Simonsson, Peter; Björnfot, Anders; Erikshammar, Jarkko and Olofsson, Thomas (2012) 'Learning to see' the Effects of Improved Workflow in Civil Engineering Projects. *Lean Construction Journal* 2012 pp 35-48
www.leanconstructionjournal.org

'Learning to see' the Effects of Improved Workflow in Civil Engineering Projects

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Abstract

Research Question/Hypothesis: Value Stream Mapping (VSM) can, independent of work repetition, improve the performance of civil engineering projects by allowing the site management to visualize the flows of materials, resources and information.

Purpose: The purpose is to show how VSM can be used by on-site practitioners to see the day-to-day flow of work, to understand the effect of straight-forward improvements to workflow, and to see the effect of applying industrialized working methods.

Research Method: Applicability of VSM to civil engineering is examined through the fixing of reinforcement in two bridge construction projects. A traditional bridge was used to map (current state) and improve (future state) workflow. The potential of modern production methods are then analyzed in a second bridge project (ideal state).

Findings: Allowing the site management to visualize and to see workflow improves the work performance of the two studied bridges. Addition of easy to understand and calculable metrics for lead time, inventory level and manufacturing costs, emphasize the potential savings of reactive and proactive workflow measures (≈ 80-90 %).

Limitations: The paper considers fixing of reinforcement in two bridge construction projects. Additionally, the so-called future state bridge was not actually constructed, i.e. the savings stated for the future state, even if reasonable, are an approximation.

Implications: The framework to visualize current, future and ideal workflow provides a framework to extend the VSM methodology to civil engineering projects.

Value for practitioners: To overcome the sub-optimized mindset in civil engineering that repeatedly leads to the same practice, the paper proposes a straightforward and easy to use framework to visualize and analyze effects of workflow improvements.

Keywords: Value Stream Mapping (VSM), Waste, Workflow, Civil Engineering, Visualization

Paper type: Case Study

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Introduction

Due to the unique nature of most on-site projects, it can often be difficult to define generic production steps that are adding value. This is perhaps more evident in civil engineering construction projects as value is often viewed differently by different participants (Simonsson and Emborg, 2009). Also, the time between award of contract and start of the construction work is normally short. Even though the construction process is not standardized and needs to be re-developed each time, the contractors focus is not to plan and optimize the on-site building process. Several productivity studies (e.g. Horman and Kenley, 2005; Simonsson and Emborg, 2007; Mossman, 2009) also indicate that there is much waste generated on construction sites.

The key to improving on-site construction is in the management of flow of materials, resources and information (Jongeling and Olofsson, 2007). Also, a standardized flow of, for example, materials makes it possible for the site management to plan ahead rather than "extinguish fires" (solve urgent matters). For this, site management must be trained to differentiate between value adding and wasteful activities and hence, eliminate waste from the construction process. Deming (cited from Liker, 2004) emphasized, that "the next process is the customer" – this kind of thinking is seldom realized in on-site construction projects. Consequently, learning to see work flow has great potential.

Value Stream Mapping (VSM), originating from the manufacturing industry, is often used to visualize material and information flows (Rother and Shook, 2004). Visualization of flows in civil engineering projects, such as road construction or bridge construction, is pretty much none-existent in literature to date. On the other hand, the application of VSM for projects of more repetitive nature, e.g. housing construction, is more common; see for example Yu et al. (2009) and Sacks et al. (2009). A reason for this is the large variation in physical lay-out and relatively few standardized work task in traditional civil engineering projects (Jongeling and Olofsson, 2007).

However, as VSM is mainly about the visualization of flows and to make these flows transparent for the whole organization (Rother and Shook, 2004), the VSM methodology should also be readily applicable to the unique nature of civil engineering projects and useful as a tool to help on-site construction practitioners see the flow of work. Björnfot et al. (2011) concluded that the effect of successfully applying the VSM methodology in construction components manufacturing is an organizational change towards a Lean culture. Certainly, the same can be expected in civil engineering projects. The hypothesis of this article is thus that VSM, independently of work repetition, can improve the performance of civil engineering projects by allowing the site management to visualize and to see the flows of materials, resources and information.

The applicability of the VSM methodology to civil engineering projects is examined through the fixing of reinforcement in two bridge construction projects. VSM is first used to map the workflow in a traditional construction project that is analyzed to identify waste and to improve the flow of work. The effect of alternative industrialized production methods is then analyzed by studying the workflow of a second bridge project where industrialized working methods were utilized. The aim of the paper is to show how VSM can be utilized by on-site practitioners to see the day-to-day flow of work, to understand the effect of straight-forward improvements to workflow, and to see the effect of applying, and utilizing the benefit of, industrialized working methods.

