

STATE-OF-THE-ART SHIPBUILDING: TOWARDS UNIQUE AND INTEGRATED LEAN PRODUCTION SYSTEMS

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ABSTRACT

The background for this paper is the Lean Shipbuilding R&D program, hosted by the Norwegian Research Council. The following shipyards participate in this program: Aker Yards, Kleven Verft and Ulstein Verft. Together they constitute a significant part (app. 75%) of the total Norwegian shipbuilding capacity.

The paper is intended to give readers an essential theoretical support towards a better shipbuilding process.

Together with the Lean theory review, current activities and plans for implementation of Lean principles at the participating shipyards are outlined and discussed as well.

The paper concludes with a series of recommendations regarding both, theoretical and practical issues leading to further development of the Lean Shipbuilding concept and its application to different shipyards in the Norwegian context.

KEY WORDS

lean shipbuilding, lean construction, project management, production system design, theory dissemination

INTRODUCTION

Currently, Norwegian shipbuilding industry has its strength in quality, delivery precision, and the ability to build technically advanced, highly complex, and customized OSVs (*offshore service vessels*). Moreover, the industry is consolidated into the Norwegian Maritime Cluster which consists of the following key-actors: equipment suppliers, shipyards, ship consultants and ship owners. Close proximity, relationships, common

traditions, knowledge transfer and the power of innovation are certainly facilitating Norway's competitiveness in the worldwide market (Dugnas and Uthaug, 2007).

However, "all time high" OSV ordering rates and the capacity shortage (both, in terms of labour and supply) is directly affecting industry's order winning advantages: The actual challenge for Norway is its ability to sustain and strengthen its competitive advantage in a worldwide market, where competition from low cost

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countries is continuously increasing. Hence, adaptation of Lean principles might be proposed as one of the alternatives for shipbuilders in order to address this challenge (Dugnas and Uthaug, 2007).

The paper focuses on Lean theory and its dissemination from mass to one-of-a-kind project-oriented production. It is also important to discuss the adaptation of Lean principles *within* one-of-a-kind industries, such as shipbuilding and construction. The effort is made in order to establish a theoretical background that could benefit to further development of the Lean Shipbuilding concept and support shipyards on their way towards own Lean production systems.

The authors outline key-Lean principles that originate from the mass automotive industry in Japan. Thereafter, it is shown that these principles, with a certain degree of their modification, are adapted to project-oriented industries as well. Furthermore, differences between construction and shipbuilding are presented, followed by the ideal Lean Shipbuilding framework. The latter is proposed as an idealistic guide for shipyards pursuing Lean perfection.

Following the Lean theory review, current activities and plans for implementation of Lean principles at the participating shipyards are outlined and discussed as well.

In the following chapter the authors present a brief description of the Toyota Production System (TPS), and its application to other industries far from the original automotive mass production. In this particular case, emphasis is given on construction and shipbuilding. Furthermore, in Norwegian perspective, shipbuilding is

one-of-a-kind, project based industry under time, price and capacity constraints.

THEORY REVIEW: FROM THE TOYOTA PRODUCTION SYSTEM TO LEAN SHIPBUILDING

THE TOYOTA PRODUCTION SYSTEM

The Toyota Production System, was devised by Eiji Toyoda and Taiichi Ohno for the Toyota Motor Company in 1977.

TPS is the next major evolution in efficient business processes after the mass production system invented by Henry Ford, and it has been documented, analyzed, and exported to companies across diverse industries throughout the world. Outside of Toyota, TPS is often known as "Lean" or "Lean Production" (Liker, 2004).

So how do we explain what Lean Production is about?

The cornerstones of the TPS (Lean Production) are the *pull system* and *built-in quality*; their sustainability is ensured by *kaizen* activities on a daily basis. Meeting and exceeding the *customers' requirements* is the task of everyone within the organization. The heart of the TPS is *delivering value by eliminating waste and ensuring undisturbed workflow* (Liker, 2004).

It is also necessary to emphasize that Lean is about developing and customizing principles that are right to a specific organization (say, a shipyard) and diligently practicing them to achieve high performance that continues to add value to customers and society. This, of course, means being competitive and profitable (Liker, 2004).

