time. These bridges were approximately 1.25 miles apart and it took the paver about 15 minutes to drive from bridge to bridge. However, instead of doing the measuring and pre-marking during this time, the crew waited for the paver to get to the next bridge before starting these activities. In the case of the eastern bridge, an asphalt flume had to be created before the second layer of asphalt could be laid. This activity took about 15 minutes and was a value-adding activity. However, instead of having two crewmembers drive ahead with the asphalt truck to create the flume, the crew waited until the paver arrived and then had two people work on the flume. This is an instance where the crew could have looked at the entire project and realized that they needed to complete the flume before paving, and thus should have had two people drive ahead to do so. To better understand this situation, the photos in Figures 20 and 21 depict what was happening onsite.

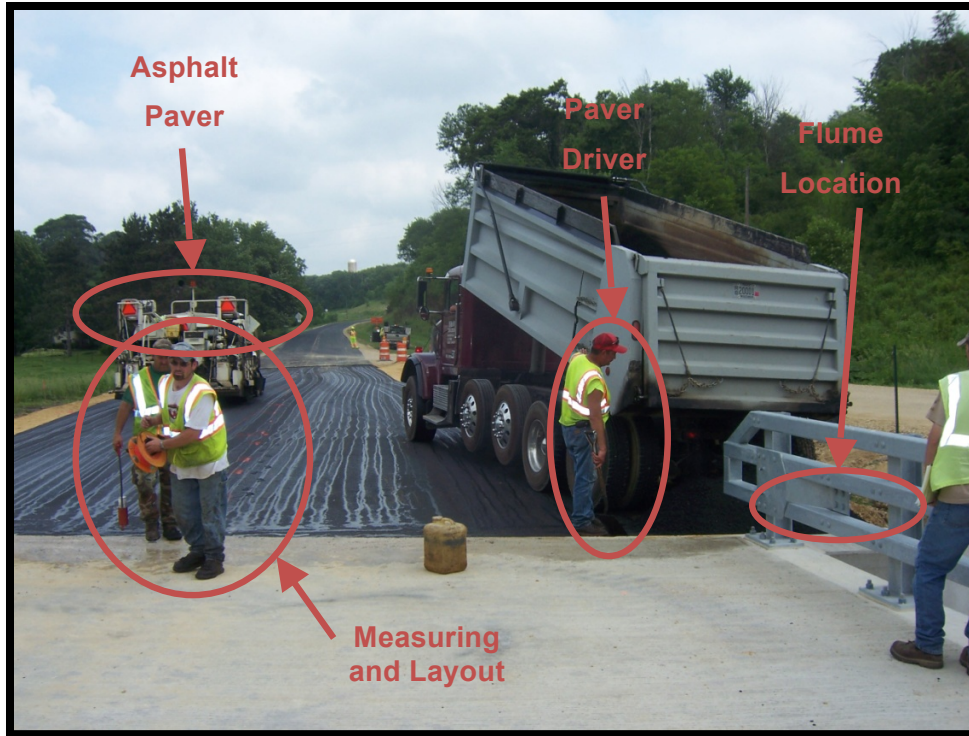


Figure 20. Asphalt Flume Picture 1

Figure 20 shows that the paver was driven the entire way and Figure 21 shows that both the layout and the asphalt flume were both started once the paver arrived. Both of these activities could have been completed before the paver arrived at the bridge. By mapping out the process ahead of time these are the types of activities that could have been identified and created a more efficient construction site.





Figure 21. Asphalt Flume Picture 2

### 3.1.4.1. Asphalt Work Sampling Conclusion

Reflecting back on the definition of Lean, it can be thought of as a group of techniques to create the most efficient process possible. The tools demonstrated in the previous section and discussed in this report are ways for projects to become more efficient. It is evident in this case study that had there been a VSM all activities would have been identified. This would have allowed the team to think of ways to best utilize their time on site. Additionally, the waiting for trucks could have been corrected by having improved coordination and a better delivery schedule. Furthermore, this crew had seven members, one flag-person, and one foreman who was onsite for a total of nine employees. Perhaps the company could have looked at the crew size and realized that they could have done the same task with fewer people.

### 3.1.5. Work Sampling Example Conclusion

As shown in both work sampling studies, there is a large amount of work that is non-value-added. Table 2 lists the LUFs (labor utilization factors) for each activity and shows that these activities had a LUF from 38-42%.

Table 2: Labor Utilization Factors for Work Sampling Study

Activity	Value Added Work (1)	Essential Work (2)	Labor Utilization Factor (LUF) = (1) + 0.25*(2)
Rebar Installation	32%	39%	41.75%
Asphalt Pavement	35%	14%	38.50%

Thus, at best, labor was only being effectively utilized 42% of the time during the rebar installation. This should be an alarming statistic as it is indicating that over 50% of the activities are non-value-adding activities. In an ideal world, these inefficiencies could be eliminated and the time to perform these processes should be reduced to only the value-added time plus a quarter of the essential non-value-added time. By being able to achieve this kind of productivity, the industry would see a dramatic improvement in productivity. In conclusion, STAs must begin identifying the steps in infrastructure project processes and finding ways to reduce the non-value-adding activities in order to achieve the most efficient process possible.



## 4. Case Studies and Company Interviews

Having defined the Lean concept and identified Lean tools, and having shown that waste exists in current construction practices, public projects in the United States were sought in which Lean techniques were specifically applied. Many attempts were made to locate a Lean public project, but no such project was found and thus the authors contacted Bechtel Corporation to learn more about the application of Lean techniques in delivery of transportation and other projects in foreign markets. This provided a better understanding of the impact Lean techniques can have on a public project. Bechtel personnel provided literature and participated in phone interviews which provided the necessary information to understand the Lean implementations currently used by Bechtel.

Bechtel is the largest contractor in the United States (ENR, 2010) and in 2007 Bechtel established their Lean tool kit through their Six Sigma Program. The reason behind this initiative was that Bechtel realized they were in the same category as all other contractors in terms of productivity declines as shown earlier in Figure 2. Since then, Bechtel has successfully implemented Lean techniques into several of their projects. For this research, case studies conducted by Bechtel were evaluated to determine the effectiveness of their Lean initiatives. The following sections describe each project's Lean strategies and show the results of the implementation impact on each project.

### 4.1. Albanian Motorway Project<sup>1</sup>

The Albanian Motorway Project summarized in Figure 22 is a 61 km motorway with a 5.5km twin bore tunnel which runs from Rreshen to Kalimash in Albania with a cost of \$915M under a fixed unit rate contract with the Albanian Government. Bechtel, along with the Turkish firm ENKA, formed a joint venture and delivered the project using a Construction Manager at Risk system.



Figure 22. Albanian Motorway Route

<sup>1</sup> Case study information comes from (Silby, 2010), (Bechtel Corporation, 2008)

The Motorway project was very important to the Albanian government because the re-election of the incumbent government was in part dependent on the successful opening of the tunnel.

#### 4.1.1. Albanian Motorway Project Delay

As the tunnel's excavation began, it was evident that the rock quality was significantly worse than the conditions described in the plans. This initially pushed the project back from March of 2009 to September of 2009 (five months). The material onsite was classified into five categories with I being the best and V being the worst. As the number of the classification increases the time and labor required to tunnel increases as well. As the project began, areas that were supposed to be type II and III material turned out to be type IV material. This created an increase of 900% in type IV material. Thus the planned construction methods for the project were not going to be adequate for completing the project on time. Tunneling was the most critical activity in getting the project open on time and had to be improved quickly.

In order to rectify the situation, Bechtel formed an improvement team that implemented a Strategic Gap Analysis (SGA) in late 2007 to create a plan for completing the project by June 2009. SGA is forecasting technique in which the difference between desired performance levels and the extrapolated results of the current performance levels is measured and examined, indicating what needs to be done and what resources are required to achieve the goals of an organization's strategy. The existing tunneling process cycle, as shown below in Figure 23, was the first step in the improvement process for the team.

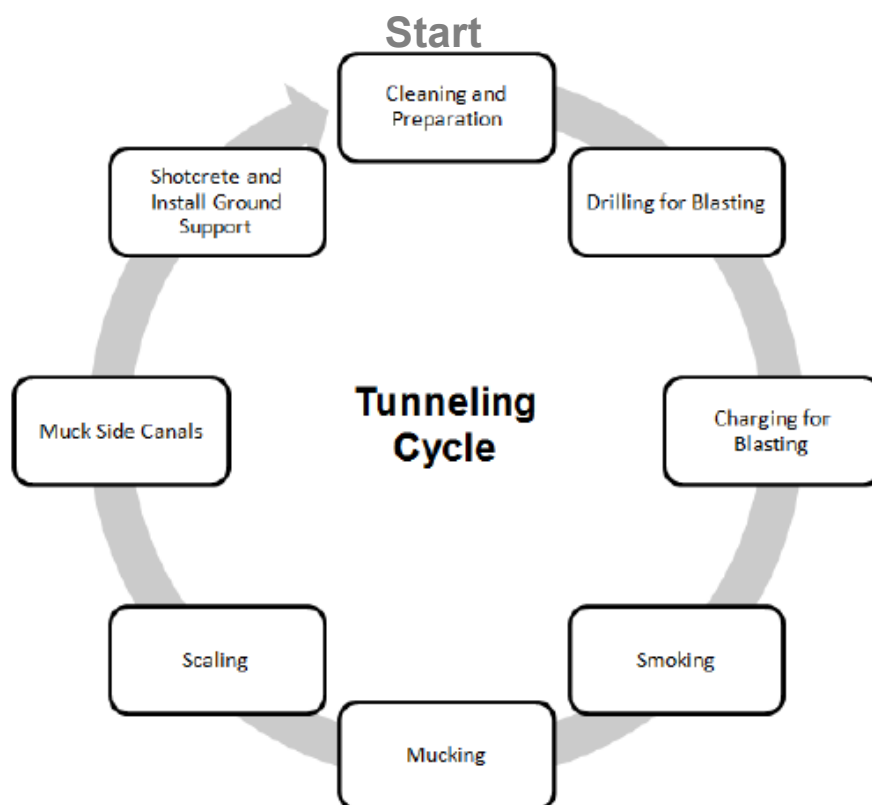


Figure 23. Tunneling Process Cycle on Albanian Motorway Project

Data was collected on the tunneling process for 100 days in order to understand the current state of the tunneling cycle. Once the process was known, a variety of Lean tools were used in

order to determine the problems and start the improvement process. The project team implemented a number of lean techniques (see Glossary):

1. A process map - A pencil and paper tool that helps to visualize and understand all the actions (both value-added and non-value-added) required, the flow of material and the flow of information as a project makes its way through the delivery process;
2. A pareto chart - A statistical technique to identify the minimum amount of activities with the most significant effect;
3. Standard work methods – A standardization process by which tasks are broken down into repetitive, easy to understand sub-tasks;
4. A fishbone diagram – A structured diagram mapping the relationships between causes and effects;
5. A time motion study and iGrafx Simulation – Methods of workflow modeling; and
6. 5-S strategies - A set of workplace organization rules designed to increase efficiency. The 5 'S's stand for: (1) Sort, (2) Straighten, (3) Shine, (4) Standardize, and (5) Sustain.

Standard processes were then developed for each process and step change. The team initiated the improvement process by creating incentives which were bonuses based on tunneling productivity. In this case, the incentives recognized the safe, high performance and fast-track improvement process.

#### 4.1.2. The Improvement Process

The improvement process was initiated by analyzing a Pareto diagram that identified the key factors in the tunneling process. As seen in Figure 24, the Shotcrete, drilling, and mucking activities were the three largest factors in improving tunneling productivity.

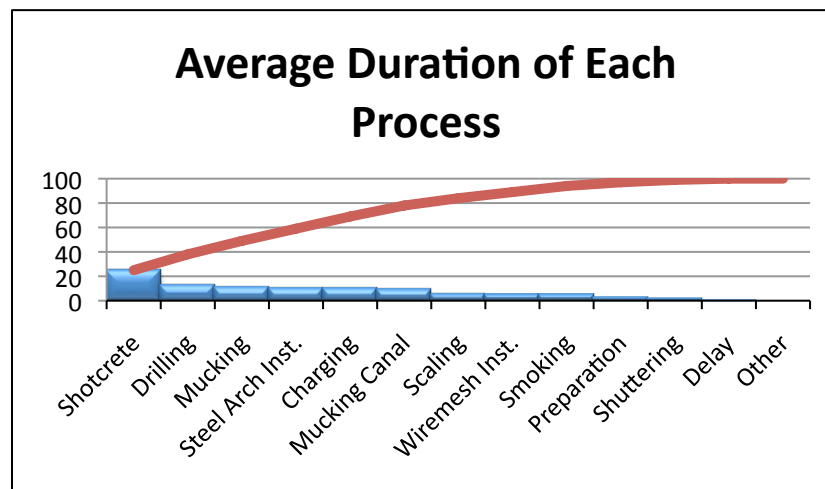


Figure 24. Pareto Analysis for Albanian Motorway Project

The team used the results of this analysis and initiated improvement programs immediately on the Shotcrete, drilling, and mucking activities which accounted for approximately 50% of the total process cycle.

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. Waiting in the process due to delays with mixer truck arrival times was one of the main wastes in the Shotcreting process. Additionally, the team found that the Shotcrete machines were not being used to their maximum capacity. By having better coordination with the mixer trucks and improved training to increase capacity the process cycle was improved by 18% (30 minutes).

The drilling process had the second highest cycle time. The team found that the most frequent recurring problem was failure of the host pipes on the booms resulting in lost production. In order to ensure that down time was minimized the team created a revised maintenance regime as well as added an extra drilling jumbo to guarantee 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. This process was reduced from an average of 98 minutes to 85 minutes which is an improvement of 13% (13 minutes).

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. Additionally, 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 reduced the mucking cycle time from 123 minutes to 105 minutes which is an improvement of 15% (18 minutes).

These improvements alone reduced tunnelling cycle time by one hour. The results of these improvements are summarized in Table 3.

Table 3: Albanian Motorway Improvement Table

	<b>Shotcrete</b>	<b>Drilling</b>	<b>Mucking Away</b>
<b>Wastes Found</b>	Delay in Mixer Truck Arrival, Poor application	Waiting due to repairs	Waiting
<b>Tools Used</b>	Walking the Site, Fishbone Diagrams	Lean performance evaluation	Simulation, iGrafx Simulation (workflow model)
<b>Solution</b>	Better coordination of Trucks	Provide an extra drill	Improved traffic control, side mucking
<b>Improvement</b>	Time was reduced by 30 minutes (18%)	Time was reduced by 13 minutes (13%)	Time was reduced by 18 minutes (15%)

#### 4.1.3. Results of the Improvement Process

Project process was tracked through the improvement process. Throughout the project, tunneling productivity in class IV rock increased by 43%. This resulted in an improvement from 3.07 m/day initially to 4.45 m/day. As an end result of these improvements, the project was successfully opened on time and the government officials were successfully re-elected.

There were many positive outcomes from this project, the most important one being that the tunnel was able to open in March as planned and did not cause any delays. In a traditional process, the contractor would have accelerated their work and more than likely been over budget. However, Bechtel and their partner ENKA were both able to walk away with a savings of \$10.5 million each. This translates to 2.3% of the project being straight profit (\$21 million / \$915 million) when traditional profits average approximately 2% for an entire project (Hanna, Spring 2009). Thus, if Bechtel had an initial 2% profit on this project, they doubled their profit through this initiative. Additionally, the improvement processes helped to provide a framework for best practices on future projects, as well as taught ENKA the Lean/Six sigma process. This

helps disseminate the improvements in construction management techniques and to increase industry confidence in the benefits of using these techniques.

The implementation of the process improvement was not unimpeded. There was a large cultural barrier that had to be overcome. This was achieved by involving the craft level workers early on in the improvement process and seeking their advice. This allowed the improvement team to fully understand what was going on in the tunneling process and experience the working conditions. By involving the craft level workers (bottom up approach / empowering the workforce), change implementation became easier since a clear understanding of the work and obstacles was set in place. However, initially it was difficult to gain interaction with the Turkish workforce and the attempts to seek improvements in performance were met with resistance. Culturally, pride was extremely important and the workforce was resistant to the direct approaches of continuous improvement. This obstacle was cleared by being empathetic towards the workers and showing that their input was valued. This goes to show the main impact of Lean management is that Lean is an overall systems approach and only works if there is buy-in from all of the players. Without the buy-in, it is only a collection of poorly understood tools.

## 4.2. Jubail Industrial City<sup>2</sup>

Jubail Industrial City (Figure 25) is one of the largest civil engineering projects in the world today. The city serves 40 primary and secondary industries including oil refining, petrochemicals and steel as well as hosts a community for 140,000 residents. Bechtel has been in charge of managing the project on behalf of the Royal Commission for Jubail and Yanbu for the past 30 years. Bechtel has provided engineering, procurement, and construction management of all of the facilities and the accompanying infrastructure for the city located in Northeast Saudi Arabia.