Understanding & improving workflow

A flow is composed of transformations, inspections, moving and waiting (Koskela, 2000). According to Womack and Jones (2003), workflow refers to the movement of materials, information and resources through a system. To create a smooth flow of work, the availability of materials, information and resources must be controlled during the whole production process (Thomas et al, 2003). Reducing on-site material handling and lead times through proper workflow management is an important part of the construction industry's improvement of productivity (Ballard et al., 2003). According to Formoso et al. (2002), waste elimination is a focus for workflow improvement within Lean production.

Womack and Jones (2003) defines waste as any human activity that absorbs resources without creating any value, i.e. waiting time, over production, unnecessary inventory, erroneous processes, unnecessary movement and transports, products with errors, and not meeting customer demands. Koskela (2000) identified construction waste as poor/incorrect quality of the product, rework, excessive and left over materials, material handling, materials in stock, and work in suboptimal conditions. Mossman (2009) argued that waste should be defined in relation to value, i.e. waste elimination through value creation. It should be noted, that an over-emphasis on waste reduction can become counterproductive as low inventory, or a lack of production capacity, can lead to supply chain disruptions.

Improving the flow of work

The most readily applicable method for improving workflow is pull production. Pull means that no upstream actor should produce anything until the customer downstream asks for it (Womack and Jones, 2003). In construction, the most recognized and applied tool to generate pull is the Last Planner system of production control. However, there are certainly other attempts at establishing pull in on-site construction of which Line-of-Balance (Seppänen et al., 2010) and pull production of multi-storey housing (Sacks and Goldin, 2007; Sacks et al., 2009) are but two examples.

Another approach to minimize wasteful activities is to standardize work tasks. The execution of work tasks varies from construction site to construction site and from worker to worker (Nakagawa, 2005). Work is standardized to systemize operations and materials so that human motion between operations and needed resources is used in the best known order and hence most efficiently. Through process standardization, the manufacturing process becomes more robust, leading to operational excellence, continuous improvement and elimination of non-value-adding activities (Álvarez et al., 2009).

Achieving the right flow of work in production processes is important. Decisions made early affects how, e.g. a bridge is to be built and hence affects the workflow on-site. Such factors as location, type and shape, material choice and detail design all affect the flow of work (Ray et al., 1996; Lam et al., 2006; Jergeas and Van Der Put, 2001). Hence, to achieve workflow at the construction site, the design and planning phase needs to be controlled and managed from a buildability perspective. Adams (1989) stated that the key to success is the early design stage where knowledge from all vital actors is gathered to create buildability for a specific project. Wong et al. (2004) states that design decisions affect how a building is to be built and determine the types as well as level of resources to be involved in the conversion process, and that designers often lack the knowledge and the incentive to make the right decisions.

Consequently, it is possible to work with workflow at both the early stages of a construction project using so called proactive workflow methods and during the project execution at the construction site using so called reactive workflow methods (Figure 1):

- **Proactive workflow management**. Aims at removing hindrances to production workflow in the design phase. Common methods are e.g. improved buildability and proper production planning. Another useful method for proactive workflow management is simulation using for example 4D planning (Björnfot and Jongeling, 2007).
- **Reactive workflow management.** Aims at removing hindrances in the production phase so that even workflow is achieve at the construction site. Common methods are e.g. planning for pull production and standardizing work tasks. Another useful method for reactive workflow management is to highlight workflow by mapping the value stream (Yu et al., 2009).

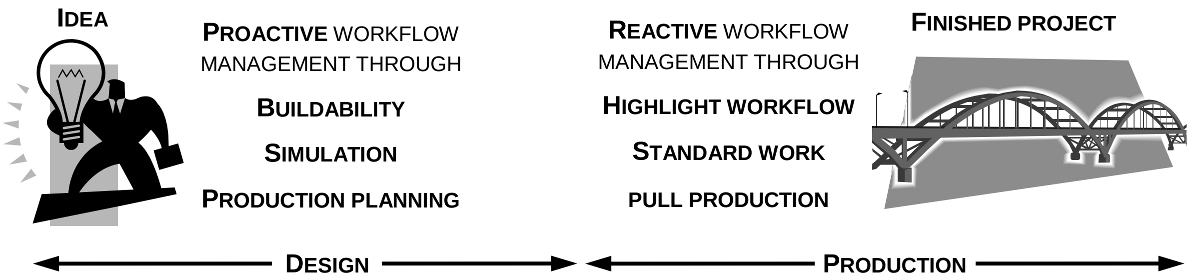

Figure 1: Applicability of proactive and reactive methods to improve workflow.