LEAN CONSTRUCTION

However, whilst Lean Production was successful in the car manufacturing industry, many believed that it would not be applicable in the dynamic and complex world of construction. Manufacturers make parts that go into products. While the design and construction of unique and complex projects, in highly uncertain environments under great time and schedule pressure, is fundamentally different (Daeyoung, 2002; Dunlop and Smith, 2004).

Furthermore, construction is characterized by site production, a feature shared by only a few other industries.

In construction, the concept of site production refers actually to a bundle of features:

- A. Site as a resource: the site is a necessary input resource for production;
- B. Creating the production infrastructure: the production infrastructure (machines, manpower, etc.) has to be planned, procured and set up on site;
- C. Space needed by production (workstations move on the product): the spatial flow of workstations (teams) has to be coordinated (in contrast to a factory, where only material flow through workstations is planned).

It is evident that these characteristics make construction a one-of-a-kind manufacturing activity which requires a specific approach (Koskela, 2000). In this article authors discuss the Lean Thinking perspective. The definition and principles of Lean Construction are presented below.

Lean Construction is a translation and adaptation of Lean Manufacturing principles and practices to the end-to-end design and construction process. Lean Construction is concerned with the holistic pursuit of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, activation, maintenance, and recycling. This approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs (Koskela et al., 2002).

Moreover, Lean Construction has the following essential principles (Chitla, 2003; Koskela, 1992):

- A. Clear set of objectives to be established for the delivery process. Customer needs and requirements are well understood;
- B. A cross-functional team designs product and process concurrently, to give more value to the customer needs – this process of parallel design helps positive iteration within the process and negative iteration is reduced;
- C. Shifting design work along the supply chain to reduce the variation and match the work content;
- D. Reducing cycle times. The different ways to reduce cycle times include eliminating work-in-progress, reducing batch sizes, optimizing plant layout, reducing variability, changing activities from sequential order to parallel order, and isolating the main value-adding sequence from support work;
- E. Build continuous improvement into the process. The effort to build continuous improvement into the

construction process is to reduce waste and ensure continuous and sustainable workflow.

Additionally, Lean Construction emphasizes effectiveness measured by cycle-time, defection rate, and completion of planned work per week. The goal is to eliminate waste (non-value adding actions) by organizing interdependence, improving reliability, reducing uncertainty, and integrating production management.

Decentralization means providing project participants with information on the state of the production systems and empowering them to take action without orders from upper level management (Daeyoung, 2002).

Another important issue in Lean Construction is *planning*. Ballard (1994) states that one of the most effective things managers can do to improve construction productivity is to improve planning. Subsequently, a well-executed project mirrors its production planning. Good production planning comprises planning elements that can effectively be executed. It is worth adding the third aspect: being flexible and able to readapt your production plan taking into account eventual deviations observed during the daily sequence of jobsite operations is just as important as planning projects itself (Conte and Gransberg, 2001).

Higher level planning in the organization tends to focus on global objectives and constraints, governing the entire project (Master and Phase Schedules). In Lean Construction these objectives drive lower level planning processes (Lookahead Plan: typically 5-6 weeks) that specify means for achieving those ends. Ultimately, someone (individual or group) decides what physical, specific work will be

done the upcoming week (Weekly Work Plan). That type of plans has been called "assignments". They are unique in Lean Construction because they drive direct work rather than the production of other plans. The person or group that produces assignments is called the "*Last Planner*" (Ballard, 2000).

Ultimately, after having outlined the main Lean Construction features, principles and techniques, it is important to emphasize the following:

Implementing Lean Production does not require making construction manufacturing by standardizing products or using standard Lean tools explicitly. Implementing Lean means adopting a "project-as-production-system" approach to construction, defining the objective in customer terms, and decentralizing management to maximize throughput and reduce inventories (Ballard and Howell, 1998).

LEAN SHIPBUILDING

The worldwide research in this area is limited. Firstly, such limitation is due to the fact that Lean Shipbuilding is actually quite similar to Lean Construction. Secondly, the term itself has not yet become a concept with a solid theoretical base.

Both branches (construction and shipbuilding) are project-driven and deliver products which normally are one-of-a-kind. However, there are some characteristics that differentiate Norwegian shipbuilding from constructing buildings, roads, tunnels, etc. The explanation follows.

