IMPROVING THE ROOT PILE EXECUTION PROCESS THROUGH SETUP TIME REDUCTION

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Recent structural transformations in the construction sector have created the need for building constructors to attend competitive criteria such as cost, time and quality. Therefore, construction companies are searching for new production philosophies to support their improvement efforts and are demanding from subcontractors a similar level of involvement and commitment to these goals. As participants of the construction productive chain, companies active in the field of foundation engineering are also being required by building firms to improve their work methods. However, because of the very nature of its work, geotechnical engineering presents peculiarities, which differentiate it from the rest of the building industry. These peculiarities are usually cited among the main causes for the slow development of its processes. This paper discusses the experience gained with the application of lean production principles to the root pile execution process. Recognizing the importance of performance measurement, the used methodology combined Work Sampling and SMED method concepts. Its application in a case study involved three phases: identification of current performance levels; development and implementation of improvement opportunities; and comparison with posterior performance levels. The methodology provided a set of coherent and related performance measures that showed how lower setup times can help increase foundation engineering productivity.

Keywords: performance measurement, foundation engineering, setup time, work sampling, productivity.

INTRODUCTION

The recent structural transformations in the construction sector in many countries have led building constructors to better manage their supply and assembly chains. In order to adapt to these changes, some construction companies are establishing management practices based on lean production principles with the objective of reducing operational costs and better meeting costumers' needs. This consists on applying concepts proposed by authors like Howell and Ballard (1997) and Koskela (2000), such as continuous improvement, elimination of waste, stabilization of workflow, teamwork, increase of flexibility and generation of aggregate value to product.

In Brazil, the pressure for adapting to these transformations and applying new production philosophies is being transferred, sometimes even imposed, by building constructors to sub-contractors in search for a collective efficiency. As participants of the construction productive chain, companies active in the field of geotechnical engineering are also suffering the ever-growing pressure for improving their work

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methods. However, foundation engineering processes present their own peculiarities if compared to the rest of the construction sector. These peculiarities reinforce what Howell (1999) said about the difficulty of designing and constructing unique and complex projects in highly uncertain environments under a great time and schedule pressure.

Like most subcontractors working under the substitution criterion described by Shimizu and Cardoso (2002), foundation engineering firms also execute operations with technical and financial risks, instead of the contractor. This makes the implementation of new production philosophies even more important. Aiming to investigate and validate the viability of diffusing lean production principles among subcontractors in charge of carrying out services with higher technical difficulties, this paper presents the results and discusses the experience gained in a case study where lean principles and methods were used to improve the Root Pile execution process.

Knowing that performance measurement can provide an important support to the implementation of lean principles, a methodology based on the combination of Work Sampling technique and Single Minute Exchange of Dies (SMED) method was tested. The combination of both tools made possible the identification and implementation of improvement opportunities, which led to waste reduction and better stabilization of workflow during the execution of Root Piles. The results achieved in the case study can be used for benchmarking by comparing performance indicators such as cycle time, occupation rates and waste costs.

ROOT PILE PROCESS DESCRIPTION

Foundation engineering peculiarities

Koskela (1992) identified as peculiarities of the construction industry aspects like one-of-a-kind projects, site production, temporary project organizations and intervention of legal authorities. However, two other peculiarities are also strongly associated with geotechnical engineering: remote site construction and subsoil variability.

Kestle and London (2002) relate the concept of remoteness to the physical distance of participants from the site. The most extreme situation happens when all project participants are initially not located adjacent to the project site and all design, construction and facility management actors are located in another city or urban area. It is a very common situation when geotechnical engineering processes are conducted in civil infrastructure projects like dams, pipelines, energy towers and transmission towers. Even when located inside the same urban area, which is the case of residential building projects, the construction site's facilities and infrastructure belong to the contractor. Moreover, these facilities are usually not prepared when the foundation work is initiated. The main consequences are lack of supervision, logistic difficulties and poor communication.

Subsoil variability is related to the frequent nonhomogeneous behavior of the soil profile at a given site. Hunt (1983) says that even using subsurface exploration to determine the resistance, thickness and lateral distribution of soil and rock strata, foundation engineers regularly encounter difficulties during construction. Although soil-mechanics theories concern idealized conditions, Das (1984) states that good professional judgment constitutes a major part of designing and constructing foundations. Therefore, geotechnical engineers very often rely on experience to plan schedules and to establish the necessary type and amount of production resources.