Figure 25 Location of Jubail Industrial City

### 4.2.1. Jubail Industrial City Delay

In 2008, the Royal Commission re-launched its “Home Ownership Program” for its employees. The first set of construction contracts for the 415 villas was awarded in April 2008. In May 2009, the contractor had failed to erect and complete the super structure for a single villa. Due to this delay, Bechtel initiated a system diagnosis to determine the root causes. The targeted area of improvement was increasing the number of exterior insulated panels that were delivered to the construction site. The baseline performance target was 18 panels per day which had to be increased by 300% to 75 panels per day. The team needed to find the best way to achieve this goal in order to get construction of the city back on track.

### 4.2.2. Jubail Industrial City: Waste Identified

In order to thoroughly understand the current state of the process the improvement team created a VSM. This map was used to identify the causes for delay and determine where the inefficiencies were occurring. The VSM focused on the cycle from mixing the batch of concrete through to transporting panels to the site. The basic panel cycle is shown in Figure 26.

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<sup>2</sup> Information for case study from (Silby, 2010), (Bechtel Corporation Civil GBU, 2009), (Rizwan, et al., 2010)

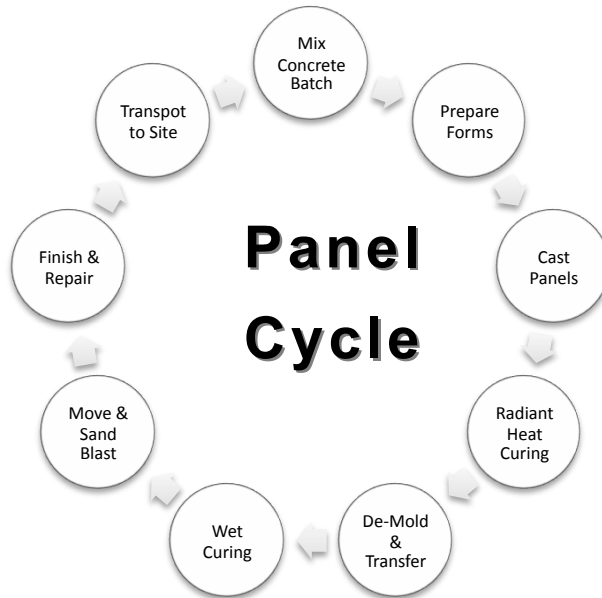


Figure 26. Insulated Panel Cycle for Villas

The team was looking for evidence of waste in the process which could be improved. The team found five main wastes that were impacting the success of the project as seen in Figure 27.

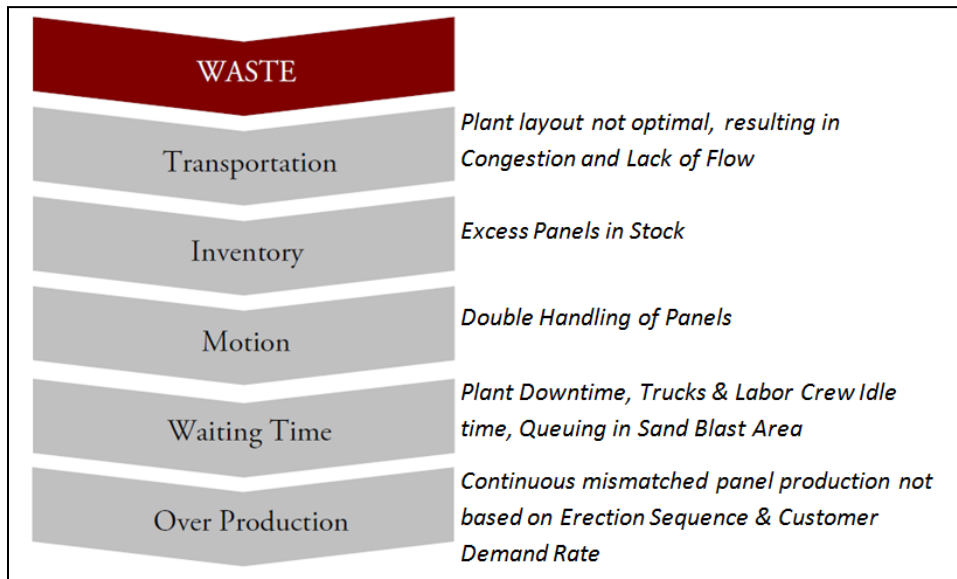


Figure 27. Initial Lean/Waste Assessment for Jubail City

Analyzing the wastes in the project, the assessment was made that the contractor had the basic resources in place; the deficiencies were due to leadership, the process, and control of the project. In order to address the new issues the team identified seven key areas of focus and used six Lean tools to establish the performance metrics and remedial measures to determine the current and desired performance. The seven improvement areas the team focused on were: 1) Organization/Leadership; 2) Process/Flow; 3) Waste/Visual Controls; 4) Pull Systems; 5) Standard Work; 6) Resource Configuration; and 7) Logistics. These seven areas were analyzed using the following six Lean tools: 1) Value Stream Mapping; 2) Simulation/Modeling; 3) Gemba/Kaizen; 4) Takt Time/Pitch; 5) Work Balancing; and 6) Control/Capability Charts.

### **4.2.3. Improvement Process**

#### **4.2.3.1 Improved Leadership/Supervision**

The team found that there was a lack of top down supervision and this had crippled the project's operations. To correct this matter, the contractor realized that they had to break down communication silos and create a collaborative environment. This was done by first identifying a plant manager as well as a general site superintendent. Additionally, four foremen were appointed to six different production areas, and a full time quality engineer was hired to reduce defects. These efforts helped to boost team morale and get the project back on track.

#### **4.2.3.2. Optimized Process Flow Through Increased Resource Utilization**

A process simulation was performed on the pre-cast facility and significant queuing time was identified for both the Gantry Cranes and the Concrete Bucket. Resources were quickly reallocated and two Gantry Cranes were then dedicated to the production area instead of the one shared crane. An additional concrete bucket was also introduced to speed up the casting process. These as well as a few other adjustments led to constant work on the production line and created a higher daily throughput.

#### **4.2.3.3. Eliminated Waste through Better Inventory Management**

Reconfiguration of the Panel Stockyard was recommended for better access and control as it was a major bottleneck of the production process. The yard was unorganized which led to double handling while moving and storing panels as inventory built up. To correct the bottleneck issue, the team utilized a grid system which provided an efficient method for correctly storing and locating panels. Also, an extra transportation lane was added in order to load the panels more effectively.

#### **4.2.3.4 Transitioned to Pull Versus Push Operations**

It was discovered that the fabrication crew was producing panels that were not needed immediately on site, which resulted in large inventory build-up. To correct this, the fabrication crew worked with the contractor to develop daily production schedules to determine which panels needed to be delivered and when. This helped the crew to develop a Takt Time (see Glossary) in which they found a measurement of four panels an hour was required to achieve the 75 panels per day requirement. This effort led to increased productivity and collaboration on the project.

#### **4.2.3.5. Documented Standard Work**

A lack of standard activities with clear roles, responsibilities, and accountabilities led to low craft productivity. The improvement team worked with site management to create uniform standard work for both shifts and created a procedure-based mode of operations. As a result of standard methods, process cycle efficiency increased from 6.6% to 22%.

#### **4.2.3.6. Expanded Sandblasting Area with Dedicated Resources**

A major bottleneck in the flow of the panels was the lack of sand blasting equipment and a secure and safe area in which to work. The improvement team found that the crew size had to be increased from two to ten in order to handle the demand of the project. Additionally, a new sand blasting area was created and one tower crane and two mobile cranes were dedicated solely to this operation.

#### **4.2.3.7. Improved Logistics and Supply Chain**

Long turnaround time of panel delivery trucks was cited as a major delay due to the fact that one truck was delivering panels to many different locations. To solve this inefficiency, the stockyard crew was instructed to load the panels in clusters of panels that were to be delivered to the same location. This helped speed up deliveries and reduce cycle time.

#### **4.2.4. Jubail Improvement Results**

By moving through these steps, the project was able to achieve a 300% productivity gain in the span of one month due to the implementation of the results from using LPD tools. Further data collection and analysis confirmed that the process was in statistical control and that the contractor was able to increase the mean output of panels to 80 per day, or a 44% increase from the baseline. Further analysis was conducted in order to confirm that the process was producing consistently and was capable of meeting the specifications. It was determined with a 95% Confidence Level that the improved process would deliver the required output 87% of the time.

### **4.3. Oil, Gas and Chemicals, Inc.<sup>3</sup>**

This section looks at three of the first Lean projects that were conducted by Bechtel for their Oil, Gas, and Chemical (OG&C) projects. When approaching these projects Bechtel saw that there was a large gap in the way projects are run. Traditionally, management was modeled after Taylor's scientific management theory which states that management should pre-plan each action of every worker (Gatlin, 2010). This practice dehumanizes the workers and treats them as machines. Therefore, this is a prime example of the eighth waste as defined by Liker, which is unused employee intellect. In contrast, Bechtel went the route of Toyota and adopted the Lean theory of shifting the focus onto the craft workers (bottom up approach) to improve productivity at the worker level.

Bechtel had determined that they had experienced a decline in productivity similar to the construction industry as a whole over the past few decades. Due to the decline in productivity and the declining craft labor force in recent years, Bechtel saw that a highly productive labor force is essential to Bechtel's competitive advantage and business growth.

To start the program Bechtel's improvement team used the Define-Measure-Analyze-Design-Verify (DMADV) process to design, pilot, and validate their Lean Construction at the Workforce Program. The process started by performing a voice of the customer (VOC) study (see Glossary) to gather customer requirements. These customer requirements were then transformed into design requirements for critical elements of the program which was first implemented on the following three projects.

#### **4.3.1. Shell Upgrader Expansion Project**

The Shell project obtained 108 improvement suggestions from the workforce during the pilot study. Of these suggestions a small set of improvements were explored further to determine the potential effectiveness of the ideas.

The first suggestion was to focus on training the piping and electrical crews as these two crews showed the largest gap between planned and actual performance. By just slightly improving the

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<sup>3</sup> All information for the case study was obtained through (Silby, 2010), (Bechtel Corporation, 2009), (Smith, 2009)



Performance Factor (Estimated Unit Rate/Actual Unit Rate) from 1.04 to 1.03 the schedule could move from 4% behind planned to 1.5% ahead of planned with a potential savings of \$120,000.

The second suggestion was to issue gloves, welding lenses, etc. to all foremen in bulk in order to reduce the craft wait time at the tool crib and to stagger times for the craft to visit the crib for additional items. This reduces the waste of waiting and excess motion and has a potential savings of \$250,000.

The third suggestion was to add small wagons for the craft to carry their tools, this eliminates the need to wait for Teamsters to transport tools. This reduces waiting and has a potential savings of \$285,000.

The fourth suggestion was to issue extra copies of field documents to foremen so they would not have to waste time making copies and adding wear to the copiers onsite. This saves one to two hours per week per foreman, which equates to 100-200 hours per week saved. This reduces the waste of intellect and motion and has a potential savings of \$155,000.

Another suggestion was to add additional radios ordered and distributed to the crews so that each crew should save two to three hours per week per crew, over fifty crews. This helps reduce excess motion and has a potential savings of \$190,000.

#### **4.3.2. Motiva Port Arthur Refinery Project**

The Motiva project obtained 196 improvement suggestions from the workforce during the pilot study. The three main suggestions are listed below.

The first suggestion was that the craft identified gaps in pipe planning, with the root cause being a lack of detailed input in the planning exercise. As a result of this, the field planners were required to regularly walkdown piping areas. By using the knowledge base of the craft and asking “why” to determine the root cause of the problem, the project realized a potential savings of \$400,000.

The second suggestion was that the rebar crews were waiting up to an hour for materials. This was solved by improving the communication with the night crew in order to ensure that the day crew had the right equipment and materials at the beginning of their shift. This reduced the waste of waiting and carried a potential savings of \$60,000.

The third suggestion was to create a checklist to develop standard housekeeping responsibilities since the labor crews were constantly training new hires on these responsibilities. By keeping a clean worksite and creating standard checklists there was a potential savings of \$50,000.

Through these three suggestions alone it can be seen that there was a potential savings of \$510,000 through just communicating and understanding what is truly needed at the craft level in order for the construction processes to run more smoothly.

#### **4.3.3. Wood River Refinery Project**

The Wood River project obtained 44 improvement suggestions from the workforce during the pilot study. Of these suggestions a small set of improvements from the project were explored further to determine the potential effectiveness of the ideas.

It was found that the buses were making too many stops, and that buses at capacity were stopping at the tool room, waiting for one person in line to get a tool and return to the bus. They found the opportunity to improve the time to work place from 15 minutes to five by requiring the

craft to walk to their work areas. This significantly reduced the waste of waiting and created a potential savings of \$1,300,000.

Additionally after several Lean sessions, an additional tool crib was added to the project to minimize the walking and waiting time at the tool crib. This helped to reduce the waste of waiting and excess motion which generated a potential savings of \$420,000.

To help with the organization on site, hooks were installed in the job boxes to hang harnesses, which provided quicker access and eliminated safety risks. This extra effort in organization saw a potential savings of \$350,000.

The fourth major improvement area found was that bright-green, snow-fence walkways and better signage were installed to clearly indicate open travel routes and reduce incidents of craft workers walking down roads only to find access was blocked. This reduced the waste of motion and had a potential savings of \$250,000.

Thus, through these four small improvement suggestions a total of \$2,320,000 was possible on the Wood River project.

#### 4.3.4. Conclusions from OG&C Pilot Projects

A major takeaway from these three pilot projects, illustrated by the numbers in Table 4, is that there is a lot of potential savings by just empowering your workforce and asking the people doing the work what can be done to improve it. At the end of these projects the craftsperson would come away saying “How can I perform this task more effectively?” rather than “I have no say in how to get this job done.” That is a huge hurdle to get over, but once the workforce feels that their voice is being heard, the ideas will continue because everyone wants a better working environment.

Table 4: Wastes Found in the Pilot Project

Project	Wastes Found	Total Potential Savings (Sample)
Shell	Waiting, excess motion, waste of intellect	\$1,000,000
Motiva	Waste of intellect, 5-Why, waiting, 5S	\$510,000
Wood River	Waiting, excess motion, 5S	\$2,320,000

#### 4.4. Bechtel Case Studies Conclusion

Reflecting upon the case studies presented above, Bechtel shows that there is not one single solution to every problem. The true value behind a Lean program is that it can be tailored to fit the unique situations of each project. As shown, it is not just one tool that is used throughout, but it is the fundamental improvement process. Bechtel does a very good job of first identifying the problem and the constraints to improvement. It is there that the focus starts to improve the project. This is very important in any improvement process because in order to get buy-in from all parties small successes have to be celebrated in order to keep the movement going. Thus, the quick fixes should be made immediately in order to show a savings and to gain momentum for the tougher challenges that may be present in the current project, or in future projects. The Lean process is a continuous improvement process which means that there will inevitably be continuous change. Because of this, participants have to feel that what they are doing is benefitting their work.

As shown in the three case studies from the Lean implementation at the craft level, Bechtel immediately went to the workers and created a bottom up approach in order to gain buy-in. This was the same in the Albanian Motorway Project where getting the Turkish workforce to buy-in was essential to any project improvement. Thus, as the Lean movement goes forward, it is important to keep the employees informed on the change process and to ask for their input. By including the workers in the improvement process there is a sense of ownership of the process and this will generate ideas that management may not know of because management is not doing the direct work.

Therefore, the essential factor in the improvement process is that the craft workers need to be included and there has to be a support structure in place to foster this type of program. Additionally, it is the culture that makes the tools useful; if there are just tools and no cultural change then it will be very difficult to create change and obtain the necessary buy-in to make the tools useful. As shown in the case studies above, it is not just one tool, it is a combination of tools that need to be selected in order to create the best process. Thus, there must be a toolbox from which individuals can choose the tools that will be most effective on a specific project. Even more importantly, individuals must be trained to use the tools and must be able to select the most appropriate tools for their situation.

## **5. Promising Lean Techniques for Use on Infrastructure Projects**

The theory of Lean is very much about creating a collaborative, continuous learning culture. The culture may be the most important part in having success in implementing Lean. To help facilitate a Lean culture, many tools have been developed to aid in the creation of the culture. The tools presented in this chapter are the tools found to be the most applicable to public sector transportation infrastructure projects.

Lean techniques can be implemented in two ways, incrementally or transformatively (or “disruptively”). Incremental techniques draw off of current practices and add a lean twist to current work habits in order to gain buy-in. A transformative technique requires a completely new outlook on a project and relies very little on current practices.

With the state of the current industry transformative change will be difficult, thus it is important to first look at the incremental techniques that can be implemented in order to gain buy-in which will eventually allow for the transformative techniques to be used. The tools below are separated into these two categories.

### **5.1. Incremental Lean Techniques**

These techniques can be implemented within the current state of the industry. They will help transition companies from the current state to a lean state. These tools will eventually plateau in individual companies and will need to then be introduced to the entire project team, which will eventually lead to a transformative change in the industry as compared to the current state. All techniques that start out as incremental will eventually become transformative once they require a nontraditional contractual partner to be involved. This inherently requires special contractual obligations, which is what is required for a true LPD program.