Highlighting workflow

Value stream mapping (VSM) is an effective method to capture both the material and the information flows of manufacturing, transactional and administrative processes and to provide a good communication tool for practitioners as well as a reference model for theoretical analysis (Álvarez et al., 2009; Mehta, 2009). By focusing on continuous flows rather than machine, transport or personnel utilization, the likelihood of sub-optimization is reduced (Ballard et al., 2003). The focus on continuous flow enables the contractor to involve suppliers, standardize processes and reduce variation of products (Arbulu et al., 2003). VSM is divided into mapping the current, future and an ideal state and the implementation of what is defined as yearly value stream plans (Rother and Shook, 2004)

Khaswala and Irani (2001) argue that VSM is best utilized for high volume production since it is difficult to follow the workflow from finished goods to raw material. However, if the processes are standardized and the project consists of multiple objects, then it is possible to use VSM even for civil engineering projects. Wilson (2009) argued that VSM can be applied to any business process including service, product development, manufacturing and office processes.

Effects of workflow improvements

A process can be characterized by lead time, inventory and operational costs. **Lead time** is the time from when a work item enters a process until it exits, i.e. time needed to produce adequate output. **Inventory**, is the stock level, or input that the project needs to transform into output. **Operational costs** are costs connected to the transformation of input into outputs, e.g. wages, rental of machines and other resources, and overhead costs. In a normal process, an optimization of either of these parameters will lead to an increase in the others; hence we have a sub-optimized situation. By looking at the system and only by reducing all three or having status quo on two and reducing one will give an improved system (Maskell and Kennedy, 2007; Brosnan, 2008).

Lead time, inventory and operational costs are actually a transformation of financial terms used to optimize the results of a project; increased net income and at the same time maximizing return on investment and increasing cash flow (Olhager, 1993). The traditional measures of lower operational costs, lower capital costs and increased sales would lead to better revenue for the project (Mehra et al., 2004; Sheu et al., 2003). From a workflow perspective, this implies:

- Smaller capital costs through fewer inventories.
- Smaller operational costs through less staff.
- Fewer inventories mean smaller storage areas at the construction site.
- Less material handling and internal transportations.
- Less damaged or obsolete materials and waste.
- More projects in a shorter time mean more income.

Based on Olhager (1993), the workflow perspective is illustrated in Figure 2; smaller batches will lead to shorter lead time and less material handling. Shorter lead time in turn means less work in process (WIP) and less safety stock. Less WIP means fewer inventories, hence reduced capital costs. Less safety stock and faster stock turnover means fewer inventories or less capital costs. Less material handling increases likelihood of delivering the project on-time which means more projects and increased income. Consequently, lead time, inventories and manufacturing costs are good measures of project performance and should indicate how workflow improvements also improve project performance. Improving a metric without making the others worse or at least status quo is an indication that the improvement has potential to improve overall project performance.

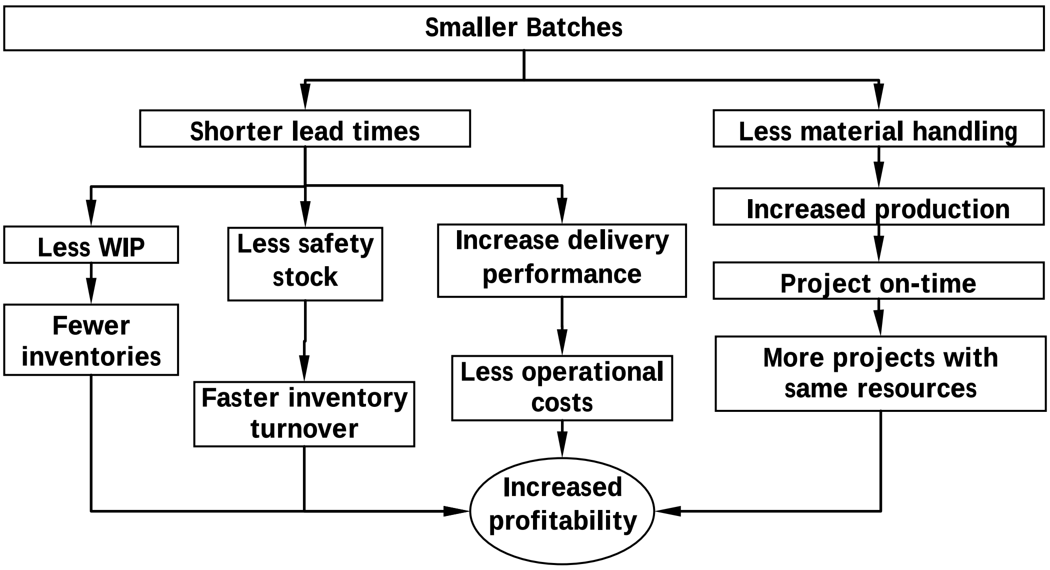

Figure 2: Illustration of the economic benefits of improving lead times, reducing inventories and lowering manufacturing costs.