Technical aspects

The Root Pile is a foundation system using small diameter cast in situ bored piles. It can achieve high load-bearing capacities (20t to 125t) with small settlements. Depending on ground conditions, there are different safe working loads for piles of various nominal diameters (100mm to 410mm). The more favorable the soil condition the higher can be the load.

Unlike driven piles, the equipment and techniques employed have been designed to cause minimum vibration and to operate with minimal noise. This has the advantage of reducing accidents, environmental problems and damages on neighboring facilities. The method can also be employed in areas of restricted access and in waterlogged soils because the piles are built using a temporary drill casing and dense fluid grout.

With the ability to bore through hard soil layers or boulders, the Root Pile is a cost effective solution since it reduces costly delays and waiting time common to other forms of piling in similar situations. Depending on access and ground conditions, the method uses either traditional tripod rigs or crane-mounted rotary drilling rigs to bore the piles by rotating and feeding down a temporary steel casing which has a special cutting bit at its leading end. Meanwhile, drilling water is circulated through the casing to cool the cutting bit and to transport the drilling spoil along the outside of the casing to the ground surface.

When the borehole reaches the required depth, a reinforcing cage extending the full depth of the pile is placed through it. After the grout tremmie tube is inserted with the located reinforcement, the temporary drill casing is withdrawn while the borehole is filled with grout.

STABILIZING WORK FLOW THROUGH SETUP TIME REDUCTION

During the construction of Root Piles, a number of contributive activities are carried out to support productive activities such as drilling the borehole, placing the reinforcement and raking the pile. They are necessary every time a new pile is constructed. However, since the cycle time to construct each pile is relatively short, it seems reasonable to pay these contributive activities the same kind of attention given to setup activities in manufacturing processes.

In manufacturing, the implementation of a new production paradigm aimed to eliminate any activity that generates indirect costs without adding value to the product has been backed up by Just-in-Time (JIT) principles. Cited by Koskela (1992) as a methodology that supports Lean Production, JIT has as one of its most important aspects the reduction of time spent on machine preparation and tool exchange.

Although setup activities are contributive to the process, the final costumer does not recognize them as being valuable and therefore does not accept to pay for the resources nor wait for the time they consume. According to Koskela (2000), the new conceptualization implies in considering time as an input resource. So one of the main objectives must be the reduction of time consumed along the entire process. Thus, reducing the share of non-value adding activities contributes to compress the cycle time. Moreover, the reduction of setup and changeover times is also aligned with other JIT goals like overlapped operations and stabilized production flows.

Harmon (1993) points the reduction of time, cost and complexity of setup activities as the easiest and cheapest of all improvements that can be made. It provides an extra capacity to the production line allowing the company to postpone the acquisition of new machines and other production resources. This improves the utilization rates and increases the production system's flexibility to produce more with the same amount of resources. It also makes the company faster in delivering products, which allows a time based competition model to be adopted among other strategies (Stalk, 1988; Rohr and Corrêa, 1998).

PERFORMANCE MEASUREMENT IN LEAN CONSTRUCTION

In lean construction theory, performance measurement practice plays an important role in increasing process transparency to support continuous improvement efforts. According to Lantelme and Formoso (2000), it turns visible attributes that are normally invisible and gives the workers a clearer vision on the efficiency of the work done, creating the basis for a decentralized control. Therefore, it is a valuable tool for achieving lean construction goals like reduction of variability and waste.

Nevertheless, Koskela (1992) argues for the need to tailor measurements closely to the requirements of the situation. Therefore, Sink and Tuttle (1993) comment that the information provided must attend site management's needs by: (a) supplying an initial diagnosis on process performance before making any intervention; (b) identifying possible deviations from established performance patterns; (c) comparing performance against a goal or its initial diagnosis.