#### **5.1.1. Value Stream Mapping**

The first principle in a Lean process is to understand where the value lies. In construction, the number one priority is to add value to the project from the customer’s viewpoint. It is important that each activity is done with a purpose and adds value to the project. The focus has to be on first defining the processes that add value to the project, and then eliminating all of the processes which do not add value.

Value Stream Mapping (VSM) is a special type of flowcharting tool that is valuable for the development of Lean processes. The technique is used to visualize product flows through various processing steps. The tool also illustrates information flows that result from the process as well as information used to control flow through the process (Rother, et al., 2009). To create a Lean process, one needs to have a full understanding of the construction process, including production processes, material flows, and information flows. VSM is a two part process, first depicting the “current state” of the process, and second a possible “future state” (Jacobs, et al., 2010).

The way to implement a value stream map is by selecting a certain process and mapping out how the work is currently done. Once the process is well defined it is important to then describe the problem areas that tend to create problems in the process. Next, a future state map is created, where the process is remapped with the problem areas taken care of. This may include eliminating double handling, excess materials, obtaining information more quickly, etc. Once the future state is created, that map becomes the new goal for the project delivery team to work towards. This then needs to be followed up routinely to ensure that the process is not reverting

back to the old basis. Thus, once a future state map is created, and the process is achieved, it then becomes the new current state map and is reevaluated. An example of a current state map and a future state map for a residential home can be seen in Figures 28 and 29. These figures also depict the typical symbols used for a traditional VSM.

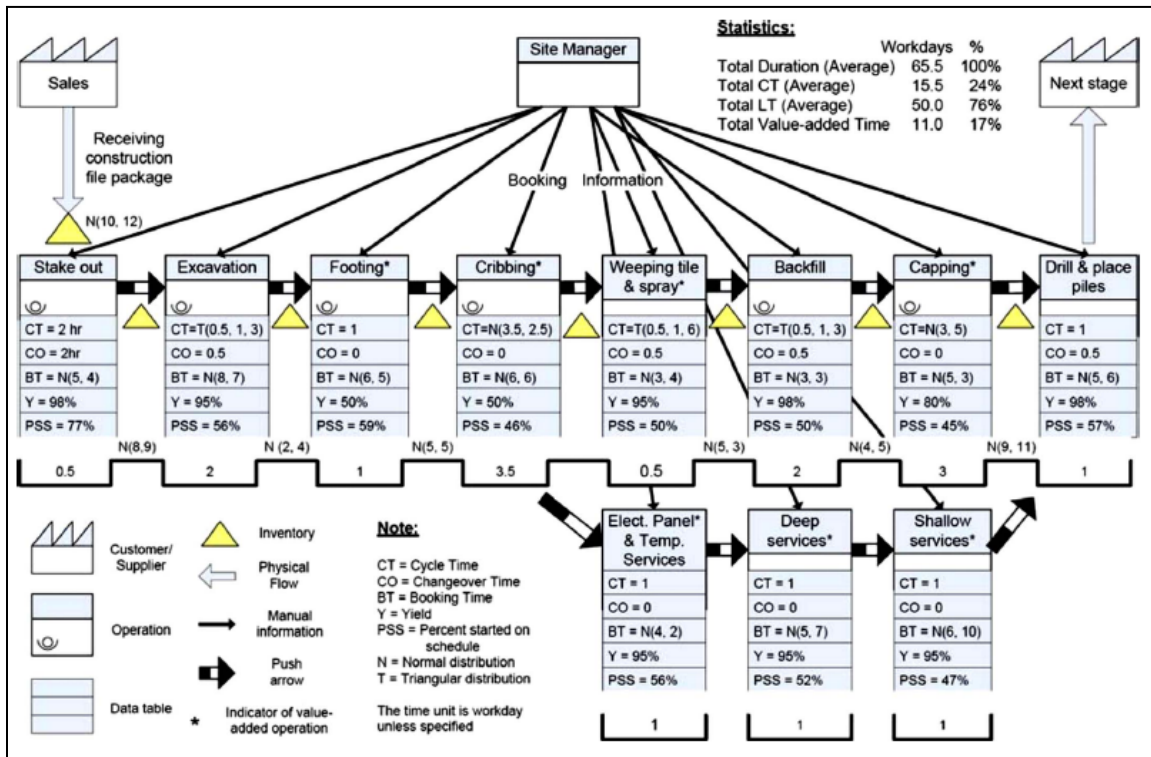


Figure 28. Current State Map of a Home Building Process (Yu, et al., 2009)

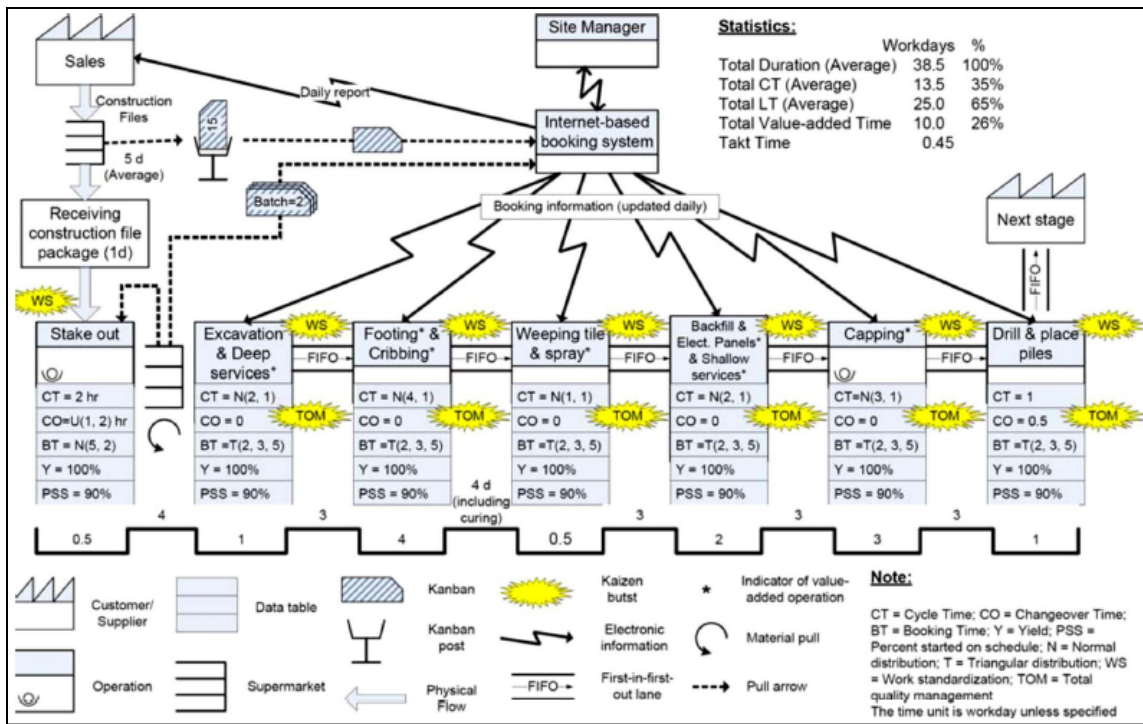


Figure 29: Future State Map of a Home Building Process (Yu, et al., 2009)

The notion of value needs to be understood early on in a project during the design phase. The process of determining value will be a learning process between the client and the design professionals as it is a new concept. But, by being able to sit down and discuss the true value of a project and what the expected outcome is, the owner will be better off because the end product is what they want, and the design professionals will have less rework and headaches due to the client not approving of their designs. The implementation of a systematic value management system allows for the project life cycle to be fully evaluated and ensures that the specified value is delivered (Bertelsen, et al., 2004).

Value stream mapping will be an incremental change as long as it is within a single entity or contract. For example, a prime contractor may find that they rely on a sub-contractor to improve a particular task. However, once they have improved all of the actions that involve solely themselves and the sub-contractor, they may find that it is the engineer, owner, or some other entity that delays the process. VSM can become a transformative change when parties start working together outside a traditional contract to improve a particular value stream.

### 5.1.1.1. Application of Value Stream Mapping

When creating a value stream map, you first identify which process needs improvement. Usually, the chosen process is a critical work process, a process that is error prone, or a highly repetitive process. A team of experts on the chosen process needs to be involved in creating the current state map of the process. The term 'expert' implies that these are the people who are directly involved with the process on a daily basis. The team must be able to have the power to change the current process. The team then needs to create a thorough current state map defining the value-added and non-value-added time of each step. While creating the current state map, it is important to identify problem areas early and often, as these are the areas where improvement should be seen first.

Once the current state is established, the team should come together to address solutions that can address the non-value-adding activities. All possible solutions should be documented, and then the steps required to achieve the solution should be established. It is essential to have individuals take responsibility for each action step in order to provide follow through. This individual will be responsible for creating and implementing a schedule as to when and how the problem will be resolved. Once every cited issue has a possible solution, a master schedule should be created which identifies when each task will be resolved. The plan needs to be distributed to every individual involved in the process in order to ensure that there is a common knowledge about the improvement effort. Meetings should continue to occur periodically (e.g. every other week, once a month) to ensure that the improvement methods are still being addressed and that other problems that arise can be solved.

#### **5.1.1.2. When to Apply Value Stream Mapping**

Value Stream Mapping should be applied wherever there is a production process that is on the critical path or there is an indication of inefficiency. This could be done on every process involved in a project, or could be reserved for the items of largest concern. The VSM should be used to create a realistic state of the current process, and so should be completed after the first trial run. Or, if historical data is available for a particular process, that information can be used for a current state map and the future state map should be created immediately.

#### **5.1.1.3. Economic Impact of Value Stream Mapping**

The old adage goes that what cannot be measured cannot be improved. By creating the VSM, value can be measured, and thus improved. By streamlining processes and identifying the critical areas, a project delivery team can greatly increase their productivity by eliminating wasteful activities. Because of the elimination of wasteful activities, there will be an inherent savings which will translate to increased revenues. Streamlining should also help to improve quality and customer services as products are completed right the first time. Successful implementation of VSM will also help to show the positive change that can be developed through the use of this Lean tool.

### **5.1.2. Last Planner™ / Collaborative Scheduling**

In a Lean culture, it is very important that all schedules are created by the people who are best able to determine actual durations and responsibilities. This means that the ones who do the scheduling are the ones who are doing the work. The best way to accomplish this goal is by asking each group to present their needs along with all other parties involved on the project. This helps to identify any constraints which may be present and provides an interactive collaborative environment.

The main idea behind the Last Planner™ is that the closer you get to an actual activity the more detail you can start attributing to the activity. This way, time is not wasted ahead of time identifying detailed tasks that are going to be off the schedule a month from then. The Last Planner™ introduces the notion of reliable promises. This means that individuals are held responsible for individual tasks and must understand why a certain task does not get done. This helps the project team determine the root cause of a problem and fix it. By scheduling this way and having to answer to the group at the end of the week, teams are more likely to identify constraints early on and complete the work in the proper sequence.

The term Last Planner™ comes from identifying the person who has the last say on a given task, and who is able to make a commitment at the last responsible moment. Thus, the person has the best idea as to when the task will be completed and is in the position to make the necessary commitment. In a traditional approach the people doing the work and the people planning the

work are two separate entities, however this process combines those two roles into one and creates a value flow of information from those implementing the schedule to those planning the schedule.

The idea behind the Last Planner™ is that the project team works together to help identify and remove those constraints that are keeping teams from achieving all of their tasks in a given week. The Last Planner™ operates around the circle of “should, can, will, did.” The “should” part comes from the master schedule which identifies broadly when certain tasks should be performed. “Can” identifies those tasks which are ready to be performed. “Will” represents the tasks that each partner will be performing during the week, and “did” represents the tasks that were successfully completed during the week. This “should, can, will, did” cycle allows for continuous evaluation throughout the project to understand how each task is completed. This process is depicted graphically in Figure 30.

The true outcome from the Last Planner™ method is that it allows commitments to be measured throughout the project. This is extremely useful in measuring reasons why work was not completed. The process can reveal poor planning, poor execution, unreasonable promises, and numerous other reasons that work is not completed on time. By identifying these problem areas during the project instead of after, it allows for a proactive approach to developing solutions.

Again, Last Planner™, represents an incremental change as long as it is within the traditional contract structure, when a single project participant uses it within their organization. However, when engineers, owners, and other government or external companies are included in the process, it becomes a transformative change. This would be necessary for any RFI’s, Change Orders, and other coordination issues that are outside of the contractor’s control.

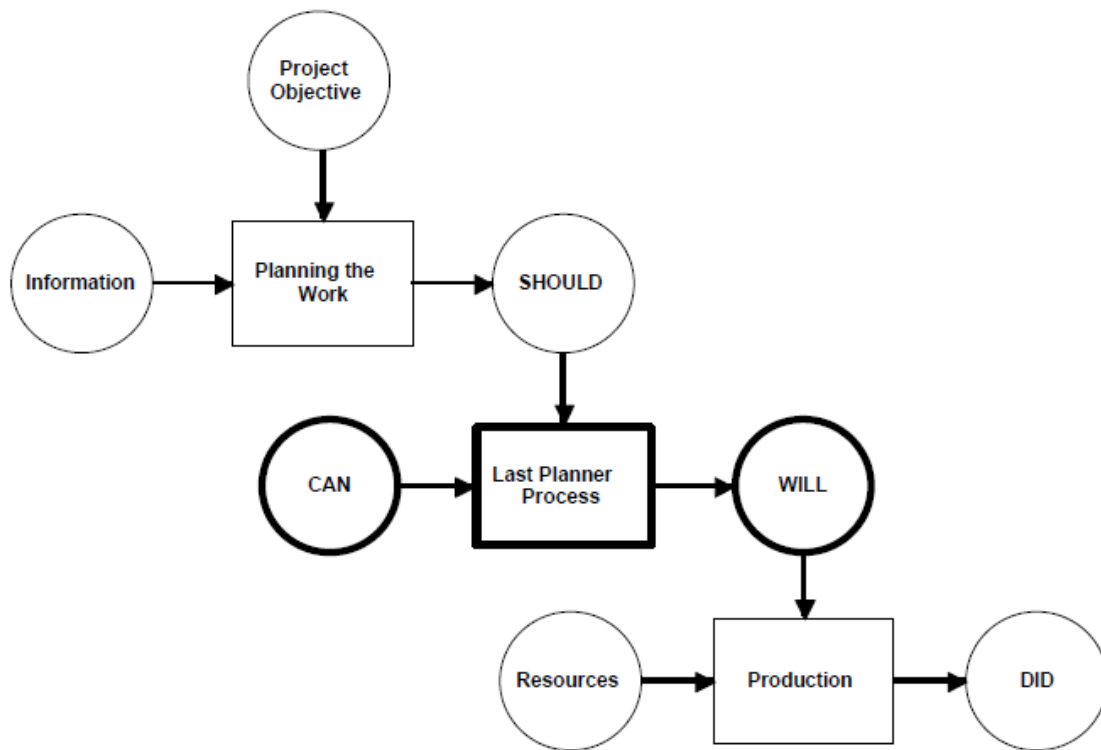


Figure 30: The Last Planner Process (Ballard, 2000)



### 5.1.2.1. Application of Last Planner™

The Last Planner is traditionally implemented at two main levels. The first part is for look ahead planning where tasks are identified up to six weeks out. This is to identify any constraints with the work early on so that they can be solved, or work can be rearranged without affecting the productivity of the project. The second part of the Last Planner™ looks at the job on a weekly basis. Tasks are assigned to individuals on the project who are responsible for getting the work done, an example of a weekly assignment chart can be seen in Figure 31. There is a spot for each activity, the person responsible for that activity during the week, what days of the week that task will be completed, if the activity was completed during the specified time, and then any reasons for a variance in the completion of the activity.

This creates a commitment from an individual party and at the end of the week allows for the task to be measurable. The measure of completed jobs is referred to as the Percent Plan Complete (PPC). By tracking the tasks and identifying whether they are completed on time, more constraints are identified. This allows for the root cause of the delay to be isolated. This is very important because many problems occur more than once on a specific project and are likely to occur on the next project as well, unless a true solution is discovered. Therefore, the Last Planner™ allows for real solutions to problems. The weekly application of the process allows for constraints to be identified during the project so that productivity can increase and any obstacles can be avoided in the future.

