Lean thinking to provide smart infrastructure

Alessandro Da Giau (dagiau@gest.unipd.it)[1]
Laura Macchion[1]
Andrea Furlan[3]
Andrea Vinelli[1]
Ennio Cascetta[2]
1. Department of Management & Engineering, University of Padua, Stradella San Nicola, 3 – 36100 Vicenza, Italy
2. Department of Transportation Engineering, University of Napoli Federico II, Via Claudio, 21 – 80125 Napoli, Italy
3. Department of Economics & Management, University of Padua, Via Ugo Bassi, 1 – 35131 Padua, Italy

Abstract

Shortage of economic resources requests to review the way in which infrastructures are designed and realized. This empirical research explores applicability of the lean thinking's principles within civil engineering. Results suggest that lean principles and techniques are suitable and lead to eliminate waste to realize cheaper infrastructures of higher quality.

Keywords: Lean infrastructure, Lean Design.

Introduction

The topic of "infrastructure development" has long been the center of political debate on the economic recovery in different countries (Cascetta *et al.* 2012, Zhang and Chen 2012). In fact, appropriate provision of infrastructure is a basic condition for fostering the development of a country making its territory attractive for settlement of new enterprises. The World Bank has published results concerning an analysis that have confirmed the existence of a positive correlation between the availability of infrastructures in a country and its relative economical performance (Estache and Fay 2007). However, there are often difficulties in carrying out the planned works quickly and within the estimated budget costs. Moreover, the projects could have characteristics that do not reflect the full needs of the whole community, fomenting dissatisfaction and opposition in public opinion that could slow or stop the project. If, on top of that, we add that some countries suffer a low ability to finance investment and some others are now investing less due to some financial turmoil, it is quite clear that the way in which infrastructures' projects are designed and implemented needs a radical change. This shortage of economic resources should suggest to review all processes that are necessary to set up an infrastructure in order to point out which wastes usually occur and which of them, if removed, could bring to a cost reduction (planning, designing, building, maintenance and eventually disposal's costs). If the expenses are under a better control, then governments could have more

money to spend in new facilities and this leads to an economic recovery.

In order to achieve these goals we studied if lean management, a scientific approach towards the gradual elimination of *muda* (i.e. activities without added value for the customer), could be applied to provide valuable facilities, such as roads and railways, characterized by lower costs and higher quality. Literature on lean management has usually focused on manufacturing, neglecting how lean techniques and principles can be applied to services (Womack and Jones 1996, Furlan *et al.* 2012). Recent studies highlighted the need to deepen the understanding of the wastes' nature in relation to services, especially those services characterized by high knowledge content (Staats and Upton 2011). Following this line of research, we aim at identifying wastes and tracing their root causes in the context of public construction engineering (i.e. designing of infrastructures with public utility). In fact, by an analysis in the literature we surprisingly discovered that in the construction industry, the overall application of lean thinking seems to be rather incomplete (Alarcón 1997, Walter and Johansen 2007). Reasons for this slow diffusion of lean thinking in construction depend at first on the greater focus of works about lean management in the manufacturing environment and moreover on the lack of international competition in the construction sector. In fact, companies operating in this environment deal with a restricted number of competitors, which usually are geographically near. This lack of wide competition and a general lack of time to invest in improvements, prevents companies to explore new ways to reduce costs (Alarcón 1997). Since the principles of lean thinking were born in high-volume manufacturing industry the extension to other contexts needs some adaptation. Specifically, construction engineering is a "design-to-order" context that realize services tailored on customer needs. The application of lean principles to the construction sector requires a careful adaptation to realize efficiency and cost improvements. Therefore, lean concepts and tools should be deeply investigated with the effort of discovering new ways to designing and realizing valuable linear infrastructures. Highlighting this gaps, we started an action research study to understand main wastes occurring in construction engineering field. Applying the second lean thinking principle (i.e. the identification of the value stream), the research identifies different clusters of wastes and their main causes, typically occurring in designing and realizing a linear infrastructure (i.e. bridges, roads and railways).

The paper is organized as follows. The next sections present the literature review and the research aim on the basis of the existing literature. Then details on method are illustrated. Finally findings, managerial implications and outline avenues for future research are presented.