DESCRIPTION OF THE METHODOLOGY

The methodology is based on the combination of Work Sampling and SMED method. The objective is to allow the SMED method to be used in the development of improvement opportunities for construction processes. In order to make this possible, the data collecting and processing procedure for Work Sampling proposed by Miranda Filho and Menezes (2002) is used to identify internal and external activities, to determine the time consumed by the activities and to generate useful ideas for improvement.

In manufacturing industry, the SMED method has been usually supported by time study methods using video cameras. This equipment helps to map setup activities and interdependencies between them. The video's posterior exhibition to the workers also generates discussions on improvement opportunities. However, since a worker's output may vary over a wide margin in construction, Harris and McCaffer (1989) claim that Work Sampling is the most suitable time study method.

Work sampling

The proposed Work Sampling procedure follows Harris and McCaffer's (1989) general orientations and suggestion on taking the observations at regular intervals. The main difference consists on giving a code to each process output (product) and using it as input data to be written on the observation sheet. This allows site management to know what activity the worker was involved with and what product was consuming it at each observation round. The sheet shows the activities listed horizontally and the columns show the number and time of the observation rounds. The cells contain subdivisions with the workers code on top and empty spaces just below for the product's code to be written down.

A slight adaptation has also been made in the collecting procedure. When a worker is observed involved in a productive activity, the product's code he is working on is written below the worker's code in the activity’s line. If the worker is observed in a contributive activity, the observation should take a little longer just to see what product will consume it. But in case of a non-contributive activity, it will be considered that it was consumed by the first product the worker is observed working on in the following observation rounds.

Costa and Formoso (2003) mention the importance of focusing on a broad set of both financial and non-financial measures. Ballard and Howell (1997) add that coherent and related performance measures facilitate an integrated analysis of production planning. Thus, activity based costing (ABC) principles are incorporated during data processing when performance measures are calculated in the following sequence:

Cycle time: The total number of rounds each team spent on the product times the interval’s duration.

Activity rating: The percentage of rounds the workers were observed in productive, contributive and non-contributive activities.

Waste costs: The labor costs are tracked to the activities that consume them by using activity rating as a resource driver.

Product costs: The cost driver is estimated as the worker or team activity ratings multiplied by the product’s cycle time.

Single minute exchange of dies

Developed to support Just-in-Time, Single Minute Exchange of Dies (SMED) is a method to analyze and reduce changeovers. By applying a gradual reflection on work methods, it distinguishes changeovers in internal activities (IED - Input Exchange of Die), that can only be executed when the machine has stopped, and external activities (OED - Output Exchange of Die), that can be executed while the machine is working. The SMED method consists on three major steps: (1) separate internal and external handling; (2) transfer internal activities into external activities; and (3) eliminate or reduce all internal and external activities.

Shingo (2000) argues that the correct distinction between internal and external activities is the first and most important step. From there, some internal activities can then be transferred into external activities by reexamining their real functions. The basic idea is to develop work methods that embody the key principles of integration and concurrency cited by Kamara (2003). The objective is to maximize parallel activities and interactions between workers and tools during the process.

The third step requires a detailed analysis to optimize all internal and external activities by: (a) standardizing routines; (b) using fast settings; (c) synchronizing tasks; (d) eliminating adjustments; and (e) automating tasks. This is conducted by a task team composed of people selected from different departments and hierarchical levels. They are direct or indirectly involved with the studied problem. The task team organizes meetings to develop and implement improvement opportunities, where each participant contributes with a different perspective to the problem. According to Coffey (2000), the elimination of waste is a fundamental activity in Lean Production, but it requires an active involvement of workers alongside with managers to be successful.

CASE STUDY

The methodology was used during the construction of Root Piles in a foundations service conducted by Geonorte Engenharia de Solos e Fundações Ltda. This geotechnical engineering firm has been working as sub-contractor for construction companies for more than thirty years in all Brazilian northeastern states. The firm is headquartered in the city of Fortaleza and offers a wide range of services in geotechnical engineering.

Over the years the firm has invested time and money developing technical expertise and acquiring equipments to increase the efficiency of its conversion activities. Amongst these, it is worth to mention the acquisition of all terrain track mounted hydraulic drill rigs capable of drilling holes up to 410 mm of diameter.