WHAT KIND OF PRODUCTION IS SHIPBUILDING?

The shipbuilding industry in Norway bases its production on different

phases due to the specific competition conditions. The key-trend now is to outsource the hull fabrication and primary outfitting to the low-cost countries. The remaining work is done at outfitting yards in Norway. Hence, there are usually four key-production phases:

- A. Hull fabrication;
- B. Primary outfitting;
- C. Final outfitting;
- D. Testing.

Such production set-up is believed to be one of the reasons why phase-based project management, supply chain management, project logistics and planning are the areas with the highest potential for improvement. While SCM and planning are widely known issues, the remaining two are relatively specific regarding shipbuilding in Norway. Hence, the authors find it appropriate to give brief descriptions of both, project logistics and phase-based project management – in the shipbuilding context.

Within the Lean Shipbuilding program the concept of project logistics is understood as the flow of parts and components *within* a shipyard facility. The focus is on optimization of internal logistics by analysing and modelling the following:

- A. transportation times and equipment;
- B. pre-fabrication and assembly times;
- C. facility layout;
- D. storage of parts and components.

Simplification, visualization, and information flow are the key-words here.

While project logistics is dealing with internal issues, phase-based project management has a wider scope

and mainly addresses project (construction) activities which are carried out in later project phases than initially planned. Having in mind the complexity of such one-of-a-kind projects which contain thousands of work packages, the lack of control of phases and their transition poses a significant threat: In Norwegian shipbuilding context it means a significant increase in project cost, disruption of workflow and planned work sequence, overburdening of workforce, and ultimately, can result in late delivery of the final product. Global supply chains make the situation even more complex. Hence, emphasis in phase-based project management is put on:

- A. identifying of project phases;
- B. identifying problems in different phases and tracking reasons for plan non-conformity at project level;
- C. identifying the scope of loss due to activity movement to later project phases – rises the motivation for countermeasures;
- D. preventing problems from re-occurrence in future projects by developing an improved planning system.

Such a system should take into consideration *all* the above mentioned issues and ensure that all of the activities are performed in their respective phase. All these elements fit to Lean Shipbuilding program framework quite well. Hence, Phase-based Project Management would hopefully become one of the specific Lean Shipbuilding methodologies.

The above mentioned production set-up and “focus areas” require a specific approach while attempting to

define the Lean Shipbuilding concept. The authors believe that further outlined characteristics of shipbuilding as an industry will be enhanced as worldwide research progresses.

So why cannot shipbuilding be treated exactly the same way as construction, when it comes to transfer and implementation of Lean principles? Let's have a look at the following characteristics:

- A. Design, Supply Chain Management and production activities are integrated and carried out simultaneously – it is rather a rule than exception;
- B. Production facilities are the same and their layout is usually optimal for different projects with similar logistics requirements;
- C. Significant prefabrication and pre-outfitting of units and modules off-site; d) Advantage of supply network within the Norwegian Maritime Cluster;
- D. Significant customization and innovation – also during the construction phase (change orders are common);

E. Capacity constrained industry (lack of workforce, critical lead times);

F. There is less randomness in shipbuilding projects' organisation if compared with construction;

G. Even if shipbuilding belongs to "one-of-a-kind" industries, there are some features similar with mass-production, e.g. production line for pipe fabrication

All the above issues make a background for analysis on researchers' way towards definition of the Lean Shipbuilding concept. However, as the concept is still under development, the following section is just an attempt to position Lean Shipbuilding next to Lean Construction – as it is today.

ADAPTATION OF LC PRINCIPLES: LEAN SHIPBUILDING IN NORWAY

Considering the principles for Lean Construction, the authors suggest that most of them would be applicable to Lean Shipbuilding. At the same time, some of the principles need to be adapted in order to better address the unique features of shipbuilding. See Table 1.

Table 1: Adaptation of Koskela's 11 LC principles to Lean Shipbuilding in Norway (Dugnas & Uthaug, 2007; Koskela, 1992).