Learning to see workflow

VSM is divided into mapping the current, future and ideal state (Rother and Shook, 2004). Mapping the **current state** reveals both value and non-value adding activities. The objective of the **future state** (to-be scenario) is to create a value stream where every individual process is connected to a customer by either continuous flow or a pull system. The **ideal state** is a representation of the organization vision; a state to strive for but not necessarily currently attainable due to, for example, a low technology level.

To evaluate the applicability of the VSM methodology as a tool for improving on-site construction management (Figure 3), the effect of VSM implementation should be tested to the identified process variables (*Lead time*, *Stock (or Inventory) level*, and *Manufacturing cost*). First a VSM of the current state is performed to identify the symptoms to occurring waste. Next, straight-forward improvements to work flow (*Highlight work low*, *Standard work*, and *Pull production*) are introduced and the process response is again checked. Finally, an ideal state is arranged in which reactive and proactive solutions to workflow (*Buildability*, *Visualization*, and *Production planning*) are implemented.

PROCESS RESPONSE	CURRENT STATE (SYMPTOMS OF WASTE)	FUTURE STATE (REACTIVE SOLUTION)	IDEAL STATE (PROACTIVE SOLUTION)
- Lead time - Stock level - Manufacturing cost	- Waiting - Erroneous processes - Unnecessary inventory - Unnecessary movement - Rework - Transports	- Highlight workflow - Standard work - Pull production	- Buildability - Visualization - Production Planning

Figure 3: Process response in relation to the VSM current, future and ideal states as well as the suggested reactive and proactive workflow improvements.

Case study research: rebar management in Civil Engineering

Two civil engineering projects were studied (Table 1) with focus on workflow during reinforcement fixing. The same contractor carried out both projects, albeit with different management and work crew. The first project represents the current traditional state, whereas the second project introduces alternative industrialized production methods, for example prefabricated reinforcement, which here is used to represent an ideal state in bridge construction. The first project is also used to analyze the potential of reactive workflow solutions, i.e. an improved future state. However, it should be noted that the future state bridge was not actually constructed. The results from the future state bridge construction are instead reliant on the experience of the authors.

Table 1: Summary of the two bridge construction projects.

Case study	Project	Year	Used for
Bridge construction	1. Traditional on-site construction methods	2005	Current & Future states
Bridge construction	2. Industrialized construction methods	2006	Ideal state

VSM, according to Learning-to-See (Rother and Shook 2004), is used to visualize and analyze the workflow. The method has been modified since it is suggested to work upstream, i.e. from finished goods backwards to raw material that of course is difficult to accomplish in the case of bridge construction as building a bridge can be considered a one-of-a-kind flow as the work crew, management, site characteristics, etc. are rarely consistent between projects. Therefore, the construction progress was followed from start to end and the data collected was used to work backwards. The studies are used to create a VSM of the current, future and ideal states that are analyzed according to Figure 3.

Data for the two projects were collected through frequent construction site visits by the main author. During the site visits, the on-site management was asked to give statements on the work performed and to validate the data collected. However, the main goal of the site visits was to collect quantitative data on lead times and inventory levels. Information about lead times was achieved by collecting data on delivery of the material to the construction sites (e.g. reinforcement deliveries) and the date for which the reinforcement was mounted and fixed into the bridges.

In addition, some of the waiting time for the reinforcement in between activities was measured and estimated. It was difficult to establish the waiting time for the current and future states, since at least one ton of reinforcement is lifted upon the superstructure at the same time and after that each single rebar is manually transported and fixed on the superstructure. Through this mounting and fixing procedure it becomes difficult to exactly establish the waiting time for each rebar and, hence, an average total waiting time for all the reinforcement in the superstructure becomes more relevant to measure and estimate.

Case study results – Bridge construction

Current state

The first project was the construction of a superstructure for a girder bridge of reinforced concrete. This bridge (Figure 4) was part of a project consisting of four bridges to be constructed by the same contractor. The different bridges were viewed as individual units resulting in little cooperation between the different construction sites despite that they were located only a few hundred meters apart. As an example, there was no cooperation in delivery of reinforcement or utilization of mobile cranes.

Figure 4: Illustration of bridge construction using traditional production methods.

The studied bridge had two abutments and a mid-support with spans of 19 and 16 meters. The width of the bridge was 11.35 meters and the total length was 48.5 meters. Approximately 420 m^3 of concrete and 60 ton of reinforcement were used during construction of the superstructure. The same work crew had already erected an identical and parallel bridge. However, interviews with site management made it clear that not much learning between projects occurred as the same kind of waste was observed, for example rebar being fixed piece by piece, highlighting unnecessary and high levels of material inventory on site. Figure 5 illustrated the current state VSM.