Literature review

Lean thinking is rooted in the Toyota Production System (Ohno 1998), whose first description appeared in the early 1990s under the name "Lean Production" (Womack *et al.* 1990). At the origin of this theory five principles were formulated (Womack and Jones 1996): 1) defining value of product/service by the end-user's point of view; 2) identifying value stream that brings to the final product/service provided; 3) letting the value flow without any interruption; 4) implementing pull systems; 5) pursuing perfection. As identified by Womack and Jones (1996), the application of lean thinking consists in identifying and then eliminating muda (i.e. waste), with the scope of gaining a process that can bring more value to customers while consuming less resources. Taiichi Ohno has identified seven causes of muda for the manufacturing environment that are overproduction, waiting, transportation, motion, inventory, over-processing and defects (Womack and Jones 2003). These causes have been later redefined to be tailored even in other contexts such as service and new product development (Bicheno and Holweg 2009, Millard 2001). The need of this redefinition is imposed by the difference between the manufacturing and

service environment. In the service context, in fact, it is not possible to storage inventories to cope with different market demand (we cannot store a not booked hotel room) and moreover the concept of "defect" is difficult to be applied, but rather occur "mistakes" or "errors". So, waste categories in service are different from the manufacturing ones and this is the reason why they have been renamed as follows: delays, mistakes, reviews, movements, duplication, processing inefficiencies, resource inefficiencies (Maleyeff 2006).

Resource consumption is justified only if it is necessary in order to create value for customers; otherwise it is a muda that should be eliminated. Therefore, lean thinking is "lean" because it leads to a production that is able to produce consuming always less resources, machineries, time, space, costs (Womack and Jones 1996). Although, at the beginning, lean concepts were developed to improve automotive industry (Holweg 2006), following studies showed that lean principles could be applied to any manufacturing system or any service (Womack and Jones 2005). Indeed, lean thinking hinge upon a performance improvement approach that in principle can be applied to many operative contexts: for example, literature and practice recognized that lean management and its principles could be extended to service operations that create value for customers through some activities like financial services, insurance, banking and healthcare (Staats and Upton 2011) and even off-the-plant floor (Keyte and Locher 2004, Tapping 2005, Thompson 1997). What arise it is an incredible adaptability of lean thinking in different contexts. Literature recognizes therefore the application of "lean thinking" in several areas but what is still missing is an important contextualization of this "lean way" in the construction field. As a matter of fact, recently, more attention has been paid on how these principles and tools could be used within design and construction activities (Alarcón 1997, Howell and Ballard 1998, Koskela 1992, Serpell *et al.* 1995). Lean Construction is the transfer and adaptation of lean thinking's principles in construction field (Howell 1999) and aims to influence, starting from the very early stages of designing, construction processes to better manage and improve them and so maximizing value while minimizing costs, through the reduction of wastes and focusing on essential needs of stakeholders involved (Koskela 2002). Deepening our knowledge on this field, we observed that only few studies have tried to map wastes usually occurring in the realization of an infrastructure. Thus, this field of research could represent a possibility to provide lean and smart infrastructures: in fact, such as in manufacturing sector, the realization of an infrastructure consists through activities that really add value and activities that do not. A reduction in the consumption of resources in terms of time and costs is therefore desirable and achievable by eliminating or reducing the impact of muda.

Research aim and methodology
According to the literature review, the aim of this paper is to identify different clusters of waste and their main causes typically occurring in designing and realizing a linear infrastructure.

Being the purpose of the research exploratory, the methodology used in this paper is an action-research approach (Westbrook, 1993). The project is an innovative research program developed by researchers of the Department of Management & Engineering and the Department of Economics & Management of the University of Padua (Italy) in collaboration with NET Engineering International. NET Engineering International is a worldwide civil engineering company operating in the design, estimation, management, service, control and testing of public and private infrastructures. In 2010 the society reached the 123rd rank in "Top International Design Firms". Its operation area ranges through Italy, Germany, Argentine, Brazil, Bulgaria and Hungary, with an income of nearly 45 million dollars (2011) and a 450 employees staff.