1 WEEK PLAN											
PROJECT: Pilot		FOREMAN: PHILLIP									
ACTIVITY		DATE: 9/20/96									
	Est	Act	Mon	Tu	Wed	Thurs	Fri	Sat	Sun	PPC	REASON FOR VARIANCES
Gas/F.O. hangers O/H "K" (48 hangers)			XXXX	XXXX						No	Owner stopped work (changing elevations)
			Sylvano, Modesto, Terry								
Gas/F.O. risers to O/H "K" (3 risers)					XXXX	XXXX	XXXX	XXXX		No	Same as above-worked on backlog & boiler blowdown
			Sylvano, Mdesto, Terry								
36" cond water "K" 42' 2-45 deg 1-90 deg			XXXX	XXXX	XXXX					Yes	
			Charlie, Rick, Ben								
Chiller risers (2 chillers wk.)						XXXX	XXXX	XXXX		No	Matl from shop rcvd late Thurs. Grooved couplings shipped late.
			Charlie, Rick, Ben								
Hang H/W O/H "J" (240'-14")			XXXX	XXXX	XXXX	XXXX	XXXX	XXXX		Yes	
			Mark M., Mike								
Cooling Tower 10" tie-ins (steel) (2 towers per day)			XXXX	XXXX	XXXX	XXXX	XXXX	XXXX		Yes	
			Steve, Chris, Mark W.								
Weld out CHW pump headers "J" mezz. (18)			XXXX	XXXX	XXXX	XXXX	XXXX	XXXX		Yes	
			Luke								
Weld out cooling towers (12 towers)			XXXX	XXXX	XXXX	XXXX	XXXX	XXXX		No	Eye injury. Lost 2 days welding time
			Jeff								
F.R.P. tie-in to E.T. (9 towers) 50%			XXXX	XXXX	XXXX	XXXX	XXXX	XXXX		Yes	
			Firt, Paacky, Tom								
<b>WORKABLE BACKLOG</b>											
Boiler blowdown-gas vents -rupture disks											

Figure 31: Example of a Weekly Last Planner™ Assignment Chart (Ballard, et al., 2009)

### 5.1.2.2. When to Apply the Last Planner™

For any given project the Last Planner can be used on day one and throughout the project to completion. By having a weekly update on work that needs to be done and analyzing what work has been completed, major roadblocks can be identified early and addressed before they are a problem in the field. This planning also can go hand in hand with the initial Master Schedule that identifies key milestones that must be met. By having target dates to get work done the team still has goals to work towards, but now the work is broken up into smaller weekly plans.

The Last Planner™ provides a tool to help all materials suppliers, subcontractors and the prime collaborate and have input in the planning of the work. What may seem to be a logical sequence on paper may not be very logical in the field. By having input in the planning of their work, the people who actually do the work are able to provide helpful insight into project processes, allowing for innovation and refinement of systems which may not have been available otherwise.

#### **5.1.2.3. Economic Impact of the Last Planner™**

Due to the enhanced reliability that the Last Planner™ creates, cost savings are inevitable. Reliable promises allow for work to be done sequentially and flow throughout the project. This reduces the float in the project and reduces stress on accelerated work at the end of projects. The reliability also decreases variability on the project which in turn reduces the uncertainty. When uncertainty is reduced, risk is reduced, and therefore costs decrease due to a lower risk on the project. Because communication flows freely through the project each worker knows what is happening around them, which allows for smarter planning.

Collaborative planning allows for innovation in project delivery because of the open communication. Innovation can lead to new techniques and approaches that may have never been applied due to the uncertainty of the trades partners. When a project can find new ways to increase productivity the job is done sooner and faster than originally planned which results in less manhours and a lower end cost. This is a benefit for both the owner and contractor, as the cost difference can be split between the two parties. This creates an incentive for the contractor because they can make a larger profit on the project, and the owner can pay less for a quality project that is completed ahead of schedule.

#### **5.1.2.4. Case Study Example of Last Planner™ (PARC)**

The Proyecto de Adecuación de la Refinería Cardón (PARC) case study was conducted by Mike Casten, Greg Howell, and Glenn Ballard from November 1994 to August 1995. This project was a 2.1 billion dollar refinery expansion that included approximately 300 national subcontractors, three major EPC (engineering, procurement and construction) contractors, and consumed 50 million field hours (Ballard, et al., 1996). To improve productivity on the project the authors asked three main questions:

1. How well is the project supplying the basic elements of work (information, materials, tools, equipment, etc.) to the crews?
2. What is the method used by the crew to perform the work?
3. How well does the accomplishment of the work itself fill the needs of the workers?

The improvement strategy focused on improving reliability in order to improve performance. This way the predictability of work flow on the project could be more easily determined. A few of the major subcontractor improvements on the project can be seen in Figure 32.

As noted in Figure 32, there were some substantial improvements in many areas of the project. This was the first major construction project on which Bechtel implemented Lean strategies such as the Last Planner™ and demonstrated the potential effectiveness of a Lean tool on a construction project.

<u>Sub</u>	<u>Before</u>	<u>After</u>	<u>% Improvement</u>
Ata	3 supports/day	22 supports/day	600%
Costa Norte	1 54" dia. pipe in 4 hr-19 min	...in 32 min	700%
Den Spie	1 wire/5 min.	1 wire/3 min.	70%
Distral	10 isos/week	15 isos/week	50%
DSD	0.087m/min.	0.9 m/min.	800%
Formiconi	2.75 mh/LM	1.72 mh/LM	50%
Piaca	1 column/hr	3 columns/hr	200%
Rivaco FM	1 siding/13 min.	1 siding/8 min.	60%

Figure 32: Examples of First Run Study Success from PARC (Ballard, et al., 1996)

### 5.1.3. Just-in-Time Delivery (JIT) and Supply Chain Management

The traditional supply system in construction procurement practice focuses on obtaining the lowest price possible for each product and its associated services. When problems occur it is due to the fact that there is a lack of focus on achieving continuous flow to deliver the maximum value to the final customer. In fact, supply systems are not typically defined or designed. The construction industry needs to take a more proactive role in better understanding the complexity of the supply chain (Arbulu, et al., 2004).

The best tools to address this problem are Just-in-time Delivery (JIT) and Supply Chain Management, which are very closely related to each other. JIT coordination of the supply chain is required to manage the flow of workers, materials, parts, components, and subsystems procured to and from a site during construction (Davies, et al., 2009). Just-in-time delivery is an inventory strategy that reduces in-process inventory and reduces carrying costs. The principle is to deliver the right material, at the right time, at the right place, in the exact amount needed (Ohno, 1988).

To correctly implement a just-in-time practice, the proper suppliers need to be able to deliver in this manner. Thus, the management of the network of suppliers and subcontractors is required. This spans all materials, work in process inventory, and finished goods from the point of origin to the point of consumption. The overall goal of managing the supply chain goes throughout design, planning, and execution of the work, to synchronize supply with demand on the project.

The way projects are currently set up, contractors are free to talk to suppliers and have materials delivered any way they like. A single contractor can incrementally improve their supply chain, but it will eventually lead to a transformative change where all contractors will communicate with suppliers, engineers, and others to obtain the necessary materials and information when needed.

#### 5.1.3.1. Application of Just-in-Time Delivery

Applying Just-in-Time Delivery relies solely on the contractor involved in the work. It is up to them to eliminate unnecessary inventory of materials and equipment that is not used to add value to the project immediately. This allows for fewer materials to be stored onsite at a given time and reduces the waste of double handling of material.

Additionally, when large stockpiles are kept on site, someone has to be in charge of managing the stock as well as protecting the stock. This is extra effort that does not add any value to the end customer and is a waste in the process. Large stocks are typically used due to an

uncertainty in deliveries or to hide inefficiencies in the production process. By co-implementing the Last Planner and JIT together it becomes easier to see when a task will be performed and thus a reliable date can be determined. Therefore, the delivery can be planned and the contractor will know that the work will be available. In a traditional sense, the schedule is a guide as to when the task may be available, but the Last Planner is more of a guarantee that the work will be ready and will allow the contractor to be confident in the date set.

#### **5.1.3.2. When to Apply Just-in-Time Delivery**

JIT should be used throughout the entire duration of a project. JIT becomes a business philosophy, and once project efficiency gains realized using JIT are identified it becomes the standard when applicable. The toughest element in applying JIT is ensuring that the suppliers are able to adhere to a consistent schedule and can provide the items that are needed when needed. JIT is an ideal tool to use for congested sites, sites in dense urban areas, and any other site where storage is limited. At the same time, JIT can still benefit projects that have large amounts of storage available.

#### **5.1.3.3. JIT Case Study Example (Heathrow Airport)**

Heathrow Airport in the United Kingdom used many different Lean initiatives in order to finish their project on time and within budget. Starting off, the program stakeholders mapped supply chains and value streams to determine the quantities of materials and resources required for the civil phase of the project. Due to the public involvement in the project, an agreement was made that construction traffic would not be permitted during the hours of 7:00 AM – 9:00 AM and 4:00 PM – 6:00 PM. The construction work had to occur within existing operational terminals and runways, and work was done post 9-11-2001, which resulted in extreme security measures as Heathrow was a known terrorist target. Because of these restrictions, onsite storage of inventory was limited to one day or less, and coordination of the supply system was essential. To better understand the supply system materials were classified in three categories:

- Made to stock – Suppliers produced based on forecasted market demand;
- Made to order – Suppliers produced standard products upon receipt of an order; and
- Engineered-to-order – Engineering must be completed prior to producing the order.

The resulting production management system was coordinated by daily production control meetings and weekly forecast meetings. These were used to pull materials from engineering through fabrication and delivery to site installation. The end results of the Civil phase show that there was an 8%-9% overall savings from planned expenses as well as achieving all major milestones on or ahead of schedule (Ballard, et al., 2007).

#### **5.1.4. Batch Size Reduction and One Piece Flow**

The idea of batch size reduction can be related to many different facets of a construction project. A few examples of large batch sizes currently are when drawings are sent for review and approval, when Requests for Information (RFI's) are made, or when there is a request from one specialist to another for more information than is necessary. The key idea in reducing batch sizes is that while often the information needed is related to a small detail, the request made may be for a design review, when all that is needed is a single piece of information.

The reduction of batch sizes can reduce the amount of time spent waiting for information on a jobsite. In the traditional system, one of the largest forms of waste is just not having information at hand. Therefore, a pull system may be necessary to help obtain the information when needed instead of just receiving a large load of information at one time. The same is true for construction processes as well. A majority of transportation work is fairly linear and dependent

on the preceding activities. In this case it is possible to develop a takt time so that there is a delay of X days of work on the site. This way activities can follow when only a portion of the preceding activity is complete instead of waiting until the entire portion of the project is complete. This will not only reduce the total time of the project, but will help each party to better understand how their work impacts their successors, and can drastically improve how the two parties interact in the future due to this better understanding of what work is absolutely necessary in order for the dependent activity to begin.

Batch size reduction and one-piece flow are incremental changes, as long as they are developed within the traditional contract structure. Again, once owners, STA's, Engineers, and other project participants become part of the one piece flow of the materials or information it becomes a transformative change.

#### **5.1.4.1. Application of One Piece Flow**

One piece flow and batch size reduction relate to creating a continuous flow to eliminate the massive amounts of stopping and starting that occur currently in the construction industry. Continuous flow is created by first establishing a takt Time (the pace of customer demand). The takt time will help to establish how much work/information can be passed. On a transportation project this may be how much roadway is graded a day for the following operation to operate without starting and stopping. Additionally, this could be used to create a timely response to a change order or a Request For Information (RFI) issued by only giving the relevant information and thus making it easier for the reviewer to quickly determine the answer instead of sifting through a stack of plans and specifications to find the one detail that is needed.

#### **5.1.4.2. When to Apply One Piece Flow**

One piece flow should be used wherever possible. To create the most efficient processes they should be able to follow in a line. For instance, on a mill and pave project in Wisconsin, the highway was being milled, while at the same time about a quarter mile behind the top asphalt layer was being repaved. This process is a prime example of one piece flow in that both of these operations were continuous and moved at the same pace. This philosophy should be used whenever practical on all aspects of the project to help streamline the project and eliminate the wasteful steps of starting and stopping.

#### **5.1.4.3. Economic Impact of One Piece Flow**

Economically, one piece flow creates a positive cash flow. Whenever work can be consistently predicted and operate on schedule the project will benefit financially. By creating a continuous flow, it will be easier to predict how long processes should take because there will be a set takt time. This takt time in a transportation sense should be used to create a certain mile/day or similar metric to use.

#### **5.1.5. Six Sigma (6 $\sigma$ )**

Six sigma (6 $\sigma$ ) 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). Six Sigma is a business improvement methodology and must be applied throughout the construction process.

By pure statistical definition, 6 $\sigma$  is a process that produces no more than 3.4 defects per million opportunities (Six Sigma Online, 2010). Six Sigma defines a defect as anything outside of consumer specifications. The Six Sigma approaches to reducing defects vary depending on whether the process is new or already established.

Six Sigma will be an incremental change while the improvements are focused on a single company or contractual relationship in a traditional sense, such as prime and sub-contractor. Once more parties are involved, such as the owner, Six Sigma implementation can be considered a transformative change.

#### **5.1.5.1. Application of Six Sigma**

For already established projects, the Define, Measure, Analyze, Improve, Control (DMAIC) methodology is used:

- Define project goals and the current process;
- Measure key aspects of the current process and collect relevant data;
- Analyze the data to determine relationships and identify relevant factors;
- Improve or optimize the process based upon data analysis; and
- Control to ensure that any deviations from the target are corrected before they result in defects.

For projects aimed at creating new products or designs, the Define, Measure, Analyze, Design and Verify (DMADV) methodology is used:

- Define design goals that are consistent with customer demands and the enterprise strategy;
- Measure and identify CTQs (characteristics that are Critical To Quality), product capabilities, production process capability and risks;
- Analyze to develop and design alternatives, create a high-level design and evaluate design capability to select the best design;
- Design details, optimize the design, and plan for design verification; and
- Verify the design, set up pilot runs, implement the production process and hand it over to the process owners.

#### **5.1.5.2. When to Apply Six Sigma**

Similar to all of the other tools, Six Sigma should be applied wherever possible. The intrinsic nature of Six Sigma guarantees that there will be nearly zero defects. If all processes in a project can be expected to be perfect, there is no reason not to apply a Six Sigma program. The most effective way to use Six Sigma is with the VSM of a process to see where the defects are occurring and to create a future state map to address any of these issues. Therefore, Six Sigma should be first established for big ticket items and then used more for the secondary processes.

#### **5.1.5.3. Economic Impact of Six Sigma**

The biggest economic impact is that with a proven Six Sigma program defects will almost be completely eliminated. This means that rework, one of the largest wastes in construction, will be eliminated from the process. Current studies have shown that up to 30% of construction is rework (BIM Journal, 2009). This is closely related to the theory of Lean in which zero defects are created. Therefore, Six Sigma is a good stepping stone to create a Lean enterprise. Minimizing defects will improve quality on projects and create a positive image for the company using the tool, and the positive press/reputation that results from creating a high quality product on budget is the greatest advantage to using these Lean tools.

## **5.2. Transformative Techniques**

Techniques are considered transformative (sometimes referred to as “disruptive”) because they are virtually impossible to implement under the current contractual agreements in use and

current legal regulations. These techniques will require innovative project delivery systems in order to achieve the full benefits of implementation.

### 5.2.1. Target Costing

Target costing is a cost management tool intended to reduce the overall cost of a product over its life-cycle. Target costing draws on many disciplines, including engineering, research, design and production management. The target costing approach makes cost an input into the design process instead of an outcome. This is in contrast to a Guaranteed Maximum Price (GMP) where the GMP is just the maximum amount an owner will pay for a project. Under a GMP the owner is only obligated to pay one price and if the project comes in under or over the GMP the contractor will either gain profit or lose money on the project. With the target cost being set up at the beginning of the project, it is important to include all parties involved in the project in order to obtain the best design at the lowest cost. This is where a LPD approach works best because the people who will be doing the work (contractors) will be able to provide feedback to the designers right away. As a result the project will have a constructability and value engineering aspect to it the whole way through.

A target cost is the maximum amount of cost that can be incurred on a project for the construction firm to still earn the required profit margin. Target cost is defined in relation to the market-based price:

$$\text{Target cost} = \text{market based price} - \text{profit}$$

Target costing begins in the design phase of a project. In target costing, the cost is defined before the design is complete. As a result, the cost requirements are closely interlinked with the project requirements. The cardinal rule of target costing is that the *target cost must never be exceeded* (Cooper, et al., 1997). This rule requires all parties to proactively work towards achieving the target cost before and during construction. If costs are increased somewhere within a facility, they must be reduced elsewhere by an equivalent amount, all without compromising quality. Any scope changes that would overrun the target costs should be rejected. The transition from design to construction must be closely managed to ensure that the target cost is not exceeded.

Product requirements and scope are defined in relationship to the target cost. Important questions during the target costing process might be:

- What am I trying to accomplish?
- What will I need in order to achieve my purposes?
- What is that worth to me? What can I afford to pay to get it?
- What can I expect to pay? Is the expected cost less or equal to the allowable cost?

Target costing is initially more expensive and time-consuming than the standard process, due to the increased focus on quality and cost-oriented design. In order for target costing to be effective, it should begin in the earliest planning stages of a project. When target costing is implemented early in the product-realization cycle, cost savings are often substantially higher (Ballard, et al., 2004). More time is spent in the project definition phase than on traditional projects. Major members of the project team are selected early and collaboration is required between design professionals, suppliers, contractors and specialty contractors.

Target costing can result in large economic benefits. When implemented successfully, target costing has been shown to consistently reduce project costs by 20 – 40 percent, depending on the project and market circumstances.

Target costing relies on a contractor, designer, and owner to work together from day one to ensure that the design can be built per the given budget. Thus, the engineer and owner have to work together to ensure that the owner ends up with exactly what they want and the contractor is required to give real time costs for the project to ensure that it can be built within the budget or at the “Target Cost.”

This is difficult to do in the current contracting environment because in most instances engineers rely on past bid tabs to determine unit costs and it is nearly impossible to understand what costs a particular contractor puts in a unit cost since this cost includes labor, materials, overhead, profit, etc. Thus, by having a contractor on board right away it becomes easier to know the exact cost of different design options. This gives the owner choices as far as what is most important to them for a particular project.