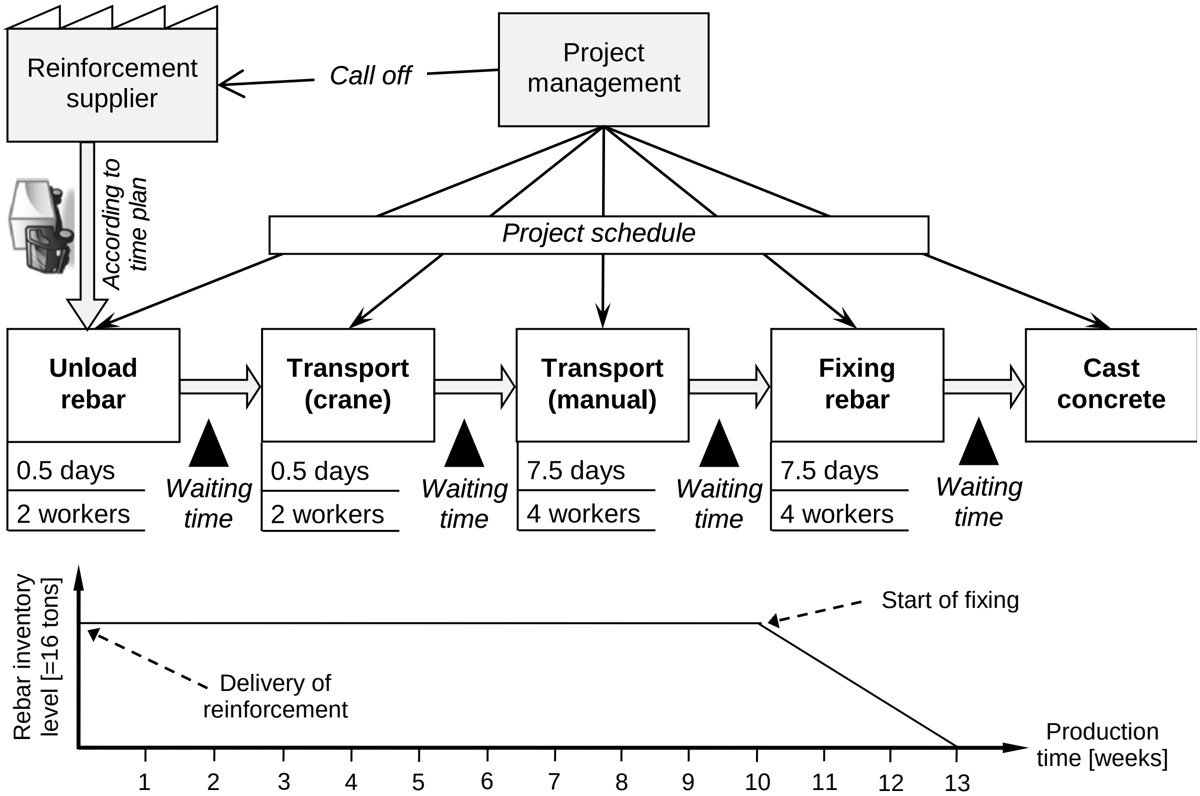

Figure 5: The *current state* VSM for the *traditional bridge* construction project and a schematically drawn diagram of the actual superstructure rebar inventory level.

On day zero of the bridge project, a truck arrived with all reinforcement required for the superstructure. The first project had 60 tons of reinforcement in the superstructure; this has been scaled down to be able to be compared with the Ideal state bridge (see below) which used 16 tons of reinforcement for the superstructure (i.e., almost four times less). The time for construction of the superstructure has also been recalculated to reflect the reduced amount of reinforcement. Unloading the rebar takes approximately half a day for two workers. The remaining value adding time for using the crane and fixing the rebar are illustrated in Figure 5. Consequently, the amount of waiting time is considerable as the reinforcement arrives on day zero and is fully consumed only after 13 weeks.

Future state

The future state can be viewed as a reactive state, involving the same activities as the current state (Figure 5). By highlighting workflow and introducing more standardized work tasks, improved production planning and control is achieved resulting in implementation of a pull system where, for example, reinforcement is delivered when needed at the construction site. In the current state, the reinforcement was delivered in large batches by full trucks for each construction site. Instead a so called "milk run system" can be implemented supplying adequate amount of reinforcement to all construction sites using one truck during the same run. These runs can be initiated using pull signaling systems either on activities to be performed or inventory levels. Implementing these changes would provide a future state VSM as illustrated in Figure 6.