LEAN CONSTRUCTION	LEAN SHIPBUILDING IN NORWAY
Reduce the share of non value-adding activities (waste).	Reduce the share of non value-adding activities (waste).
Increase output value through systematic consideration of customer requirements.	Increase output value through systematic and continuous consideration of customer requirements (Awareness of 'change orders', Agile production¹).
Reduce process variability. Consider process interdependency and isolate supply-related variation.	Reduce process variability. Consider process interdependency and isolate supply-related variation.
Reduce cycle times. Eliminate inventory stock and decentralize the organizational hierarchy.	Reduce cycle times. Eliminate inventory stock and decentralize the organizational hierarchy.
Simplify by minimizing the number of steps, parts and linkages in a product and the number of steps in a material or information flow.	Simplify by minimizing the number of steps, parts and linkages in a material or information flow. The product's complexity is a competitive advantage in Norway: gain more control in this area.
Increase output flexibility. Use modularized product designs, reduce the difficulty of setups and changeovers and train a multi-skilled workforce.	Increase output flexibility. Use modularized product designs, reduce the difficulty of setups and changeovers and train a multi-skilled workforce.
Increase process transparency.	Increase process transparency.
Focus control on the complete process. Allow autonomous teams to exercise control over the process and build long term co-operation with suppliers.	Focus control on the complete process. Allow autonomous teams to exercise control over the process and gain more involvement in often temporary co-operation with suppliers chosen by the end-customers .
Incorporate the best practices into the organization and combine existing strengths with the best external practices.	Incorporate the best practices into the organization and combine existing strengths with the best external practices.
Build continuous improvement into the process.	Build continuous improvement into the process.
Balance flow improvement with conversion improvement.	Balance flow improvement with conversion improvement.
By improving performance at the planning level increase performance at the project level. The Last Planner method is an appropriate alternative.	By improving performance at the planning level increase performance at the project level. The Last Planner method is an appropriate alternative.
Shift the design work along the supply chain to reduce the variation and match the work content.	Shift the design work along the supply chain to reduce the variation and match the work content.
Benchmark.	Benchmark. Take advantage of knowledge-transfer within the Norwegian Maritime Cluster and beyond.

A specific Norwegian market situation has influenced authors' reasoning. Furthermore, the presented table could serve as a framework for ideal shipbuilding. While it is not possible to

become ideal, the authors believe that such framework can serve as a tool for the best practice evaluation (internal benchmarking) and become a kind of

¹ While Lean management emphasizes the pursuit of process efficiency - generating the greatest outcome from the least input through the minimization of wastes, agility refers to effective, flexible accommodation of unique customer demands (Goldsby et al., 2006). The authors and their research partners currently discuss whether it would be more appropriate to replace Lean Shipbuilding with Leagile Shipbuilding due to industry's hybrid nature / environment.

idealistic guide for companies pursuing Lean perfection.

DEVELOPING THE ULSTEIN PRODUCTION SYSTEM

As the theoretical part of this paper is presented, the authors would like to take a closer look at some practical issues. Some of the activities within the Lean Shipbuilding R&D program are already carried out, while the remaining ones are in the planning phase. Currently, Ulstein Verft has the clearest internal guidelines towards their Lean vision – the Ulstein Production System. So how do they imagine their journey towards the ultimate goal?

As it was described above, market situation within and beyond the Norwegian Maritime Cluster is not favourable for shipbuilders. Full order books up till 2011, global supply chains, frequent change orders, lack of workforce / supply capacity are the factors that make shipyards look for new or improved production solutions in order to stay competitive. Ulstein Verft is not an exception. Implementation of Lean principles was chosen, based on successful cases in the construction industry. However, it soon became obvious that shipbuilding differs from construction. In addition, each shipyard has its specific strategy, organization and facility layout. Hence, in order to assess long-term feasibility and sustainability, it is necessary to consider similar issues, such as proposed by Quarterman (2007):

- A. Do we need the entire list of "tools" and techniques?
- B. If not, which do we employ?
- C. Which elements come first?

D. What brings quickest benefits and strengthens motivation immediately?

E. Do we implement plant-wide or in focused areas?

F. How does kaizen fit into the picture?

G. How detailed should the plans be?

H. How do we know when we are really lean?

In cooperation with the research partners (Fafo, Molde Research Institute and Danish Technical University) the decision was made. Namely, start the implementation process by getting up and running the Last Planner system. This decision was found appropriate after carrying out the pre-project at the shipyard. In addition it is proven (Lean Construction experience) that the Last Planner method delivers positive results quite soon after the implementation process takes place. This would help strengthening employee motivation and ensure smooth and effective change of everyday routines. An article regarding the latter issues will be presented at the IGLC16 conference by Bertelsen and Aslesen (our research partners).