#### **5.2.1.1. Application of Target Costing**

Target Costing is used to orient products to consumer affordability or to a market-driven pricing. This treats the product cost as an independent variable during the definition of a product’s requirements and allows the team to proactively work together to achieve the target cost during the product and process development. The target cost is the dependent variable where the market-based price must first be determined, then the desired profitability is found. Finally, the target cost is simply the price minus the profit. As shown in Figure 33, target costing is an iterative process in which the target price is first set, and the design is then constrained to meet the target price. If the design does not fit within the target price it is redone until a successful design is obtained. This then holds true for the construction phase as well, since construction will not begin until there is a planned schedule that will allow the target price to be achieved.



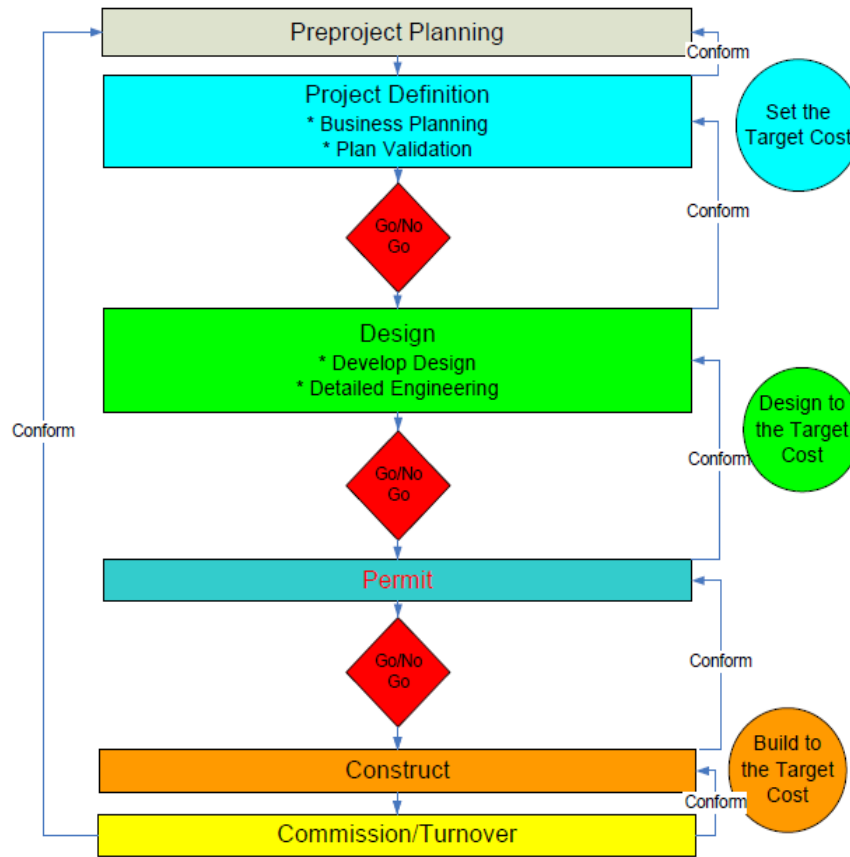


Figure 33: Target Costing Cycle (Ballard, 2008)

### 5.2.1.2. When to Apply Target Costing

Target costing should begin at the very beginning of the so-called “fuzzy front end” of the project-realization process. That is when it is most important to get the project and its functional design right the first time. There is a strong correlation between the cost savings obtained and how early in the project cycle target costing was initiated.

### 5.2.1.3. Economic Impact of Target Costing

Target costing can have a very positive economic impact on any project. The nature of target costing keeps the project costs aligned with the customer’s willingness to pay throughout the entire process. This helps to deliver what the customer wants at a price the customer can afford.

### 5.2.1.4. Target Costing Case Study (St. Olaf College)

St. Olaf College in Northfield, Minnesota hired The Boldt Company (Boldt) to construct a Field House from 2001-2002. The project used a \$12,000,000 gift from an alumni family to construct the Field House. Target costing was introduced on this project after the completion of schematic design. Boldt was involved in the project from the very beginning and provided cost estimates and massing models. Target costing proved very helpful in constructing the project on time and under budget. In comparison there was another private college in the same city that had constructed a Field House in the spring of 1998 to April 2000 which implemented the traditional DBB strategy. The comparison Field House went 10 months over schedule and incurred costs of 15% more than those at St. Olaf (Ballard, et al., 2004). A summary of that comparison is shown in Table 5.

Table 5: Target Costing Comparison (Ballard, et al., 2004)

	<b>St. Olaf Fieldhouse</b>	<b>Carleton College Recreation Ctr</b>
Completion Date	August 2002	April 2000
Project Duration	14 months	24 months
Gross Square Feet	114,000	85,414
Total Cost (incl. A/E & CM fees )	\$11,716,836	\$13,533,179
Cost per square foot	\$102.79	\$158.44

Target costing helped to reduce the cost of the project because during the design phase everything was designed to meet the target cost. Designers worked together with the construction team to associate an actual cost with each element of the design immediately. The project was designed and constructed within the allocated budget because cost estimates were being prepared simultaneously with the design of the facility. This is in contrast to a DBB delivery where a final cost is relatively unknown until 100% of the design is complete.

### 5.3. Relationship of STA Best Practices to Lean Techniques

Currently, there are many best practices being used by STAs that are similar to Lean techniques. Because some of these practices already exist, it will be easier for the transportation industry to implement certain tools before others. Appendix B details the relationships between Lean tools and techniques used in manufacturing and vertical construction with best practices from transportation projects. An important aspect of these relationships is that, while Lean techniques may seem very unfamiliar to STAs, a number of these techniques are related to current STA practices. It may be appropriate to focus first on Lean techniques that match up well with current STA practices, before moving to apply some of the other types of Lean techniques. Appendix B is not an exhaustive list of every tool or practice, but is meant to show that there is a correlation between practices in the various industries. Examples of how Lean techniques have been implemented in the public sector were shown in the case studies in Chapter 4.

### 5.4. Lean Technique Rankings for Ease of Implementation in the Transportation Industry

Table 6 gives a list of transportation practices that mirror lean techniques. These techniques are ranked as being ‘Straightforward,’ ‘Moderate’ or ‘Difficult’ in terms of their ease of implementation in the transportation industry. Ease of implementation is based on the amount of agreement between a potential lean technique and the current STA delivery process, including the overall delivery system, individual resistance to change, and legal issues. The most promising techniques, as identified by the research team (designated by ‘\*’ in Table 6) are then described briefly.

Table 6: Ease of Implementation of Lean Techniques in the Transportation Industry

<b>Lean Techniques in Vertical Construction</b>	<b>Ease of Implementation in the Transportation Industry (Straightforward/Moderate/Difficult)</b>	
	<b>Contractor</b>	<b>STA</b>

5-S (organizing work flow)	Straightforward	
A3 Reporting	Straightforward	Straightforward
Batch Size Reduction	Moderate	
*Collaborative Planning	Straightforward	
Continuous Flow (One Piece Flow)	Moderate	
Customer Focus	Straightforward	
*Daily Huddle Meetings (pre-task planning)	Straightforward	
First Run Studies	Difficult	
Integrated Form of Agreement	Difficult	Difficult
Increased Visualization (visual management)	Moderate	Moderate
Just-In-Time Delivery	Straightforward	
Kanban	Difficult	
*Last Planner	Straightforward	
Plan Do Check Act Analysis	Straightforward	Straightforward
*Pull Schedules	Straightforward	
Root Cause Analysis (5 Why)	Moderate	Moderate
*Simulation and Modeling (BIM)	Moderate	Moderate
*Standard Work	Straightforward	Straightforward
Supply Chain Management	Straightforward	
Takt Time	Straightforward	
Target Costing		Difficult
Transparency		Difficult
*Value Stream Mapping	Straightforward	
Visual Control	Low	
Workflow Leveling	Moderate	

Workflow Diagram	Straightforward	
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\* Discussed in further detail below

### 5.4.1. Collaborative Planning

Collaborative Planning is the process of involving all stakeholders in a project at the same time in order to ensure that all players are on the same page. Together with the design team and owner, the general contractor, sub-contractors and suppliers assemble as a team to form a master plan, and then to develop a detailed analysis of the activities planned for the first portion of the project. Regular meetings are held for the team members throughout the project to plan the following week's activity. Collaborative planning allows for early and effective interaction among the project participants. While construction project planning is usually the responsibility of the general contractor, collaborative planning techniques allow the sub-contractors and suppliers who will work on the project to be involved in construction planning. The benefits of collaborative planning include a more predictable project schedule, better utilization of the full project team's expertise, less waste and less frustration for project participants (6ix Consulting 2010). This tool is very useful to find areas where resources can be shared amongst team participants which may not have been recognized if the two tasks were planned independently.

Contractors can utilize collaborative planning when they are planning for the project with the owner, all subcontractors, and material suppliers involved in order to fully understand what every organization will be doing on the project.

STA's have the potential to benefit from using the collaborative planning technique by utilizing similar resources on adjacent projects or combining efforts to minimize travel time amongst contractors on projects in close proximity to one another.

Similar benefits can also be realized by contractors, especially specialty contractors. For example, cranes are an extremely important component of bridge projects, and by working with other contractors as well as other projects in the area, one may be able to reduce the number of cranes necessary on the nearby projects by correctly coordinating the multiple projects.

The largest difficulty is getting all of the necessary people together to proactively plan the project early in the process. It is generally easier up front for each entity to plan their own work independently, and so until all project participants are made aware of the potential benefits of collaborative planning, there is a real risk that the project and the STA will miss out on opportunities to improve their process.

One legal issue that may arise with collaborative planning may lie in disagreement over delays in a project, where one party may attempt to place responsibility for failure to meet a deadline on the collaborative planning process. Clear contract language could help to minimize this issue. Collaborative planning does not appear to significantly conflict with traditional STA project delivery rules or state/federal procurement laws.

### 5.4.2. Daily Huddle Meetings (Pre-Task Planning)

A daily huddle meeting is an opportunity for the project team to get together at the beginning of each day to go over that day's tasks and to reflect upon the previous day's accomplishments. This is meant to be a short 5-10 minute meeting to update everyone on the project progress as well as identify any issues that may need to be addressed. At these meetings with project participants, the following six questions are asked and answered as a group (Grunau 2008):

1. What are our productivity goals for today?

2. Do we have what we need?
3. Are there any obstacles to achieving our goals?
4. Does anyone see a better way?
5. Were there any near misses yesterday?
6. What safety hazards should we be aware of today?

STAs could utilize this technique with their various project teams to stay updated on the progress of projects around the state as well as any internal projects that may be ongoing. Contractors would utilize this technique at the beginning of each day to identify individual tasks that each trade will perform that day and to coordinate between the trades. The benefits to both parties from application of this technique lie in enhancing value to the project while minimizing waste.

Some benefits of the daily huddle meeting technique to both STAs and contractors include the opportunity to keep the entire project team informed, identify and resolve problems sooner, and improve scheduling work amongst various subcontractors. Daily huddle meetings keep the lines of communication open and provide an opportunity for each trade to update the team on their individual progress quickly on a daily basis, opening a dialogue that keeps team members informed about which tasks may be ahead of, on, or behind schedule.

As with collaborative planning, the most difficult aspect of implementing daily huddle meetings will be to involve all necessary project participants in the meetings and to gain buy-in on the importance of the meetings.

The daily huddle meetings technique came up against no legal concerns. There are no identifiable conflicts between implementation of this technique and the existing project delivery methods and state/federal statutes.

The biggest difficulty associated with implementation of the daily huddle meetings will be to ensure that all the required project participants attend the meetings.

### **5.4.3. Last Planner System**

Last Planner is a scheduling tool where work is scheduled by the person who is closest to the work actually being done, "The last planner." The Last Planner system is based on some simple forms or spreadsheets. The last planner may be a site foreman, design team leader, or subcontractor project manager. These last planners work through the project schedule collaboratively to understand the overall project processes before commencing work. This person is the one who is able to make that final commitment as to when the work will begin and end. These commitments are then recorded, allowing project managers to either confirm that the work was completed as planned or analyze causes and solutions when work was not completed as planned. The Last Planner system was developed to make schedules and project plans more predictable, and to motivate project participants to cooperate for the benefit of the project. The Last Planner system is designed to manage the relationships and commitments among project participants.

STAs can use this technique to track any problems that may arise, as well as previously identified solutions or lessons learned. Similar work techniques can then be utilized and problems may be quickly identified because work and commitments are being tracked on a weekly basis. Contractors are able to utilize the tool to better plan work, as well as gain a better sense of how long tasks actually take. By documenting what the commitment is and what is actually done, an actual duration can be used on similar tasks and estimated times will more likely reflect the actual time required to complete a task.

The benefit to be realized through implementation of the last planner system is that problems are identified early, and any commitments that are not fulfilled are identified immediately and solved. Additionally, realistic time frames are used which allows all other project participants to plan their work with more certainty. This system could also improve schedule reliability, leading to increases in productivity and profit.

The most difficult aspect of implementing the last planner system will be getting a commitment from the respective partners, as well as finding a time to go through weekly work plans. There will also need to be a person dedicated to following up on the root cause of problems. Difficulties may lie in determining the actual root cause of a problem. There may appear to be an easy solution, but the actual root cause may be difficult to identify.

The traditional design-bid-build project delivery systems may lead to difficulties in implementing the last planner system, as the contractual relationships in these delivery systems make it difficult to require all project participants to commit to utilizing the Last Planner.

#### **5.4.4. Pull Schedules**

Pull schedules are a tool where a project is planned from the end to the start in order to understand which work tasks are impacted by a particular construction activity. The project is planned in reverse, starting with the completed project or some series of milestones as goals. The schedule is then “pulled” backwards to include the steps needed to achieve those goals. Pull scheduling is also traditionally done in a collaborative manner involving all major project participants. This early collaboration can open dialogues and create a better understanding of dependencies in the project tasks. Pull planning was adapted from the Toyota Production System by the Lean Construction Institute (Realignment Group 2011).

STAs could use this technique for yearly work planning and to better understand work task interdependencies. Contractors could use this technique to schedule a project and analyze the schedule for any areas where there is added float. The float can then be eliminated due to more accurate knowledge of the progression of work.

The benefit of pull scheduling is that it allows each participant to know who they are impacting and what work they need to perform in order for the following participant to begin their work. This can lead to compression of schedules as added days due to uncertainty can be removed.

As with a number of the other lean techniques discussed in this Chapter, gaining the total buy-in and assembling the entire team early in the project are the most difficult aspects. This may also be difficult as certain trades may not exactly know who they directly impact with their work.

The main legal concern with implementation of the pull scheduling technique will be how to institute the necessary communication and collaboration early in the project. It may be difficult to achieve this collaboration without making it a contractual obligation for all project participants.

#### **5.4.5. Simulation and Modeling (BIM)**

The Simulation and Modeling technique covers a number of ways to virtually plan and construct a project before breaking ground. This can be a very key part of resolving any logistical issues before arriving onsite. BIM (Building Information Modeling) is a parametric method for simulating virtual construction of a project in the design or pre-design phase. It may also be applied in the field as a construction tool. BIM relates closely to the concept of Integrated Project Development (IPD), which is based on bringing all project participants together early in the process to create a team approach to the building project. Simulation and modeling allow the project team to identify and solve problems early in the design and construction process, and to resolve issues during design before they become problems during construction.

STAs could use simulation and modeling techniques to simulate certain traffic patterns to gain an idea of how projects in various locations will impact nearby facilities. Simulation and modeling techniques such as BIM are also beneficial for many other pre-project purposes, including clash detection, identification of construction bottlenecks or other challenges. Contractors would be able to use these techniques to plan the construction sequence and find the most efficient way to produce the final product. Bridge contractors, in particular, may benefit from these techniques, which will allow for a bridge to be built digitally before beginning in the field. This can improve logistical issues involving cranes, girder placements, deck pours, etc. that can be conducted virtually before expensive tasks are begun in the field.

A benefit of the modeling and simulation technique is the ability to identify and address problems or issues with the logistics of construction early before work is started instead of when there are employees onsite getting paid to wait for directions. Implementation of this technique could be both a time and money saving measure.

The largest difficulty to be overcome in implementing these techniques would be the time and money spent to create the model and run the simulations. On large, complex interchange projects significant value could be achieved, but on smaller scale projects the cost savings involved may not be worth the effort to model. There may also be a steep learning curve as well as a high initial cost to implement some of these techniques. Finally, an accurate virtual model is essential for these techniques to succeed. An inaccurate or incorrect model can lead to more complicated construction, potentially negatively impacting both cost and schedule.

Legal issues may also be encountered in situations where discrepancies exist between the virtual model and the plans, or the as-built project. Legal issues may also exist regarding ownership of the virtual models, and which party is to pay for these models, or for errors in the models.