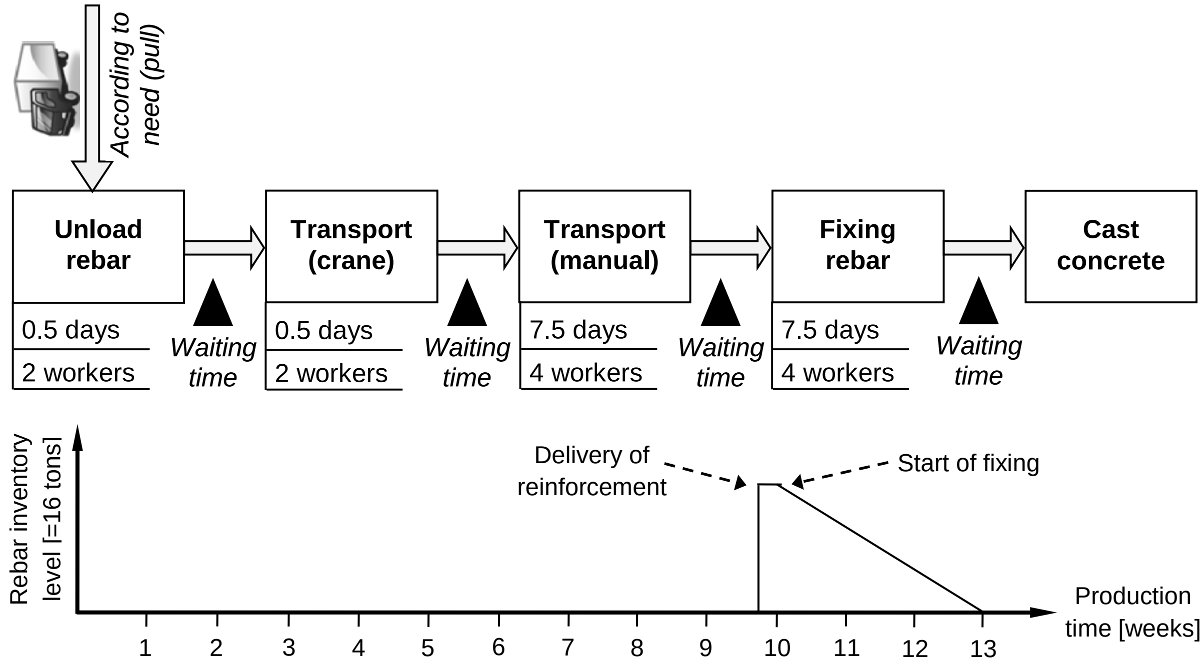

Figure 6: The *future state* VSM for the *traditional bridge* construction project and a schematically drawn diagram of the actual superstructure rebar inventory level.

The production process is in this case similar (in terms of lead time and workers) to the current state process, with one exception; the reinforcement arrive "Just-in-time". Just-in-time here means the arrival of reinforcement approximately two days prior (Figure 6) to the planned fixing to provide a small buffer for unexpected disturbances in the production process. It should be noted that pull production as explained above was not implemented as this version of the bridge was never constructed. Therefore the presented process, even if highly likely, cannot be verified.

Ideal state

Besides pull production, as described in the future state, the ideal state involves design and planning, i.e., proactive workflow management by improved buildability. The ideal state was evaluated on a slab bridge with a total length of 17 meters, a width of 15 meters, and approximately 250 m^3 of concrete and 25 ton of reinforcement were used, i.e. in all regards a similar bridge, albeit smaller, to the one studied in the current state. Due to the utilization of prefabricated reinforcement cages (Figure 7) for the foundations and rebar carpets (Figure 7) for the superstructure, the construction process involved fewer activities if compared to traditional bridge construction.

To fully utilize the potential of the new production methods, production planning was improved, especially in the precision of deliveries. For example, the reinforcement cages were pulled to the site and mounted directly in the formwork. Also, the rebar carpets used for the superstructure were delivered at about the same day as they were used. All reinforcement for the superstructure was fixed in one week which resulted in an average time of 2.5 days for reinforcement in stock during fixing and another 2 days for early delivery as a time buffer for unforeseen events. Consequently, more efficient use of inventory at site was achieved. The VSM for the ideal state is illustrated in Figure 8.


Figure 7: Use of prefabricated reinforcement cages (left) and rebar carpets (right).