Collaboration with NET Engineering started in February 2012 thanks to the willingness of the company to analyze sources of wastes in designing and building infrastructures, in order to reorganize their own processes and gain more market share by reducing their costs. During this period, researchers have been studying infrastructures' contexts and peculiarities by analyzing technical reports and interviewing key informants and experts, in particular designers and managers of NET Engineering. The deeply involvement of NET Engineering's managers helped the researchers to delve into the underpinning workings and micro-level organizational mechanisms of the infrastructure sector. Analysis was focused on activities that are necessary in order to obtain an infrastructure and on the identification of processes' wastes. To map muda a three steps method was implemented: at first we analyzed technical reports (studies, screenings, analysis and documents realized by committees, associations and experts in linear infrastructures) in order to highlight main wastes of the sector; then, through the use of some focus groups with NET Engineering experts, we drafted a list with main wastes that occur in works; finally we compared these two lists to verify their completeness. Through these steps we were able to understand the basic background that generally supports plan, design and construction phases necessary to obtain an infrastructure. Moreover, we realized two instant surveys. The first one pursued the scope to identify the importance and frequency for each mapped muda in order to quantify its related global impact. To obtain this valuation we asked to the seven interviewed managers of Net Engineering to express their opinion on a Likert scale from one to nine (1=low; 9=high) to characterize the importance and the frequency for every muda. Then, once we calculate the average frequency and importance for every muda, we used the product of these two values to quantify the global impact for every waste. The second instant survey followed a brainstorming session in which we discussed with managers about main root causes of mapped wastes. We obtained a list of six macro-causes and then we asked through the instant survey to specify, for each of the seventeen muda, up to two main causes that they considered as main source of that waste. On the survey form, we left an empty space to give the chance, for the respondents, to point out other causes. To quantify the data collected, for every root cause we counted the number of occurrences of wastes that managers have related to it. Then, after having gathered the number of instances for every source of waste, we calculate its percentage on the total number of occurrences. Managers, working closely with the research team, actively contributed to data gathering, feedback, analysis, action planning, implementation and evaluation of all phases of the project research. The research team organized periodical meetings to examine the collected data and to share possible actions. By adopting several points of view we curb the main methodological weaknesses that typically flaws the action research method (Westbrook, 1995).

The complexity of the research subject makes it difficult to achieve a quantitative assessment of the muda (Rounce 1998). This is not just related to the expenditure in time and resources that should be consumed, but also to that the value stream related to the development of a linear infrastructure requires a long period of time to be completed. To overcome these difficulties we preferred to adopt the perspective of qualitative research.

Findings
Our main finding deals with the identification of the main wastes in the field of civil engineering, in particular in linear infrastructures. We started from the literature review, analyzing the well known seven causes of wastes (Shingo 1981). Then we restricted the analysis only to five causes, pointed by technical reports and different document about civil engineering as the most

important categories of wastes in the field of linear infrastructures. Categories not considered were "transportation" (i.e. transportation of material with no scope) and "motion" (i.e. motion of employees with no purpose) because of their low impact on global performance on infrastructures. Moreover, we redefined the meanings of the five causes considered: in fact these kind of wastes have been defined by Shingo (1981) for a manufacturing context, that is different from the civil engineering one. The description of the adapted meaning for the five causes of wastes follows:

- Overproduction: products' features, functionality or performance that exceed the needs of project stakeholders or their requests;
- Waiting: delays caused by waits for testing, funding, approvals, decisions or anything that do not produce increases in value for project stakeholders;
- Over-processing: activities or ineffective processes that do not add value to the infrastructure by the end-view of project stakeholders;
- Inventory: inability to meet what is necessary (i.e.: real demand for mobility), resulting in a reduction of the perceived quality;
- Defects: changes made when projects are already approved; errors in evaluation or in design that lead to a rework; sub-optimal solutions or potential damage in service.

With some focus group, developed with the collaboration of experts from NET Engineering, we discussed these main wastes that usually face in linear infrastructures' projects. Combining the identified muda from technical reports and those presented by key experts interviewed, we developed a list of seventeen muda, which do not have any claim to be exhaustive: we do not exclude the possibility to find out other kind of wastes by enhancing the detail level. Table 1 sums up the outcomes from our analysis.

Table 1 - Muda of linear infrastructure

TYPE OF WASTE	DESCRIPTION
Not necessary work	Design or build a work that is not necessary because it does not answer to a real need
Excessive functions	Design or build a work that presents oversized performance if compared with real demand for mobility. Work in this case could be useful.
No timetable programming	Work is built immediately with dimensions that fit peak demand expected for the future. In this case it would have been better to adapt dimensions of the work according with the growth of the demand
Insufficient functions	Design and build a work that presents undersized performance if compared with real demand for mobility
Compensation measures	Excessive use of compensations in order to obtain consensus to realize the work