The firm was interested in improving the Root Pile execution process because it commonly uses the most expensive equipments and has a great local market demand. Moreover, the study focused on improving labor efficiency since the construction materials are usually supplied by the contractor as a way of reducing the service's contracted price.

Project

The research was conducted during the construction of a residential duplex apartments project in the city of Fortaleza. With a heterogeneous subsoil profile, the project's large site required 214 piles, each with 180 mm of nominal diameter and bored as much as 8 m deep. The foundation service was divided in two phases. The first phase consisted on constructing 88 piles during a period of 20 days. Another 126 piles were constructed in the second phase, which lasted 30 days.

Work Sampling was used during the first phase to determine current performance levels before intervening in the process. Initially, a preliminary survey was necessary to collect information, plan the observations and explain to the workers involved the objectives of the study. The daily observations were planned at regular intervals of 10 minutes and the total number of observations was calculated taking as usual 95% confidence.

Nine workers distributed in two teams were identified. While four workers were exclusively involved with the drilling subprocess, the rest was responsible for the cement grouting subprocess. Based on conversion model concepts discussed by Koskela (1992), each team had specialized skills and was formed by a leader and his assistants. As part of the data collecting procedure, the workers received numerical codes from 1 to 9.

After finishing the first phase, the collected data was processed and the SMED method was applied. A task team composed of a civil engineer, a foreman, a warehouseman, a maintenance chief, an undergraduate trainee and two team leaders analyzed the information. The observation sheets and performance measures showed that productive activities presented a good standardization. There was a clear definition of responsibilities and a constant distribution on the number of workers in productive activities when the piles were constructed. However, the lack of standardization when performing contributive activities was also evident and resulted in the occurrence of waste. The analysis indicated an overestimated total number of workers and a lack of coordination and integration between both teams as the main causes.

All contributive activities necessary for drilling and cement grouting setup were also listed with their labor utilization rates. Concluding that some activities could be executed while the hydraulic drill is running, the task team classified them as external activities. A careful and individual analysis of each activity provided improvement opportunities. These were registered in an Action Plan elaborated to serve as a guide for implementing improvements (see Table 1).

Table 1: Example of an Action Plan for some improvement opportunities

Activity	What	Where	Why	When	Who	How
Preparing grout	Use a sieve machine	Concrete mixer	Reduce non-value adding activity	August	Maintenance Chief	Build and test the equipment
Transporting grout	Use a grout pump	Concrete mixer	Reduce transporta-tion waste	August	Warehouse-man	Purchase the equipment
Positioning the casing’s screw-jack	Transfer to external activity	Hydraulic drill rig	Reduce changeover time	September	Civil Enginner	Test and establish routines

This was followed by meetings, training sessions and field tests with the workers to gradually illustrate the importance and advantages of applying improvements to the process. As mentioned by Coffey (2000), workers must recognize benefits for themselves in order to contribute with ideas and compromise with changes. For example, the higher productivity rates obtained by adopting simple solutions like the grout pump and the sieve machine diminished the concern that eliminating workers would be harmful to process efficiency.

This concept was very important when both teams were united and the total number of workers was reduced to seven men with the objective of improving coordination and process output quality. Originally the two teams worked separately receiving different financial incentives, but the “new” multi-skilled team with seven workers became fully responsible and received the same financial incentive for each constructed pile.

After implementing the changes and training the workers involved, Work Sampling was once again used during the foundation service’s second phase. The objective was to verify through performance measures the impact of improvement actions in the process. This gave the opportunity of comparing performance measures obtained in different periods but under the same environmental conditions and technical specifications.

Results

Comparison of the cycle time to construct the piles in both phases showed an increase of 20% in productivity with the improvements. Even with the casual occurrence of problems due to machinery breakdown and drilling difficulties caused by significant features of the geologic environment, there was an average cycle time reduction of 15 minutes (see Table 2). The saved time allowed more piles to be constructed. During the first phase, around 10 piles were executed each day. Eight were fully constructed and two had their boreholes made. In the second phase, the daily production was raised to an average of 12 piles per day, ten fully constructed and two with just the boreholes. These results can be better understood by analyzing the other performance measures.