#### **5.4.6. Standard Work**

Standard work is the process of creating standard items and tasks in order to take methods and products produced or used on one project and apply them to another. The standard work method breaks all processes into three types of tasks: (1) routine core, (2) non-routine core, and (3) ancillary. Routine core tasks are simple repeatable tasks. Non-routine core tasks can be more complicated, with multiple routes to completion, and support the project work. Ancillary tasks are less repetitive and less predictable. The standardized work method seeks to reduce variation in methods of work and find the most appropriate methods to complete the work. Standard work methods focus on optimizing the entire system, rather than optimizing individual components of the system (Feng and Ballard 2008).

STAs can use the standard work method in the design and bidding of their projects to ensure that all projects use the same terminology, units, design standards, etc. This way anyone looking at the plans for a particular project will already know what the standards are. This is already done in many states such as Wisconsin, where STAs have internal standards for project plans.

Contractors can utilize standard work to deploy their crews more efficiently. If each project uses the same standards and techniques, these can become standardized, reducing the inevitable learning curve on each new project.

Using the standard work method, STAs would develop standards that are required on all projects so any project participant knows what to expect in every set of plans, and contractors would have the ability to reduce their learning curve because repetitive work would be the same from one project to the next, leading to potential cost and schedule reductions.

The largest difficulties in implementing the standard work method would involve finding the most appropriate starting point for standardization, and ensuring that each standard reflects best practices. These standards also require updating as techniques and conditions change to keep up with advances in knowledge and technology. Implementation of the standard work method may require a significant upfront effort to develop standards if an STA does not have existing standards already in place.

The most important legal concern for an STA would be ensuring that the standards they set are followed. This would need to be formalized in project contracts.

#### **5.4.7. Value Stream Mapping**

Value Stream Mapping (VSM) is the process of identifying all of the steps in a particular process and listing the value-added time and total time of each task. These value stream maps are then used to identify methods to decrease the non-value-added time. VSM ties lean concepts and techniques together. It is a graphical tool that allows users to visualize and understand the flow of material and data as a product or process works its way through the value stream.

STAs can use this technique to map out a process, such as a document review process, to ensure that it works as efficiently as possible. Similarly, contractors can use these techniques to identify areas of waste in their standard work items. Identification and elimination of waste in the value stream is an iterative process, which needs to take place continuously in order to realize the full benefits of the VSM technique.

VSM has the potential benefit of reducing wasted time and money for STAs, speeding up processes to reduce cost and time on projects. Contractors can utilize VSM to find wasted steps in processes and maximize their value-added time on a project. This is a way to provide a quality product at a discounted price to improve their future competitiveness in a low-bid system.

The largest difficulty faced in implementing this technique would be the significant upfront investment of time to identify all of the steps in a process and understand whether the task is a value-added or non-value-added task. The next step in implementation of the VSM method is to create a future state map, in which an ideal process state is created. The goal is to go from the current state to a future state and it may be very challenging and time consuming for project participants to identify and characterize the future state.

No legal concerns were identified for the VSM technique, independent of any existing contractual obligations.



## **6. Summary of Barriers and Impediments to Lean Construction in a 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. Barriers and impediments to implementation were identified through the combination of literature review, case studies, and interviews with organizations that have put lean techniques into practice presented in this report. Listed below are the most important barriers to implementing LPD in transportation projects.

### **6.1. Legislative Issues**

For public construction contracts, there are often restrictive laws governing the selection of contractors. In particular, competitive bidding is often mandated or strongly encouraged. Competitive delivery processes that require selection of the lowest bidder create a challenge when implementing a LPD system. Lean relies on the careful selection of contractors and subcontractors, which conflicts with several of the characteristics of a competitive bidding process. With LPD, 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 the design be completed for bidders to evaluate. Furthermore, a LPD 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 are generally extensive, detailed laws governing the selection of contractors, subcontractors and design professionals. These legal issues must be investigated and adequately resolved before an effective LPD system may be completely implemented. However, as discussed in Chapter 2 regarding P3s, there are contracts being written that allow for a collaborative agreement, but still control any profits or damages that could be caused by using a different form of contracting.

### **6.2. Fear of Change**

Since the start of the modern construction era, the main delivery system has been DBB. Until the last few decades, it was essentially the only delivery system available to STAs (Federal Highway Administration, 2006). The working and management philosophies of STAs 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 LPD is an effective way to familiarize staff with the new delivery method processes.

The construction industry is well trained and is familiar with the DBB method. Transportation contractors have a fear of selection bias and political influence, which the low bid criterion of a DBB project prevents. Therefore, the industry is reluctant to use delivery methods other than DBB.

### **6.3. Incompatibilities with Traditional STA Organization and Processes**

Many STA systems involve a potentially large number of reviews and project stages. These reviews may be overseen by independent divisions within the STA, consultants, or in other areas of state government, which may not be co-located and may not have an existing communication network. The reviews often represent milestones that are dependent on one another, which may lead to difficulties in developing a holistic review of the project (e.g., a review of the project alignment may be required before the environmental review, leading to revisions that might be avoided if these reviews could take place simultaneously). These organizational and process issues may lead to barriers with many lean techniques that require early and extensive collaboration among project participants. Administration of the hand-off from designer to contractor may also cause barriers to implementation of lean techniques, by changing the set of project participants part way through the execution of the project.

### **6.4. 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 are 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 techniques and LPD 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.

### **6.5. 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: (1) eliminating risk; (2) transferring risk; or (3) 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 of, and benefit from the assumption of the 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.

Fully implementing LPD will require reexamining the way risk is allocated among the STA, designers, prime contractor, subcontractors, and material suppliers on a project.

### **6.6. Insurance**

Due to the newness of LPD, there are currently not any insurance products that align with the collaborative contract where no one entity bears the responsibility alone. Due to the group nature of the project, insurers are hard pressed to create policies that cover the project instead of the parties involved. This is due to the disconnect between the no-fault environment of LPD

and the pro-fault environment of professional liability insurance. It has been found that it is difficult to create a template for future policies because each LPD project appears to have a different contractual agreement. By working towards creating a standard LPD agreement, a standard insurance policy can be established. Until a standard is available, current policies will be expensive because they are highly customized (Post, 2010). The American Institute of Architects (AIA) has developed a multi-party agreement for IPD projects that “provides the framework for a collaborative environment in which the parties operate in furtherance of cost and performance goals that the parties jointly establish” (AIA 2009). This model agreement may be the best place to start when an STA is searching for a way to implement LPD.

## **6.7. No Guaranteed Cost**

Many critics of LPD cite the fact that these multiparty agreements do not include a guaranteed price. Public entities currently use the DBB delivery to ensure the public that the project is being completed at the lowest responsible price. Without that measure in place it will be difficult for public entities to explain how or why a particular team was selected over another. Before LPD can become widely used, a standard has to be developed for selecting the integrated team without bias. Additionally, once several projects are completed there will be data that can be used to compare the final cost of an LPD project with a similar DBB project to address any cost differences (Post, 2010).

The highway industry is changing by implementing new delivery techniques such as DB and CM@R, and as these techniques become more popular it will become easier to implement a true LPD.

## 7. Management Plan for Adoption of Lean Techniques

The research team was charged with developing a management plan for adopting lean techniques in public transportation infrastructure projects. The management plan can be summarized by Figure 34.

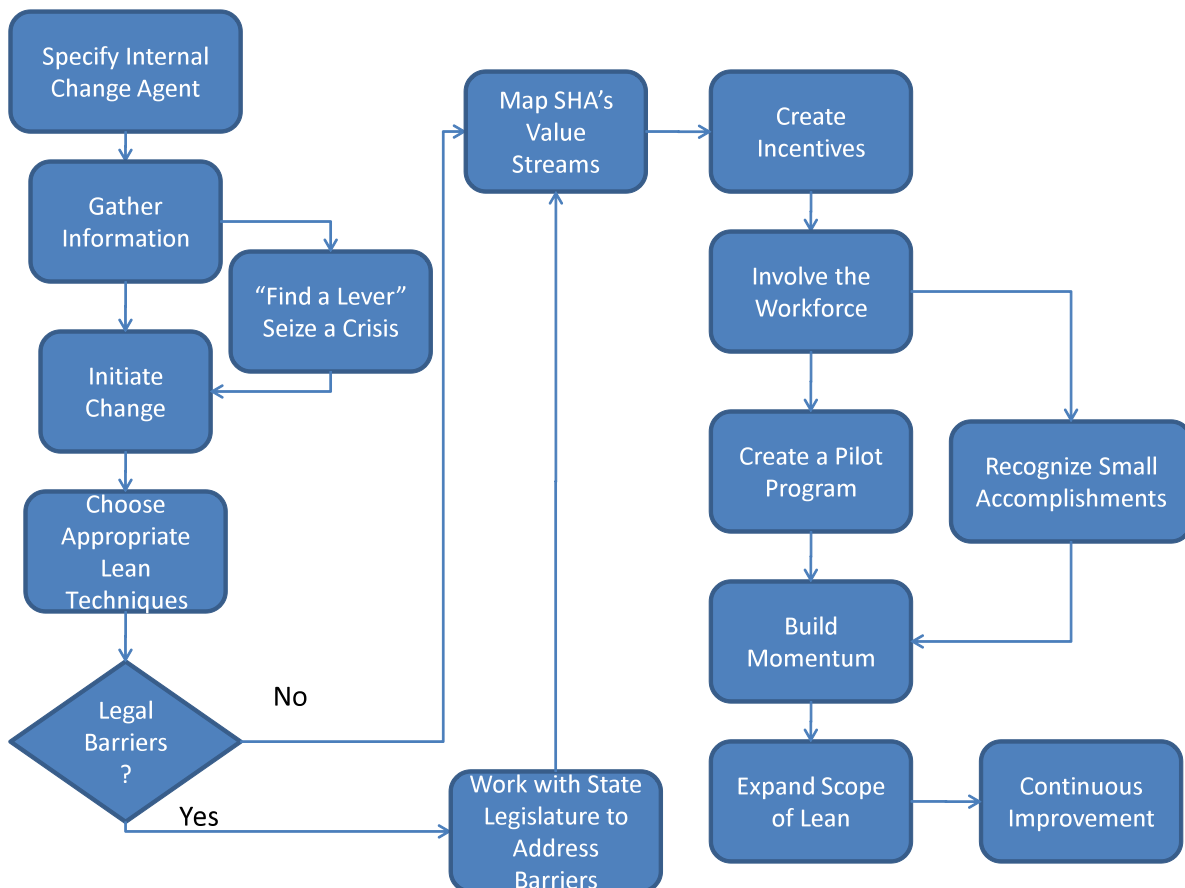


Figure 34: Management Plan for STA Adoption of Lean Techniques

### 7.1. Specify Internal Change Agent

The most important first step in implementing a Lean Delivery System at a STA is to overcome the inertia of long-standing traditions and procedures to improve processes. It has been documented (Womack and Jones 1996) that successful manufacturing transitions to lean systems share the characteristic of having a strong change agent, and that unsuccessful transitions generally lack one. The change agent does not need to be a pre-existing lean expert, but does need a willingness to modify the philosophical approach to project delivery, to apply lean tools, and to gather the necessary information. Before change can be initiated, a clear strategy and vision need to be developed and communicated to all involved with the transition. This will ensure that the participants will work toward a common goal as the transition to using lean techniques gets underway (Kotter 1996).

## **7.2. Gather Information**

While a great deal of literature exists on lean transitions, it is generally recommended that experts are consulted as advisors. It is important that the change agent learn the lean processes so that the agent can pass that information on to others in the STA. The change agent and the upper management level of the STA must understand lean processes completely (Womack and Jones 1996).

## **7.3. “Find a Lever”**

Womack and Jones (1996) advocate the idea of finding a ‘lever’ by seizing a crisis as an opportunity for change. A sense of urgency must be established to identify and discuss current crises as well as potential crises. This allows for discovery of major opportunities in the existing system, which can act as leverage for the implementation of lean techniques within the organization (Kotter 1996). STAs that are facing higher workloads with smaller staffs may be able to seize these conditions as a crisis. Dictionary.com defines *crisis* as: “a stage in a sequence of events at which the trend of all future events, especially for better or for worse, is determined; turning point.” At some point, the phenomenon of being asked to do more with less will reach a turning point in each STA dealing with these conditions. This may be the ‘lever’ that an STA could use to move forward with implementing lean delivery techniques.

## **7.4. Initiate Change**

To make the leap to initiate lean techniques at public STAs, the change agent and upper management must take the initiative to implement the techniques. The biggest factor in overcoming inertia in project delivery methods is to start. Even if the implementation team does not yet have all the backing needed or information needed, it is important to initiate changes. The change agent can put the process in motion, begin studying the barriers and help to make small improvements in delivery processes, building momentum.

## **7.5. Choose Appropriate Lean Techniques**

STAs must choose appropriate lean techniques to apply within their own project delivery system. Techniques were identified in Table 6 based on the potential benefits available to STAs and the applicability of the method within the STA’s project delivery process. Techniques for application should be chosen to maximize the potential benefits available to the STA, and to balance with that the applicability of the technique to the STA’s individual situation and existing processes.

## **7.6. Are There Legal Barriers to Implementing Lean Techniques?**

Lean techniques for implementation in the delivery of public works are often not compatible, to various degrees, with the traditional low-bid project delivery process. Once appropriate lean techniques are chosen by the STA for implementation, the STA must integrate these techniques with their existing system. Lean delivery processes must work seamlessly with the state’s standard specifications. Lean delivery processes can be developed as a set of supplemental specifications, or as a special provision. Supplemental specifications are additions and revisions to the state’s standard specifications, which have the potential of being integrated into the standard specifications when they are regularly updated, while special provisions are applicable to a specific project, and may be inserted into the specifications for appropriate projects (Thompson et al. 2002). With the many options of lean techniques discussed above, it may be appropriate to incorporate these techniques as special provisions, at least in the early stages of

implementation. In addition, some of the Lean tools might be adopted through best practices and procedures detailed in the STA's Construction Manual.

As the STA works to incorporate lean techniques into their standard project delivery process, they must also work to evaluate the existence, within the legal framework of the state, of barriers to implementation of the techniques.

## **7.7. Work with State Legislature to Address Barriers**

If legal barriers exist within the state preventing implementation of lean project delivery techniques on public transportation infrastructure projects, the STA must work with the state legislature and government agencies to develop an implementation plan that will fit within the legal framework of the state. This may start with special permission for a demonstration project, and may work up to an eventual modification to the state procurement statutes. For instance, the Federal Highway Administration (FHWA) has been allowing special contracting methods under Special Experimental Projects No. 14 – Alternative Contracting (SEP14). This initiative was created in order to evaluate innovative contracting practices that have the potential to reduce the life cycle cost of the project while maintaining project quality (Federal Highway Administration, 2009).

## **7.8. Map STA's Value Streams**

Value streams need to be mapped activity by activity and step by step according to project type. This consists of developing a 'map' identifying every action required to design, procure, and construct a specific project, and to sort these actions into: (1) activities that create value perceived by the customer; (2) activities that create no value but are currently required to meet the requirements of the STA's responsibilities; and (3) actions that create no value and are not required to meet the STA's responsibilities (Womack and Jones 1996). This mapping of value streams will help the STA to identify waste and determine where lean techniques best fit into their existing value streams and project delivery processes.

## **7.9. Create Incentives**

Currently many STAs are paying for activities that improve delivery of the construction process as a pay item such as schedule development, partnering, and dispute review boards. It is recommended that STAs extend these pay items to compensate the contractor for costs associated with implementing Lean techniques. This practice is already associated with a DB contract and could be a consideration for the selection of a particular DB team.

## **7.10. Involve the Workforce**

Additionally, involving everyone in the project (STAs, contractors, stakeholders, etc.) in Lean initiatives will help to expedite the crossover into a LPD. The case study in Section 4.3 showed how Bechtel has done this by implementing a Lean Construction at the Workforce initiative in their Oil, Gas, and Chemicals Global Business Unit to help improve productivity performance across the enterprise, improve their Six Sigma visibility and performance, and to increase the use of the developed Lean tools. In their three pilot projects over 300 improvement suggestions were generated from the craft. These suggestions ranged from something as simple as printing off extra copies of field documents so foremen do not waste time making copies while they are on site to creating a standardized checklist for housekeeping responsibilities.

The craft were trained on the basics of Lean by learning how to identify the eight forms of waste, design a pull system for delivery of materials, design devices that prevent errors from occurring,

perform a root cause analysis, and train other craft workers, thus creating a self-sustaining program owned and managed by the craft. Approximately \$3.8 Million in savings was achievable in these three projects by using the suggestions from the workforce (Bechtel Corporation, 2009). It is reasonable to assume that involvement will increase over time as employees realize that their input is valued and the organization experiences positive results.

Additionally, it has been recorded in other industries that in a given company top management is only aware of about 4% of production problems, whereas the frontline workers are aware of 100% of the problems (Finster, 2010). Thus, involving the entire workforce in the Lean implementation should address 100% of all production problems and not just the small amount that management is aware of. A breakdown of the percentage of problems known is shown below in Table 7.

Table 7: Identifying Issues by Group Knowledge (Finster, 2010)

Group	% of Problems Known:
Top Management	4%
Middle Management	9%
Supervisors	74%
Frontline Workers	100%

Even if an improvement effort is not originated at the workforce level, these individuals need to be involved as soon as possible to help identify issues with the current process. In any company the largest asset is the employees, empowering them with the ability to help identify issues and provide solutions will only increase the value the employees provide.