Overdesign	Technical regulations that lead to a higher increase of costs and delivery-time of the work and that do not bring to an enhancement in value perceived by customers
Lack of project management	Governments do not efficiently manage activities that lead towards the design and realization of a work
Opposition	Delays due to a lack in approvals for the work
Poor planning	Lack of adequate financial resources to realize efficiently the planning and designing phases
Inefficient allocation of resources during construction	Lack of adequate financial resources to build the planned work
Litigation in the tender process for engineering services	Administrative appeals by subjects who are not successful bidders of engineering services
Litigation in the tender process for the provision of job	Administrative appeals by subjects who are not successful bidders of work performance
Litigation during execution of the engineering companies	Reserves by designer during the execution of the project
Litigation during execution of the construction companies	Reserves by successful bidder company during the execution of works
Technical variations	Variations on the already approved project requested by contracting authority in order to face new needs of project stakeholders
Design errors	Errors during design phases which affect quality of the work
Changes required by validation activities	Excessive claims by validation activities which lead to an enhancement in costs and times but no in added value

The definition of these muda has been followed by their allocation into the five causes that we formerly defined, as presented in Table 2.

Table 2 – Main causes of muda

OVERPRODUCTION	Not necessary work Excessive functions No timetable programming Compensation measures Overdesign
WAITING	Lack of project management Inefficient allocation of resources during construction Litigation in the tender process for engineering services Litigation in the tender process for the provision of job Litigation during execution of the engineering companies Litigation during execution of the construction companies
OVERPROCESSING	Changes required by validations Opposition
INVENTORY	Insufficient functions
DEFECTS	Poor planning Technical variations Design errors

Once we obtained a complete list including muda in infrastructures, through an instant survey which involved seven key experts by NET Engineering we gathered their single opinion about frequency and importance for every muda mapped. Experts assigned, on their experience, for every waste a value to represent its frequency and its importance. In Figure 1 is presented the global impact of muda.
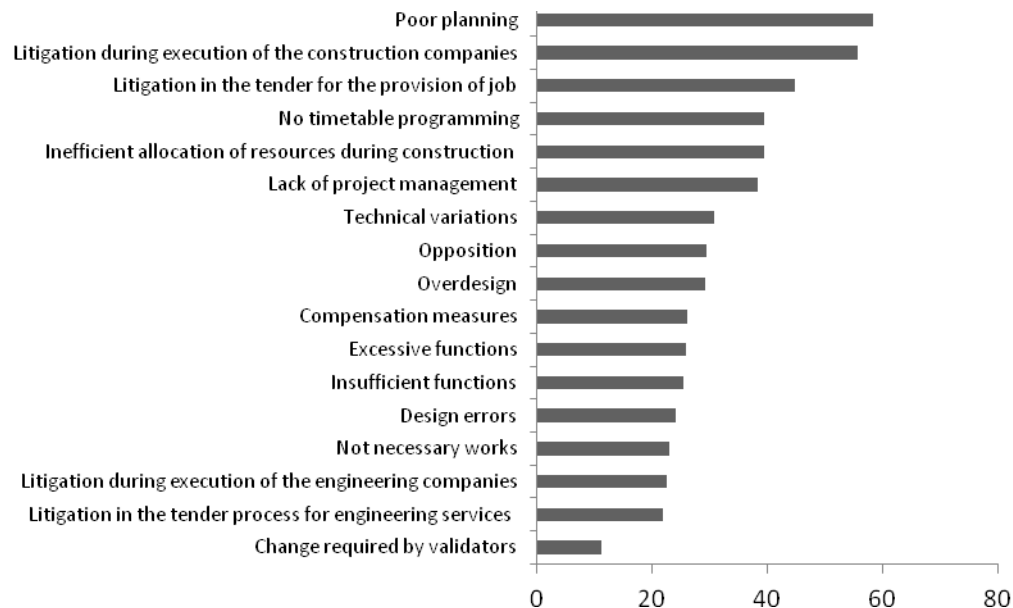

Figure 1 - Impact of muda

As presented in the figure above, we can identify "poor planning" as the principal muda that afflicts an infrastructure. This demonstrate that an incorrect valuation, during early stages, of right financial resources to allocate, brings to a degradation in the quality of the work realized. "Litigation during execution of the construction companies" and "litigation in the tender for the provision of job" are administrative claims that do not really afflict the quality of the works, but lead to a delay and to higher costs in the realization process. Other main wastes such as the "lack of a timetable programming", the "inefficient allocation of resources during construction" and the "lack of project management" demonstrate that managers and professionals in the field should really invest more resources during the planning stages to better anticipate every complication that could emerge during the later phases.