After intervening in the process, the workers' utilization rates demonstrated a considerable reduction in the time spent on non-contributive activities, which was almost completely transferred to performing contributive activities (see Table 3). On the other hand, the percentage of labor time consumed by productive activities remained practically unaltered because they already presented a good level of organization and standardization.

Table 2: Cycle times before and after process improvement

Cycle Time	1° Phase	2° Phase	Reduced by
Minimum	80 min	70 min	10 min
Maximum	140 min	120 min	20 min
Medium	110 min	95 min	15 min

The percentage of time spent preparing grout dropped from 16.9% to 7.4% when the work method was improved and the sieve machine was used during the service's second phase. The same happened to transporting grout to boreholes after the grout pump was adopted. Labor time consumed in this activity fell from 6.5% to 1.5%. Still, practice has shown that benefits from using the grout pump are greater and easier to notice in large sites, generally those other than a single building at a fixed location.

Table 3: Work rates before and after process improvement

Activities	1° Phase	2° Phase
Productive	17%	14%
Contributive	71%	84%
Non-contributive	12%	2%

The formation of one team favored the workers' cooperation through the entire process. For example, the workers' utilization rate connecting or disconnecting casings rose from 4.6% to 11.3%. In the old method, only one worker regularly executed this activity while in the new method it became the responsibility of two workers. The percentage of time installing or removing casings also presented an increase, going from 12.3% to 21.7%. The number of workers involved in this activity changed from three to four men. The higher collaboration between workers made the team faster in accomplishing contributive activities. This allowed the construction of more piles, which was reflected by the utilization rates' increase.

The combination of actions to improve teamwork, analyze changeovers and automate activities permitted to transfer some contributive activities from internal to external. It made possible to perform activities such as cleaning casings, transporting the casing's screw-jack and operating pumps and motors while the hydraulic drill is working. The total percentage of labor time consumed by these activities increased from 16.2% to

26.5%. The developed work method conceived on the principle of concurrency contributed to reduce changeover time and to better stabilize workflow.

The progress in stabilizing workflow was demonstrated by calculating waste costs. For example, waiting time waste caused by waiting for equipments, construction materials and workspace originally consumed 2.4% of labor costs and decreased to near 0% after improving the process. Drilling delays caused by the lack of temporary drill casings was also a common situation. It happened because all temporary drill casings were occupied inside boreholes. Such problems were reduced with the resulting higher process-focused control, synchronization of activities and interaction between workers and equipments.

Finally, the firm's flexibility was also increased. The principle of flexibility can be defined as the production system's capacity to meet the market's variable and diverse needs without significant alterations in the amount and variety of available production resources and processes. Thus, three new teams of seven workers were formed to use the firm's track mounted hydraulic drill rigs. Each team eliminated two workers providing a total number of six workers available for other jobs. These six workers were divided in two teams equipped and assigned to perform rotary drilling, percussion drilling and tiebacks in other construction projects.

CONCLUSION

This paper has presented a case study in a sector of the construction industry that is rarely studied by lean practitioners. Based on the belief that production theories are the primary drivers of better performance, this paper shows the initial results of an ongoing effort to implement lean production principles in foundation engineering. A correct understanding of the principles and a good knowledge of geotechnical engineering processes and peculiarities made possible to implement improvement opportunities that resulted in higher productivity rates. The results help to improve the validity of lean ideas and to further develop work methods based on them.

Acknowledging that variability in foundation engineering processes can be partially credited to the difficulty of working with non-homogeneous sub soils, this study has demonstrated that it is also caused by lack of standardization, efficiency and organization when performing contributive activities. Instead of only investing in new equipments and machines to improve conversion activities, foundation engineering firms should also balance such investments with flow improvements. The results have confirmed that a good starting point is the reduction of setup time for construction, since the cycle time is relatively short.

Although some of the applied solutions have already been done before for other construction processes and sub contractors, they are well aligned with lean principles and represent the firm's initial attempts for pile construction improvement. More recently, an on-the-job-training program has begun aiming to develop multifunctional skills among all field workers. One of its features is the temporary exchange of workers between parties.

Furthermore, the case study proved the Work Sampling procedure's success in supporting the SMED method. It provided performance measures and identified interdependencies between activities. However, its main weakness lies in the fact that it doesn't detail the activities in a fine level as much as filming the whole operation would. This is probably due to the fact that it is more suitable for larger cycle times.