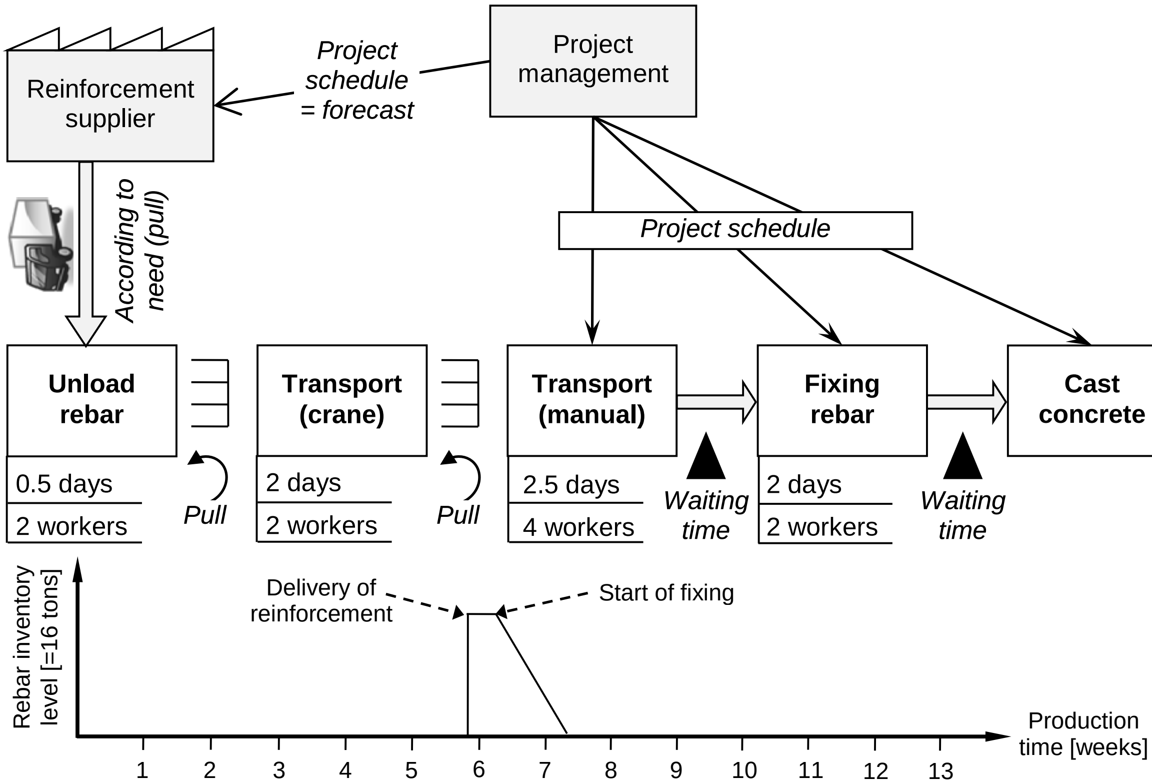

Figure 8: The *ideal state* VSM of the *industrialized bridge* construction project and a schematically drawn diagram of the actual superstructure rebar inventory level.

Mounting the rebar carpets takes approximately one day in total for upper and lower layers of reinforcement. The shear force reinforcement takes an additional 4 days of fixing for four workers. The reason why the project is finished earlier than the traditional bridge is because more prefabricated construction methods were used. As an example rebar cages for the foundations were used (see Figure 7). This reduced the on-site work of fixing the reinforcement for the two foundations from 6 days in total to 1 hour.

Seeing the potential of workflow improvements

Waste observed in the current state was moving materials around the construction site, waiting for materials, machines or instructions, rework, and interruptions of progressive work. In fact, a study of productivity at the specific bridge indicated that only about 30 % of working time was actually adding any value. Other typical wastes that were observed are presented in Table 2. By introducing reactive solutions such as a pull system, "milk run" deliveries and improved production planning, the current state can be improved. As a consequence of the improvement, the waste of high inventory levels and long lead times can be reduced. Also moving the reinforcement inventory around the site due to other activities is reduced dramatically. In addition, cash funds being tied up in inventory are minimized and in some cases it might even be possible to earn money on interest on advance payment from the client.

Table 2: Observations of waste during bridge construction

Type of waste	Cause of waste
Unnecessary sorting and measuring of reinforcement	Disorder upon delivery and too large stock
Lifting, measuring and sorting	Stock size
Waiting	Lifting, measuring and sorting
Discussion	Disorder and sorting
Errors and rectification work	Disorder and sorting

In the ideal state, much of the reinforcement was pulled just-in-time to the construction site, i.e. it came the same day as it was supposed to be fixed into the construction (plus a two day buffer). The ideal state improved the lead time and inventory levels from current state with approximately 90 % (Table 3). Also, the manufacturing cost at site decreased significantly (-68 %) in the ideal state at the expense of an increase in the procurement of the prefabricated rebar structures of approximately 30 %. Still, the overall construction cost decreased as well as construction time on-site.

Table 3: Lead time, inventory level and manufacturing cost for the current, future and ideal states of bridge construction. Numbers in brackets are improvement in percent.