Furthermore, when analysing the 11 principles for Lean Construction proposed by Koskela (1992), (see Table 1) it becomes obvious that Last Planner addresses *some* of them, while the remaining ones have to be ensured by other Lean tools (Dugnas, 2007). Here it is important to emphasize that sequence of application of different Lean techniques for different principles is strictly dependent on current shipyard's situation and strategy.

Today, the Last Planner system is up and running at Ulstein Verft, and change orders, process transparency and variability, together with continuous improvement are managed better (Toftesund, 2007).

Further plans are to address the following issues: waste elimination, minimization of cycle times, simplification and output flexibility. In this case, application of the concept "Project Logistics" is planned at Ulstein Verft. Master degree students from the Molde University College will contribute with necessary data collection, initial process modelling and simulation.

It is also important to emphasize that in line with implementation of other relevant Lean principles, the Last Planner system will be developed and customized further. There also are concrete plans of applying Last Planner routines in other departments, such as technical and procurement.

Now, if we consider the widely known TPS "House Diagram" (Liker and Lamb, 2000) we will see that some of its elements are addressed to some extent by applying Last Planner and Project Logistics. However, there are many more Lean principles and techniques that would help Ulstein ensure that its "house" is robust. Examples are project supply chain integration, social logistics (managing multinational workforce) and process standardization. The sequence of their implementation is highly dependent on the following issues: a) current situation; b) speed of positive results' delivery; c) employee motivation; d) effectiveness of the preceding Lean applications; e) resource availability. The management is making significant efforts in order to ensure smooth implementation process and continuity

of improvement leading towards their ultimate goal – the Ulstein Production System.

DISPOSITION OF THE LEAN TOOLBOX IN GENERAL: R&D PLANS FOR THE REMAINING SHIPYARDS

The other three shipyards are in the early phase of Lean principles' implementation. But some trends of their Lean journey are visible already. These shipyards are different from Ulstein Verft, but at the same time they outline similar project issues that need immediate attention. These are: project process variability and transparency, project planning and root cause analysis. However, not all of the shipyards chose Last Planner as the first priority. Aker Yards Langsten and Kleven Verft are first aiming at improved Phase-based Project Management, while Aker Yards Brattvåg is starting with implementation of the Last Planner.

CONCLUSION

Construction and shipbuilding industries belong to the same industrial branch as both are delivering one-of-a-kind products and are project oriented. However, when it comes to production improvement and optimization a deeper understanding is necessary. Lean Thinking is a total manufacturing philosophy and does not represent a strict list of tools that would deliver positive results in most cases. On the other hand, there are several domains where Lean ideology is to some extent adapted to the particular branches. For example, accumulated knowledge from Lean Construction will certainly be helpful in developing the Lean Shipbuilding concept with its specific (adapted) Lean toolbox. Especially in Norway, the shipbuilding industry has

its own specific issues that require a specific approach – and application of Lean principles is an emerging trend. A great interest is displayed from the largest shipyards. At the same moment, it is challenging to work with R&D under such ship-ordering rate and time constraints.

Furthermore, as the Norwegian research indicates, the shipyards have to be aware that not all of the Lean principles that are successfully applied in construction are applicable to the same extent in shipbuilding, and vice versa. As the R&D program Lean Shipbuilding is not completed yet, it is difficult to propose the strict implementation framework for the shipyards pursuing Lean Perfection. The research results also indicate that the implementation process should

start where it is most appropriate in terms of strategy, facility layout, available resources and such. Priorities for Lean principles' implementation should correspond with shipyard's unique situation and strategy – it is crucial to avoid "list thinking". So long the Last Planner System and Phase-based Project Management might be the two most appropriate techniques that enable a smooth and sustainable implementation of other Lean tools – in a shipbuilding context.

The authors believe that Lean Shipbuilding might have the potential to become a separate production concept which requires a specific approach and efforts regarding the implementation process.

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