Once data was collected, we set a brainstorming session in which the interviewed experts were asked to discuss about root causes of the mapped wastes. A list of six macro-causes, to whom they are assignable, was then prepared. Thus, with another instant survey, we request the key experts to specify, for each of the seventeen muda, up to two main causes that they considered as primary source of that waste. Main root causes are shown in Figure 2.
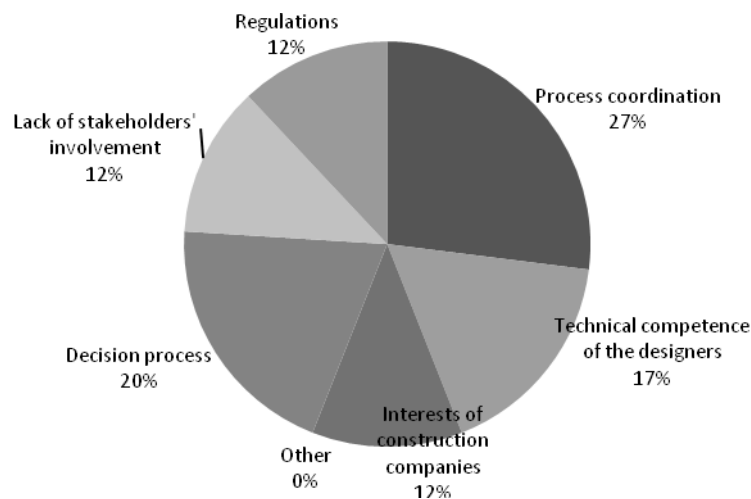

Figure 2 - Main sources of wastes

Results in figure 2 highlights that only few causes involves the major number of wastes in planning, designing and realizing an infrastructure. "Process coordination" rises as the most important root cause. In this case, the problem is due to a lack of an actor able to coordinate all processes necessary from the planning to the realization of a work. "Decision process", instead, is the second important source of waste. In fact, key experts from NET Engineering deem that actors who are responsible to take decisions about the infrastructure usually do not pay much attention to early moments. Initial phases imply decisions that will affect the final cost of the infrastructure. So, it is critical to plan as well as much possible initial decisions. These mapped sources of waste are seen as the main root causes for the growth of costs in infrastructures and should be faced by managers in the field.

The action research project presented in this paper has led us to identify the main classification of muda that characterize the processes of planning, designing and building of linear infrastructures. Key experts interviewed have observed *poor planning* as the most important waste, followed by *litigations during building activities*: the former is responsible for

the construction of facilities that are sub-optimal. As a matter of fact, if more financial resources had been invested during first designing stages, it would have been possible to realize a cheaper and more effective alternative project. "*Litigations during building activities*" causes extensions of costs and time expenditure during construction activities. Then, interviewed engineers have shown other important muda such as *litigation in the tender for the provision of job* (construction companies can have great impact on global performance of the final work), *inefficient allocation of resources during construction* (it could bring to a delay in the realization of an infrastructure), *lack of program timetable* and *lack of project management* by authorities. Other wastes mapped result to gain lower importance, but are still to be considered if we want to achieve the goal of "zero–waste". This list allowed us to understand how important is to spend the right time and proper financial resources during the very early stages, in a way that can reduce the impact of wastes due to a hasty planning of works to undertake.

Conclusion
The main purpose is to achieve the concept of lean infrastructure. Through this work we studied therefore the possible application of lean thinking in design and construction industry by focusing on linear infrastructures. The construction industry is extremely characterized by high variability in the customers' requests and in the type of works: even two quite similar infrastructures could request really different costs, developing-times and efforts, depending on the morphology of lands selected, competences of designers, etc. Differently from manufacturing sector, here there are no machineries that can repeat always the same set of activities with pre-defined times; every project in the field of infrastructure is carried out by many different players that work together towards a progressive definition of an idea which meets legal, safety, aesthetic, strength constraints. Therefore, variability that can occur within activities and processes is due to the fact that transformed resources are information, concepts and ideas, while transforming resources are not machineries with a definitive cycle time, but human resources, which employ different time in developing activities of their competence. We narrowed this research only to linear transportation infrastructure in order to limit variability inside activities and processes. Using data collected by this action research project, this paper provides an analysis of waste that could occur during planning, design and building activities in an linear infrastructure project, splitting them up into their main causes. Results highlights how only few causes are responsible for the most of the waste in a typical infrastructure. Managers should first face these causes in order to reduce the obstacles that prevent the value from flowing correctly.

Results are both theoretical and practical. This is a theoretical contribution since existing literature about waste in construction is not so detailed referring to linear infrastructures. Secondly, it is a practical contribution because by knowing which are these wastes, firms operating in construction engineering industry could be able to eliminate or reduce them: in fact, it is not possible to achieve the "lean way" if firstly we do not map muda in the process.