So the required information was obtained after performing a large number of instantaneous observations and after an extensive analysis of the observation sheets.

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REFERENCES

Ballard, G and Howell, G (1997) Implementing lean construction: stabilizing work flow. In: Alarcón, L (Ed.). Lean Construction. Rotterdam: Balkema.

Coffey, M (2000) Developing and maintaining employee commitment and involvement in lean construction. In: Tommelein, I D and Ballard, G (Eds.), Proceedings of the 8th annual conference of the International Group for Lean Construction, 17-19 July 2000, University of Sussex. IGLC.

Costa, D B and Formoso, C T (2003) Guidelines for conception, implementation and use of performance measurement systems in construction companies. In: Formoso, C T and Martinez, J C (Eds.), Proceedings of the 11th annual conference of the International Group for Lean Construction, 22-24 July 2003, Virginia Tech. IGLC, 567 - 579.

Das, B M (1984) Principles of foundation engineering. Monterey: Books⁄Cole Engineering Division.

Harmon, R L (1993) Reinventado a fábrica II: conceitos modernos de produtividade na prática. Rio de Janeiro: Ed. Campus.

Harris, F and McCaffer, R (1989) Modern construction management. 3ed. BSP Professional Books.

Howell, G A and Ballard, G (1997) Lean production theory: moving beyond ´can-do`. In: Alarcón, L. (Ed.). Lean Construction. Rotterdam: Balkema.

Howell, G A (1999) What is lean construction. In: Tommelein, I D and Ballard, G (Eds.), Proceedings of the 7th annual conference of the International Group for Lean Construction, 26-28 July 1999, University of California. IGLC, 1-10

Hunt, R E (1983) Geotechnical engineering investigation manual. New York: McGraw-Hill.

Kamara, J M (2003) Enablers for concurrent engineering in construction. In: Formoso, C T and Martinez, J C (Eds.), Proceedings of the 11th annual conference of the International Group for Lean Construction, 22-24 July 2003, Virginia Tech. IGLC.

Kestle, L and London, K (2002) Towards the development of a conceptual design management model for remote sites. In: Formoso, C T and Ballard, G (Eds.), Proceedings of the 10th annual conference of the International Group for Lean Construction, 6-8 August 2002, Federal University of Rio Grande do Sul. IGLC.

Koskela, L (1992) Application of the new production philosophy to construction. Technical Report, 72, CIFE, Stanford Univ., CA, September, 75 pp.

Koskela, L (2000) An exploration towards a production theory and its application to construction. VTT Publications 408, Espoo, Finland, VTT.

Lantelme, E and Formoso, C T (2000) Improving performance through measurement: the application of lean production and organizational learning principles. In: Tommelein, I D and Ballard, G (Eds.), Proceedings of the 8th annual conference of the International Group for Lean Construction, 17-19 July 2000, University of Sussex. IGLC.

Miranda Filho, A N and Menezes, E A (2002) Development of an operational parameter measuring system. In: Formoso, C T and Ballard, G (Eds.), Proceedings of the 10th annual conference of the International Group for Lean Construction, 6-8 August 2002, Federal University of Rio Grande do Sul. IGLC.

Rohr, S S and Corrêa, H L (1998) Time-based competitiveness in Brazil: whys and hows. International Journal of Operations and Production Management. 18 (3), 233-245.

Shimizu, J Y and Cardoso, F F (2002) Subcontracting and cooperation network in building construction: a literature review. In: Formoso, C T and Ballard, G (Eds.), Proceedings of the 10th annual conference of the International Group for Lean Construction, 6-8 August 2002, Federal University of Rio Grande do Sul. IGLC.

Shingo, S (2000) Sistema de troca rápida de ferramenta: uma revolução nos sistemas produtivos. Porto Alegre: Bookman.

Sink, S and Tuttle, T (1993) Planejamento e medição para performance. (Planning and measurement in your organization of the future). Rio de Janeiro: Qualitymark.

Stalk, JR G (1988) Time: the next source of competitive advantage. Harvard Business Review, July-August.