An additional benefit in creating a collaborative environment is that there will be people involved in discussions and decisions that would not normally be there. This is invaluable because this will provide a person who will ask “why?” and try to understand the current practice. This will force the experts on the topic to explain their practices which should help them to improve their understanding of the system and to uncover additional wastes in the system. The more people that are asking “why?” and trying to understand a process the more ideas for improvement will be generated.

## 7.11. Create a Pilot Lean Program

The best way to overcome the fear of change is to initiate a Pilot Program and work out any obstacles. Lean techniques have the potential to improve cost, time and quality in the transportation industry, but need exposure to the public sector in the United States. By creating a Pilot Program the transportation industry can become more familiar with Lean techniques and discover what does and does not work in the industry. If the current economic times continue, it will be imperative that infrastructure projects are completed with the highest quality and lowest cost possible. By creating pilot projects a database can be created to evaluate Lean and to create the best possible project delivery for the future. This is the only way to ever fully determine if Lean is the future of transportation project delivery.

It is important to start with an impactful and visible lean technique – something where improvements will be noticed immediately. Womack and Jones (1996) argue that when implementing lean techniques, it is important to start as quickly as possible and with a specific

technique, and that it is best to begin in an area where large results are possible (that is, an area where there is significant room for improvement). Implementation of lean techniques should also show immediate results. There will always be room for improvement as implementation progresses, but some positive results should be expected and demanded immediately.

### **7.12. Recognize Small Accomplishments**

As positive results are realized, it is important to recognize these accomplishments, large and small, to increase acceptance, recognize performance, and build momentum (Womack and Jones 1996). Short-term wins need to be celebrated to maintain the momentum of the lean effort. This will help turn neutrals into supporters and reluctant supporters into active helpers. Short-term wins provide evidence that the efforts to implement lean techniques have led to improvements, and help to justify the short-term costs involved with the transition (Kotter 1996).

### **7.13. Build Momentum**

It is important not to implement lean techniques in isolation. Once results have been realized in one project, it is important to build on that success, either by extending and improving the implemented technique, or by focusing on an additional portion of the STA's value stream. Implementing lean techniques in isolation, or in a scattershot fashion, does not allow the improvements that are possible using these techniques to be fully realized (Womack and Jones 1996).

### **7.14. Expand Scope of Lean**

It is important to keep expanding the scope of the lean technique implementation. As one success is completed, move on to another portion of the value stream, or dig deeper into the technique implemented. This step requires spreading lean education beyond the personnel involved in the pilot or demonstration project to a wider group of personnel within the STA (Womack and Jones 1996). Expanding the scope of lean techniques requires work within the agency to examine and, if necessary, modify, the agency's construction delivery philosophy.

### **7.15. Continuous Improvement**

In the words of Womack and Jones (1996), "when you've fixed something, fix it again." It is important to take the attitude that no level of performance is ever "good enough." The change agent within the STA should always be on the lookout for ways to improve delivery processes through application of a new lean technique, or improvement of a technique already in use. Beyond that, all members of the STA should be encouraged to look for areas where improvements and innovations are possible. Organizations need to keep reinvigorating the process with new projects, themes, and change agents. This keeps developing employees who implement the vision to keep the philosophy alive. Organizations must continue to articulate the connections between new behaviors and organizational success. By continuously developing leadership experience and encouraging succession within the organization, continuous improvement can be achieved (Kotter 1996). Another way that Womack and Jones (1996) state this principle is that "two steps forward and one step backward is O.K.; no steps forward is not O.K." It is important not to discourage innovation with lean techniques. It is important to teach lean thinking and skills to everyone in the organization.



## **8. Final Report**

This Final Report was developed directly from the work completed under Tasks 1 – 5.

### **8.1. Project Brief**

A Project Brief summarizing the management plan for adopting lean techniques (Task 5) for distribution to STAs was completed under Task 6. The Project Brief is included as Appendix C to this report.

### **8.2. Conclusion**

Construction companies and contractors should find that utilizing the lean techniques improves productivity and profits. This will help mitigate the fear of change in project management. The more projects that are completed utilizing these tools the more individuals will learn the techniques and be able to spread the knowledge. With continuous improvement in mind, industry-wide productivity should improve as more contractors begin to utilize these Lean techniques. Utilizing Lean delivery techniques, construction industry productivity will be more likely to mirror the productivity increases seen in other industries.

Implementation of lean techniques requires a significant shift in the organization's core philosophy. How large this shift will be is one of the key questions. To apply lean delivery in a transformative fashion, a major shift in core philosophy is required, along with, potentially, legislative approval. Without these two prerequisites, it will only be possible to apply lean techniques incrementally to public transportation projects. If current trends continue, putting increased stress on state and SHA budgets, state governments may become increasingly open to innovative ways of saving time and money, improving quality, and increasing the efficiency of project delivery such as LPD.

Incremental implementation of any of the lean techniques discussed in this report does not constitute a true LPD system. Development of a true LPD system requires integration of a coherent lean philosophy, implemented through the systematic application of appropriate lean techniques discussed in this report within an integrated project delivery framework. While many lean techniques and tools can be implemented in isolation, utilization of the IPD framework seems to be a baseline requirement for development of a truly lean project delivery system. SHAs are encouraged to implement incremental moves toward lean techniques while in parallel pursuing the ability to apply the full LPD system through the legislative process.

Many obstacles to SHAs implementing a Lean delivery process are related to legal and contractual obligations. By creating an in-house improvement process, it is possible to improve projects with the current delivery methods using the lean techniques and tools presented in this report. This can also help to alleviate any legal issues that may arise.

Even though improvement can be made by implementing Lean at the contractor level, much greater improvements can be made by involving the owner, contractor, subcontractors, and suppliers early in the design phase to create a true LPD. Currently, this is not possible under the DBB delivery system, but increased use of DB procurement methods does provide greater opportunities for implementation of LPD techniques. Building construction has made the change, and highway construction may be able to use this example to apply similar techniques and realize some of the same benefits.

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## Glossary

**5S** – A set of workplace organization rules designed to increase efficiency denoted as Sort, Straighten, Shine, Standardize, and Sustain.

**A3 Report** – A report documenting process that succinctly states the problem, documents the current situation, determines the root cause, suggests alternative solutions, suggests the recommended solution and generally has a cost benefit analysis that fits on an A3 (11" x 17") piece of paper.

**Fishbone Diagram** – A cause-and-effect diagram structured map showing the relationships between the causes and effects.

**Gemba** – Japanese for the actual place or real place.

**Grid System** – an inventory strategy that allows for the location of an object to be described in a way that is meaningful and universally understood.

**Just In Time Delivery (JIT)** – In a flow process, the right parts needed in assembly reach the assembly line at the time they are needed and only in the amount needed.

**Kaizen** – Continuous, incremental improvement of an activity to create more value with less waste.

**Kanban** – A production management process which utilizes a small card or other object that regulates a pull system by signalling upstream production and delivery to preceding activities.

**Last Planner™** – The person or group that makes assignments to direct workers. Superintendent or foremen are common names for last planners in construction processes.

**Last Planner™ System** – The process of taking project wide objectives and constraints and assigning lower level planning to specific individuals in order to achieve the project goals by deciding which individual or group will perform a specific task at a specific time.

**Lean Construction** – A production management-based approach to project delivery – a new way to design and build capital facilities.

**Lean Production** – A production practice that focuses on the sole goal of creating value for the end customer and eliminating all waste in the process.

**Pareto Charts** – A statistical technique to identify the minimum amount of activities with the most significant effect.

**Plan Do Check Act (PDCA) Analysis** – A continuous improvement cycle which focuses on surface problems (Plan), Countermeasures (Do), Evaluating Results (Check), and Creating Flow (Act).

**Public-Private Partnerships (P3s)** - contractual agreements formed between a public agency and a private sector entity that allow for greater private sector participation in the delivery and financing of transportation projects.

**Pull Schedules** – Schedules based on the theory of initiating the delivery of input based on the readiness of the process into which they will enter for transformation into outputs.

**Six Sigma (6σ)** – A statistics driven approach to quality control for achieving virtually zero defects (3.4 parts per million) in manufacturing and business processes.

**Strategic Gap Analysis** - Forecasting technique in which the difference between the desired performance levels and the extrapolated results of the current performance levels is measured and examined. This measurement indicates what needs to be done and what resources are required to achieve the goals of an organization's strategy.

**Target Costing** – A structured approach to determine the life-cycle cost at which a proposed product with specified functionality and quality must be produced to generate the desired level of profitability over its life cycle when sold at its anticipated selling price.

**Takt Time** – German for rhythm or meter, takt is the rate of customer demand.

**Target Costing** – A cost management tool intended to reduce the overall cost of a product over its life-cycle by making cost an input into the design process instead of just an outcome.

**Value Stream** – All the actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product.

**Value Stream Mapping (VSM)** – A pencil and paper tool that helps to visualize and understand the flow of material and information as a product makes its way through the value stream.

**Voice of Customer (VOC)** – a market research technique used to capture the particular aversions, expectations, and preferences of the customer for a specific product.



# Appendix A: Work Sampling Study Observation Sheets

## Rebar Installation Work Sampling Data Sheet

	Activity	F*	O*	W1*	W2*	W3*	W4*	Comments
Direct Work	1 Formwork							
	2 Rebar Installation							
	- <b>Subtotal</b>							
Essential Contributory Work	1 Moving Materials (~ 25 ft.)							
	2 Moving Equip ~ 25ft							
	3 Getting Tools ~25ft							
	4 Reading Plans/Specs							
	5 Measuring/Layout							
	6 Inspection							
	7 Talking about objectives							
	- <b>Subtotal</b>							
Ineffective Work	1 Moving Materials > 25ft.							
	2 Moving Equipment > 25 ft.							
	3 Getting Tools > 25 ft.							
	4 Waiting							
	5 Talking / Cell phone							
	6 Bathroom							
	7 Smoke Break							
	- <b>Subtotal</b>							
<b>TOTAL</b>								

\*F = "Foreman"

W2 = "Worker 2"

O = "Operator"

W3 = "Worker 3"

W1 = "Worker 1"

W4 = "Worker 4"

## Asphalt Work Sampling Data Sheet

		Activity	W1*	W2*	W3*	W4*	W5*	W6*	W7*	Comment
Direct Work	1	Shoveling/Raking Asphalt								
	2	Paving								
	3	Compacting								
	-	▪ Subtotal								
Essential Contributory Work	1	Moving Materials (~ 25 ft.)								
	2	Moving Equip ~ 25ft								
	3	Getting Tools ~25ft								
	4	Reading Plans/Specs								
	5	Measuring/Layout								
	6	Inspection								
	-	Subtotal								
Ineffective Work	1	Moving Materials > 25ft.								
	2	Moving Equipment > 25 ft.								
	3	Getting Tools > 25 ft.								
	4	Waiting								
	5	Talking / Cell phone								
	6	Walking (empty								
	7	Bathroom								
	8	Smoke Break								
	-	Subtotal								
<b>TOTAL</b>										

\*W1 = "Worker 1"

W4 = "Worker 4"

W7 = "Worker 7"

W2 = "Worker 2"

W5 = "Worker 5"

W3 = "Worker 3"

W6 = "Worker 6"

## Appendix B: Relationships Among Lean Manufacturing, Lean Vertical Construction, and Current Transportation Practices

Table 8 shows the relationship between Lean tools and techniques used in manufacturing and vertical construction with best practices from transportation projects. Lean techniques are numbered in the Vertical Construction column (Column 2). These numbers are shown in parentheses in Columns 1 and 3 as examples of similar techniques in manufacturing and transportation. This is by no means an exhaustive list of every tool or practice, but is meant to show that there is a correlation between the various industries. For instance, 'Constructability Reviews', the first entry in Column 3, is listed as related to entries 5 ('Collaborative Planning') and 6 (Continuous Flow/One Piece Flow) in Column 2.

Table 8: Lean Tools and Transportation Practices

Lean in Manufacturing  (Column 1)	Lean in Vertical Construction  (Column 2)	Transportation Practices (Hanna, et al., 2010)  (Column 3)
<ul style="list-style-type: none"> <li>• 5-S(1,</li> <li>• 5 Why analysis(21,</li> <li>• A3 Reporting(2</li> <li>• Cause and Effect Diagram (Fishbone)(4,</li> <li>• Conflict Resolution Diagram</li> <li>• Current Reality Trees</li> <li>• Error Proofing(12</li> <li>• Future Reality Diagram</li> <li>• Inventory Turnover Rate</li> <li>• <b>Just-In-Time(15</b></li> <li>• Kaizen(19</li> <li>• Kanban(20</li> <li>• Lead time ratio</li> <li>• Lean Metric(24,</li> <li>• Lean Performance Indicator(24</li> <li>• Load Balancing(32</li> <li>• One-piece Flow(6,</li> <li>• Plan Do Check Act Cycle(19</li> <li>• <b>Prerequisite Tree(17,20</b></li> <li>• Quick Changeover(</li> <li>• <b>Six Sigma(23</b></li> <li>• Standard Rate or</li> </ul>	<ol style="list-style-type: none"> <li>1. 5-S</li> <li>2. A3 Reporting</li> <li>3. Batch Size Reduction</li> <li>4. Cause and Effect Diagram (Fishbone)</li> <li>5. Collaborative Planning</li> <li>6. Continuous Flow (One Piece Flow)</li> <li>7. Control Charts</li> <li>8. Customer Focus</li> <li>9. Daily Huddle Meetings</li> <li>10. Deployment Flowchart</li> <li>11. First Run Studies</li> <li>12. Fail safe for Quality</li> <li>13. Integrated Form of Agreement</li> <li>14. Increased Visualization</li> <li><b>15. Just-In-Time Delivery</b></li> <li>16. Kanban</li> <li><b>17. Last Planner</b></li> <li>18. Pareto Charts</li> <li>19. Plan Do Check Act Analysis</li> <li>20. Pull Schedules</li> <li>21. Root Cause Analysis (5 Why)</li> <li>22. Simulation and</li> </ol>	<ul style="list-style-type: none"> <li>• Constructability Reviews(5,6,</li> <li>• Change Management Team(</li> <li>• Context Sensitive Design(8,</li> <li>• Cooperation and commitments from external agencies for quick project reviews, approvals and permits(5,</li> <li>• <b>CPM Schedule/Linear Schedules (17,</b></li> <li>• Design Build (DB) Delivery(5,</li> <li>• Dispute Resolution Board</li> <li>• Document Management Systems(</li> <li>• <b>Earned Value Analysis(17,</b></li> <li>• Incentive/Disincentive Specifications (27,</li> <li>• <b>Just-In-Time Logistics(15,</b></li> <li>• <b>Materials Management (17,</b></li> <li>• Multi-parameter (best value) bidding(27,28</li> <li>• Off-site Fabrication, Pre-Assembly, Modular Production</li> <li>• Operation Integration for Hand Over(5</li> <li>• Partnering (5,</li> <li>• <b>Performance Management System (17,</b></li> <li>• Performance Specifications(</li> <li>• Preconstruction</li> </ul>

<p>Work(24</p> <ul style="list-style-type: none"> <li>• Takt Time(26</li> <li>• <b>Theory of Constraints(17</b></li> <li>• Total Productive Maintenance</li> <li>• Transition Tree</li> <li>• Value added to Non-value added(30</li> <li>• Value Stream Costing</li> <li>• Visual Management(14</li> <li>• <b>Value Stream Mapping(29</b></li> <li>• Workflow Diagram(32,</li> </ul>	<p>Modeling</p> <p><b>23. Six Sigma</b></p> <p>24. Standard Work</p> <p>25. <b>Supply Chain Management</b></p> <p>26. Takt Time</p> <p>27. Target Costing</p> <p>28. Transparency</p> <p><b>29. Value Stream Mapping</b></p> <p>30. Visual Control</p> <p>31. Workflow Leveling</p> <p>32. Workflow Diagram</p>	<p>Conferences(20,25,</p> <ul style="list-style-type: none"> <li>• <b>Program Management Plan(17,</b></li> <li>• <b>Quality Assurance Program(23,</b></li> <li>• <b>Quality Management Plans(23,7</b></li> <li>• Risk Assessment Workshops(</li> <li>• Standardized design(24,</li> <li>• Shared Project Goals(5,</li> <li>• Third-Party Agreements(</li> <li>• <b>Three Week Look-ahead Schedules(17,20,</b></li> <li>• Tool-box Meetings(28,</li> <li>• Warranty Specifications(</li> <li>• Zero Accident Techniques(12,9</li> </ul>
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## Appendix C: Project Brief

### C.1. Introduction

It is well documented that construction productivity has been declining since the 1960's. Additionally, studies have shown that only 40% of construction workers' time is considered to be value-added work. Lean Techniques are being used successfully on general construction and other non-transportation projects throughout this country, and their use is growing.

Manufacturing and vertical construction have shown that a project using Lean techniques can be delivered in less time, at lower costs, and with improved quality. However, Lean techniques are not currently being used by State Transportation Agencies (STAs). The implementation of Lean techniques with a Lean Project Delivery (LPD) method can lead to higher quality projects, faster project completion, and more efficient delivery. To attain this goal, the transportation industry as a whole needs to work closely together using non-traditional approaches to achieve the necessary improvement.