Process response	Current state	Future state	Ideal state
Lead time [days]	65	17 (-74 %)	7 (-89 %)
Inventory level [days]	57.5	9.5 (-83 %)	4.5 (-92 %)
Manufacturing cost [€]	3.1	3.1 (0 %)	1 (-68 %)

The **lead time** (Table 3) is calculated as the total time for the process to be completed, i.e. the times indicated in the current (Figure 5), future (Figure 6) and ideal (Figure 8) state VSM's. The **Inventory level** is the average time the reinforcement is laying in inventory on site, i.e. basically 'the area' under the inventory level curves (Figure 9). The inventory level has in all cases been simplified to a linear consumption, which it in fact is not but it provides a good approximation and a straight forward analysis. The **manufacturing cost** is calculated as the amount of work performed (in hours) × number of workers × hourly salary (Figure 9). In Table 2, the manufacturing costs are normalized with one for the ideal state as the case company does not wish to reveal any economic data.

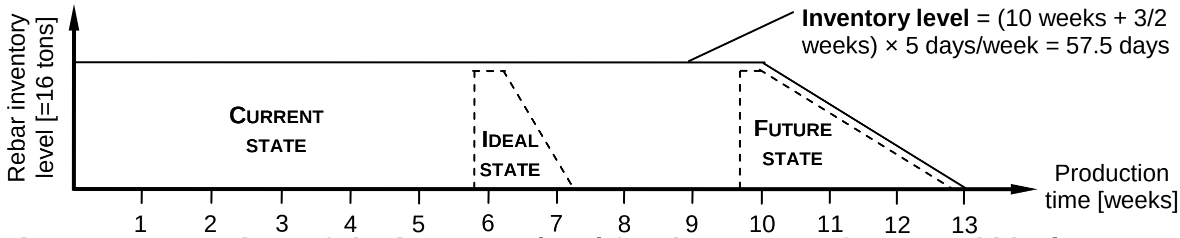

Figure 9: Comparison of the inventory level for the current, future and ideal states of bridge construction.

Visually comparing the inventory levels for the current, future and ideal states (Figure 9) clearly indicates the impact of reactive and proactive solutions for improving the workflow on site. Firstly, the inventory level is drastically reduced by such simple reactive measures as dividing the delivery of reinforcement into smaller batches, in the future state meaning delivery of all reinforcement for the superstructure in good time (two days) before production is commenced. Secondly, proactive workflow management at the early design stage admitted the use of e.g. rebar carpets in the ideal state solution. The resultant inventory level can thus be decreased by about 50 % from the future state (Table 3). However, without commitment from all participants i.e. contractor, client, material supplier and designer, the ideal state would not have been possible to achieve.

Discussion & Conclusion

In this paper, we have shown that *the performance of civil engineering projects can be improved by allowing the site management to visualize and to see the workflow on the construction site*. By 'learning to see' workflow, the on-site management is able to understand the potential effect of improving the **current workflow**. Schematically visualizing the traditional flow of work and merely identifying potential waste, is rarely enough for changing traditional practices. However, with the inclusion of easy to understand and calculable metrics for lead time, inventory level and manufacturing costs, the potential savings of reactive solutions (**future workflow**) is emphasized. For example, in the two studied bridges it was possible to improve project performance by 74–83 % by using relatively simple methods such as reduced batch sizes and pull supply.

By relating rebar management to project time table and the expected work load or consumption, and making sure that deliveries are made using visual planning according to e.g. the Last Planner System, managers will decrease holding costs, minimize steel corrosion, avoid theft of rebar, and minimize wasteful activities. Consequently, productivity will increase as well as profits for the specific construction site. Instead of sub-optimizing the system by resource or sub-process utilization, focus should be moved to the whole process, as is the case using the Value Stream Mapping (VSM) method. Another benefit is that bridges are often constructed in compact urban environments with limited space for inventories; proper planning thus becomes a necessity.

On-site management often minimizes transportation costs with the mentality that "the trucks are so expensive" since this is a cost viewed at the project income level. However, the minimization of transportation costs will sub-optimize the construction process, decreasing overall project performance as is quite obvious from the relatively simple VSM analysis performed in this article, e.g. delivery of the 16 tons of reinforcement required for the superstructure as a batch "Just-in-time" would in this case reduce the lead time by 74 %. In addition, the use of large inventory levels leads to lower inventory turnover that in turn leads to more material handling and obsolete or disappearing materials. Consequently, there is great potential to work with reactive production methods to improved workflow using VSM visualization and analysis. However, to truly improve the performance of bridge construction, the on-site management must learn to see the benefits of an **ideal workflow** using proactive solutions such as buildability.

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