To make our approach applicable to other kinds of works (such as buildings, for example), we suggest to follow these three steps: 1) identify main type of wastes; 2) measure the weight for each type of waste; 3) analyze root cause for every waste.

Principles and tools of this theory should be deeply investigated with the effort to discover new ways to develop linear transportation infrastructures.

References

Alarcón, L. 1997. *Lean Construction*. Taylor & Francis, New York.

Alarcón, L. 1993. Modeling waste and performance in construction. Alarcón, L, ed(s). *Lean Construction*. Taylor & Francis, New York, 51-66.

Bicheno, J., M. Holweg. 2009. *The Lean Toolbox: The essential guide to lean transformation*. PICSIE Books, Buckingham, United Kingdom.

Cascetta, E. 2012. A new look at planning and designing transportation system: markets, decision making models and the role of quantitative methods. *Proceedings of the LATSIS – Symposium Quantitative methods in Transportation Systems*, Lausanne, Switzerland.

Estache, A., M. Fay. 2007. Current Debates on Infrastructure Policy. Policy Research Working Paper n. 4410, The World Bank.

Furlan, A., A. Vinelli, G. Dal Pont. 2011. Complementarity and lean manufacturing bundles: an empirical analysis. *International Journal of Operations and Production Management* **31**(8): 835–850.

Holweg, M. 2006. The genealogy of lean production. *Journal of Operations Management* **25**(2): 420-437.

Howell, G. 1999. What is lean construction. *Proceedings of IGLC – 7*. Berkeley, California, USA.

Howell, G., G. Ballard. 1998. Implementing lean construction: understanding and action. *Proceedings 6th Annual Conference International Group Lean Construction*. Guarujà, São Paolo, Brazil.

Keyte, B., D. Locher. 2004. *The Complete Lean Enterprise: Value Stream Mapping for Administrative and Office Processes*. Productivity Press, New York.

Koskela, L. 2002. The Theory of Project Management: Explanation to Novel Methods. *Proceedings of the 10th Annual Conference of the International Group for Lean Construction*, Gramado, Brazil.

Koskela, L. 1992. Application of the New Production Philosophy to Construction. Technical Report No.72, Center for Integrated Facility Engineering, Stanford University, California, USA, 75 pp.

Maleyeff, J. 2006. Exploration of internal service system using lean principles. *Management Decision* **44**(5): 674-689.

Millard, R.L. 2001. Value stream analysis and mapping for product development. Master's thesis in Aeronautics and Astronautics, Massachusetts, Institute of Technology, Cambridge.

Ohno, T. 1988. *Toyota Production System: Beyond Large-Scale Production*. Productivity Press, Portland, OR.

Rounce, G. 1998. Quality, waste and cost considerations in architectural building design management. *International Journal of Project Management* **16**(2): pp.123-127.

Serpell, A., A. Venturi, J. Contreras. 1995. Characterization of waste in building construction projects. Alarcón, L, ed(s). *Lean Construction*. Taylor & Francis, New York, 67-77.

Shingo, S. 1981. *Study of Toyota Manufacturing System*. Productivity Press.

Staats, B.R., D.M. Upton. 2011. Lean Knowledge Work. *Harvard Business Review* **89**(10): 72-84.

Tapping, D. 2005. *The Lean Office Pocket Guide: Tools for Elimination of Waste in Administrative Areas*. MCS Media, Chelsea, MI.

Thompson, J. 1997. *The Lean Office*. Productive Publications, Toronto, Canada.

Walter, L., E. Johansen. 2007. Lean Construction Prospects for the German Construction Industry. *Lean Construction Journal 3(1): 19-32*.

Westbrook, R. 1995. Action research: a new paradigm for research in production and operations management. *International Journal of Operations & Production Management* **15**(12): 6-20.

Westbrook, R. 1993. Oderbook models for priority management: A taxonomy of data structures. *Journal of operations Management* **11**(2): 123-142.

Womack, J.P., D.T. Jones. 2005. *Lean Solutions: How Companies and Customers Can Create Value and Wealth Together*. The Free Press, New York.

Womack, J.P., D.T. Jones. 1996. *Lean Thinking. Banish waste and create wealth in your corporation*. The Free Press, New York.

Womack, J.P., D.T. Jones, D. Roos. 1990. *The Machine that Changed the World: the Story of Lean Production*. Rawson Associates, New York.

Zhang, X., S. Chen. 2012. A systematic framework for infrastructure development through public private partnership. IATSS Research.