This study focuses on the benefits of Lean techniques in the delivery of transportation projects, along with potential obstacles to adoption. Case studies are provided which document the successful use of Lean techniques in the infrastructure industry. The transportation industry provides unique challenges in implementing Lean techniques due to public sector constraints. Special care is needed in identifying obstacles to implementation when going forward with Lean.

#### C.1.1. Traditional Project Delivery

Traditionally, STA's use the design-bid-build (DBB) project delivery method for transportation infrastructure projects (Figure C1), where the STA contracts first with a design entity for 100% complete design documents. Once the design is complete the STA then solicits bids from contractors to perform the work and selects a contractor based upon their bid.

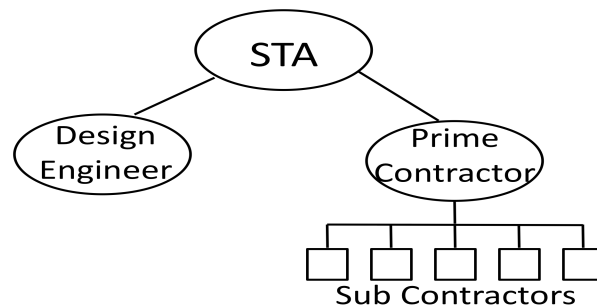


Figure 35: Traditional Design Bid Build Organization

#### C.1.2. Lean Project Delivery

Lean Project Delivery uses a holistic, non-traditional project delivery approach to managing the various collaborative relationships that exist on a project for better integration of the individual management components to maximize project benefits. Lean Techniques systematically identify and minimize waste (non-value-added activities) through continuous improvement, and when implemented 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 and productivity improved through more predictable work flow.
- 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, as shown in Figure 36.

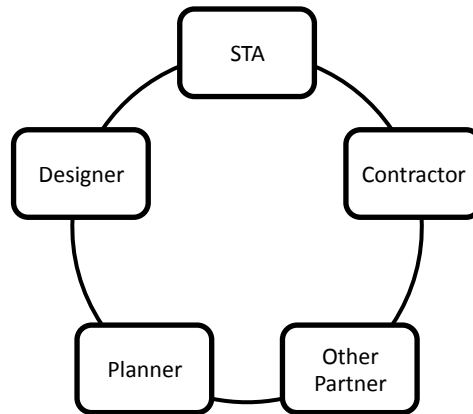


Figure 36: Lean Project Delivery System

## C.2. Identifying Waste

Waste is inherent in any process, and one of the key principles of the Lean approach is to identify these wastes. Eight types of waste have been identified as being present in any process. These wastes are:

1. Overproduction;
2. Waiting;
3. Unnecessary transport or conveyance;
4. Over or incorrect processing;
5. Excess inventory;
6. Unnecessary movement;
7. Defects / Rework; and
8. Unused employee creativity.

## C.3. Variations of Lean

The transition to LPD by STAs has taken many forms throughout the years. Two of the most popular forms of moving away from DBB are the uses of a Design Build (DB) or Construction Manager at Risk (CM@R) contracting method. Both of these have been heavily researched and described in the past. Two of the newer transitions into Lean are Project Alliancing and Public-Private Partnerships (P3s).

## C.4. Work Sampling Study

To exemplify the industry trend that less than 50% of time spent on the construction site is value- added work, a work sampling study was conducted on a county highway bridge project to observe the wastes that existed in the construction process. Work sampling studies help identify the actual tasks being performed and can help identify wasteful activities within a process.

The results of the work sampling study found that the rebar installation task consisted of only 32% direct work, and 29% pure waste. Asphalt paving work was found to include only 35% direct work, and 51% pure waste.

## **C.5. Case Studies and Company Interviews**

Public projects were sought in which Lean techniques were specifically applied in the United States, but no such project was found. This required that the case studies be done to learn more about the application of Lean techniques in foreign markets. Bechtel Corporation personnel provided literature and participated in phone interviews which provided information to better understand the Lean implementations currently used by Bechtel.

### **C.5.1. Albanian Motorway Case Study**

The first project studied in depth was a Motorway project in Albania, which utilized an improvement team, strategic gap analysis, pareto charts, standard work, fishbone diagrams, process mapping, workflow simulation, and 5-S strategies to identify wastes, improve productivity, reduce completion time of individual activities and the overall project, and improve cost-effectiveness.

### **C.5.2. Jubail Industrial City Case Study**

The second case study performed for this study focused on Jubail Industrial City in Saudi Arabia. It is a planned city of 140,000, including facilities and infrastructure construction. Bechtel used a value stream map, system diagnosis, process simulation, pull operations, standard work, and improved supply chain logistics to improve the construction performance, identify wastes and drastically improve productivity.

### **C.5.3. Oil, Gas and Chemicals, Inc. Case Study**

Bechtel's improvement team used the Define-Measure-Analyze-Design-Verify (DMADV) process to design, pilot, and validate their Lean Construction at the Workforce Program. The process started by performing a voice of the customer (VOC) study to gather worker requirements and ideas. These requirements and ideas were then transformed into design requirements and actions, resulting in large cost savings.

## **C.6. Promising Lean Techniques for Transportation Projects**

Value Stream Mapping (VSM) is a special type of flowcharting tool that is used to visualize product flows through various processing steps. VSM should be applied wherever there is need for a process to be mapped out. It allows processes to be streamlined and critical areas identified, leading to increased productivity by eliminating wasteful activities.

*The Last Planner<sup>TM</sup>* holds individuals responsible for individual tasks and for understanding why a delayed task has not been completed, allowing root causes to be identified and problems solved. Under Last Planner<sup>TM</sup>, schedules are created by the people who are best able to determine actual durations and responsibilities, so the people who do the scheduling are also the people who do the work. Last Planner<sup>TM</sup> can be used throughout the project process. The enhanced reliability that the Last Planner<sup>TM</sup> creates can lead to cost savings.

*Target costing* is a cost management tool intended to reduce the overall cost of a product over its life-cycle. The target costing approach makes cost an input into the design process instead of an outcome by designating a maximum cost that can be incurred on a project for the construction firm to still earn the required profit margin. Target costing should begin at the very

beginning of the so-called “fuzzy front end” of the product-realization process, and can have a very positive economic impact on a project.

*Just-in-time (JIT) delivery* is an inventory strategy that reduces in-process inventory and reduces carrying costs. The principle is to deliver the right material, at the right time, at the right place, in the exact amount needed. While the contractor involved in the work must take the lead in applying JIT, the method also requires management and participation of the network of suppliers and subcontractors. Once implemented, JIT becomes a business philosophy, and should be used throughout the entire duration of a project.

*Batch size reduction* can be related to many different facets of a construction project, including large batch sizes when drawings are sent for review and approval, when requests for information (RFI's) are made, or when there is a request from one specialist to another for more information than is necessary. Reduction of batch sizes can reduce the amount of time spent waiting for information on a jobsite. One piece flow and batch size reduction relate to creating a continuous flow to eliminate extra stopping and starting that occur currently in the construction industry. One piece flow should be used wherever possible. Whenever work can be consistently predicted and operate on schedule the project will benefit financially.

*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. For established projects, Six Sigma advocates the Define, Measure, Analyze, Improve, Control (DMAIC) methodology. For projects aimed at creating new products or designs, the Define, Measure, Analyze, Design and Verify (DMADV) methodology is used. Six Sigma should be applied wherever possible. A successful Six Sigma program will have an economic impact by almost completely eliminating defects, which will limit rework, one of the largest wastes in construction.

## **C.7. Relationship of STA Best Practices to Lean Techniques**

Currently, there are many best practices being used by STAs that are similar to Lean techniques. Because some of these practices already exist, it will be easier for the transportation industry to implement certain tools before others. It may be appropriate to focus first on Lean techniques that match up well with current STA practices, before moving to apply some of the other types of Lean techniques. Appendix B of the Report details the relationships between Lean tools and techniques used in manufacturing and vertical construction with best practices from transportation projects.

## **C.8. Ranking Lean Techniques for Application in the Transportation Industry**

Lean techniques were ranked according to their ease of implementation in the transportation construction industry as “Straightforward,” “Moderate,” or “Difficult.” Ease of implementation was based on the amount of agreement between a potential lean technique and the current STA delivery process, including the overall delivery system, individual resistance to change, and legal issues. Table C1 summarizes the lean techniques found to be of Straightforward or Moderate ease of implementation in the transportation industry.

The most promising lean techniques include: (1) Collaborative Planning, which is the process of involving all stakeholders in a project at the same time in order to ensure that all players are on the same page; (2) Daily Huddle Meetings (Pre-Task Planning), which are short 5-10 minute daily meetings to update project progress as well as identify any issues that may need to be addressed; (3) Last Planner System, which is a scheduling tool where work is scheduled by the



person who is closest to the work actually being done; (4) Pull Schedules, which are a tool where a project is planned in reverse from the end to the start in order to understand which work tasks are impacted by a particular trade; (5) Simulation and Modeling, which covers a number of ways to virtually plan and construct a project before breaking ground, including BIM (Building Information Modeling) and IPD (Integrated Project Delivery); (6) Standard Work, which is the process of creating standard items and tasks in order to take methods and products produced or used in one project or project task and apply them to another; and (7) Value Stream Mapping (VSM), which is the process of identifying all of the steps in a particular process and listing the value-added time and total time of each task.

Table 9: Ease of Implementation of Lean Techniques in the Transportation Industry

Lean Techniques in Vertical Construction	Ease of Implementation In Transportation Industry (High/Medium/Low)	
	Contractor	STA
5-S (organizing work flow)	Straightforward	
A3 Reporting	Straightforward	Straightforward
Batch Size Reduction	Moderate	
*Collaborative Planning	Straightforward	
Continuous Flow (One Piece Flow)	Moderate	
Customer Focus	Straightforward	
*Daily Huddle Meetings (pre-task planning)	Straightforward	
Increased Visualization (visual management)	Moderate	Moderate
Just-In-Time Delivery	Straightforward	
*Last Planner	Straightforward	
Plan Do Check Act Analysis	Straightforward	Straightforward
*Pull Schedules	Straightforward	
Root Cause Analysis (5 Why)	Moderate	Moderate
*Simulation and Modeling (BIM)	Moderate	Moderate
*Standard Work	Straightforward	Straightforward

Supply Chain Management	Straightforward	
Takt Time	Straightforward	
*Value Stream Mapping	Straightforward	
Workflow Leveling	Moderate	
Workflow Diagram	Straightforward	

\* Discussed in further detail in Report

## C.9. Barriers to Lean Construction

Public transportation projects present particular challenges to the implementation of Lean techniques. For public construction contracts, there are often restrictive laws governing the selection of contractors. In particular, competitive bidding is often mandated or strongly encouraged. Lean relies on the careful selection of contractors and subcontractors early in the project cycle, which conflicts with several of the characteristics of a competitive bidding process.

The construction industry is well trained and is familiar with the DBB method. Transportation contractors have a fear of selection bias and political influence, which the low bid criterion of a DBB project prevents. The working and management philosophies of STAs were designed to complete projects using the DBB delivery system.

Many STA systems involve a potentially large number of reviews and project stages. The reviews often represent milestones that are dependent on one another, which may lead to difficulties in developing a holistic review of the project. These organizational and process issues may lead to barriers with many lean techniques that require early and extensive collaboration among project participants.

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

Risk is an inherent part of the construction industry and is present on every project, Lean or otherwise. The important fundamentals of risk management are:

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

Due to the newness of LPD, there are currently not any insurance products that align with the collaborative contract in which no one entity bears the responsibility alone. Due to the group nature of the project, insurers are hard pressed to create policies that cover the project instead of the parties involved. This is due to the disconnect between the no-fault environment of LPD and the pro-fault environment of professional liability insurance. The American Institute of Architects (AIA) has developed a multi-party agreement for IPD projects that “provides the framework for a collaborative environment in which the parties operate in furtherance of cost and performance goals that the parties jointly establish.”

Many critics of LPD cite the fact that these multiparty agreements do not include a guaranteed price. Public entities currently use the DBB delivery to ensure the public that the project is being

completed at the lowest responsible price. Without that measure in place it will be difficult for public entities to explain how or why a particular team was selected over another.

### C.10. Management Plan for Adoption of Lean

The proposed management plan for adopting LPD can be summarized by Figure 37.

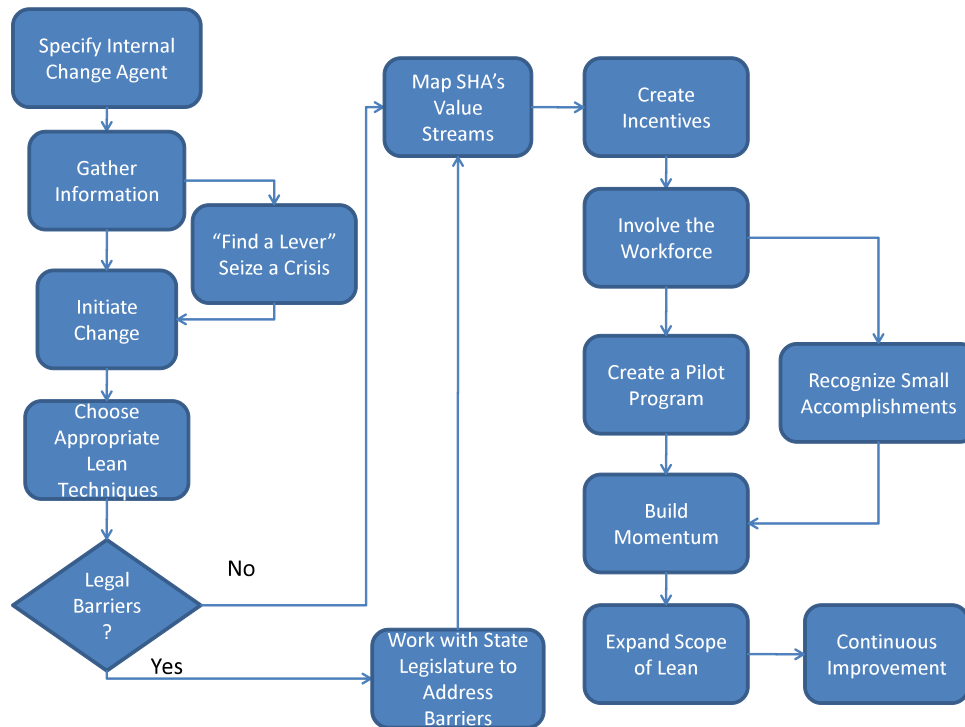


Figure 37: Management Plan for STA Adoption of Lean Techniques

To implement an LPD system, an STA must overcome the inertia of long-standing traditions and procedures to improve processes, designate a change agent to become the resident LPD expert, find a “lever” to help move forward with the implementation process, initiate the changes, choose appropriate Lean techniques, determine whether there are significant legal barriers to implementation, work with the state legislature to address any barriers identified, map the value streams within the STA, create incentives to involve the workforce, create a pilot program, recognize small accomplishments, build momentum by building on these accomplishments, expand the scope of the LPD within the organization, and work for continuous improvement.

### C.11. Conclusion

By creating an in-house improvement process, it is possible for STAs to improve projects by implementing some Lean techniques within the current delivery methods. With Lean principles in place and with continuous improvement in mind, industry-wide productivity should improve as the use of Lean techniques spreads. Utilizing Lean delivery methods, construction industry productivity will be more likely to mirror the productivity increases seen in other industries.

Implementation of lean techniques requires a significant shift in the organization’s core philosophy. How large this shift will be is one of the key questions. To apply lean delivery in a transformative fashion, a major shift in core philosophy is required, along with, potentially, legislative approval. Without these two prerequisites, it will only be possible to apply lean techniques incrementally to public transportation projects. If current trends continue, putting

increased stress on state and SHA budgets, state governments may become increasingly open to innovative ways of saving time and money, improving quality, and increasing the efficiency of project delivery such as LPD.

Incremental implementation of any of the lean techniques discussed in this report does not constitute a true LPD system. Development of a true LPD system requires integration of a coherent lean philosophy, implemented through the systematic application of appropriate lean techniques discussed in this report within an integrated project delivery framework. While many lean techniques and tools can be implemented in isolation, utilization of the IPD framework seems to be a baseline requirement for development of a truly lean project delivery system. SHAs are encouraged to implement incremental moves toward lean techniques while in parallel pursuing the ability to apply the full LPD system through the legislative process.

Many obstacles to SHAs implementing a Lean delivery process are related to legal and contractual obligations. By creating an in-house improvement process, it is possible to improve projects with the current delivery methods using the lean techniques and tools presented in this report. This can also help to alleviate any legal issues that may arise.

Even though improvement can be made by implementing Lean at the contractor level, much greater improvements can be made by involving the owner, contractor, subcontractors, and suppliers early in the design phase to create a true LPD. Currently, this is not possible under the DBB delivery system, but increased use of DB procurement methods does provide greater opportunities for implementation of LPD techniques. Building construction has made the change, and highway construction may be able to use this example to apply similar techniques and realize some of the same benefits.





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