MANUFACTURING ASPECTS OF OFFSHORE FABRICATION AND INSTALLATION

(DOI No: 10.3940/rina.ijme.a3.302)

P Sjögren, M Bellgran and **B Fagerström**, Mälardalen University, Sweden, **P Sandeberg,** ABB Offshore Wind Connections, Sweden

SUMMARY

The research presented in this paper aim at identifying research commonalities between shipbuilding, offshore fabrication practices and manufacturing. As part of an exploratory effort a literature review and a case study of two offshore structures projects were performed. Research concerning shipbuilding and offshore fabrication, together with literature from other industries in construction, larger engineering projects and traditional manufacturing was reviewed. The two offshore structures projects were analyzed by means of interviews and complemented by direct observations and document reviews. The study concludes that there are gaps in the research concerned with holistic perspectives on the fabrication and installation phases of shipbuilding and offshore projects. The number of actors involved in any project of this magnitude increase barriers and communication interfaces. The dynamic nature of these types of projects was also observed and the changeability should always be a accounted factor when dealing with projects of this sort. The interviews held as part of the verification of observed phenomena in literature was limited to two projects and a single company and actors perceptions. However the collected data served well in being complementary to the literature review. It could be the task of academia to patch the gaps for overall project success, in the cases where single industry actors simply cannot see the benefit or do not have the recourses to fill them themselves. This study combines findings from traditional manufacturing industries, shipbuilding, offshore structures fabrication and large engineering projects in general.

NOMENCLATURE

CoPS	Complex Products and Systems
CAPEX	Capital Expenditure
EPC	Engineering Procurement and Construction
F2F	Face to face
FEED	Front End Engineering Design
HLV	Heavy Lift Vessel
HTV	Heavy Transport Vessel
T&I	Transport and Installation

1. INTRODUCTION

Large scale shipbuilding and subsequently offshore structures fabrication can be sorted under the category of complex products and systems, CoPS. CoPS comprise a product of systems that are interdependent and interrelated but are not definable on a single level of description [1]. This complexity is also true for the stakeholder's organisation in a large construction project. Offshore structures projects require large project and administration organisations. However economical prerequisites and contractual differences between involved parties often lead to problems in information and interface management, both product physical related and organisational [2].

In order to grasp the extent and scope of a project a FEED-study is often performed. The FEED also control project execution feasibility for a product that cannot be prototyped. The benefits of this work methodology is evident, front loading engineering efforts in early design phases, while the order of constraints are low is an affordable insurance against future failure and risk to most companies. Project stakeholders gather around the FEED and base much of their individual efforts to achieve what has been written and decided to meet the design and project end-goal. However the economic incentives and interests work against the interests and purpose of FEED, the start-up of projects and placing of orders before engineering is complete circumvents potential FEED related gains [2]. In other words, in the absence of ready detailed designs, FEED studies are being inappropriately used as a substitute. This has implications further downstream when fabrication commences, certificates has not been issued because of lacking documentation resulting in delays and rework [2].

As fabrication of offshore structures enfolds a substantial part of the CAPEX much research has been focused on the fabrication's process efficiency. As in every other industry, the Toyota way [3] and lean production concepts has also been implemented in shipbuilding, both on sub-assembly level [4] and to overall production aspects [5],[6]. While lean production has its place in shipbuilding, the extent of its application to different types of products and production systems can be complemented with agile manufacturing principles [7]. Lean production principles are sprung out of an industry with high series, high level of standardisation and line oriented manufacturing [3]. Shipyards however are manufacturing based companies producing one-off-products or highly customised series and, to a large extent, utilises fixed position assembly, thus shipyards can rather learn from the body of production theory research surrounding agile manufacturing and apply developed concepts to their own businesses. Some researchers define agile manufacturing as a continuation of lean principles whereas the former can only be accomplished through implementing the latter. Agile manufacturing's aim is to achieve flexible organisations that are ready for change [8] and as rework has been identified as an intrinsic fact of large construction projects [2] agile manufacturing principles could prove helpful for project execution.

The physical difference between a conventional shipyard and an offshore engineering yard is mainly the absence of a slipway or other ship launching facilities, nor is it needed to have a drydock for all cases, depending on the structure to be constructed. Offshore structures are either lifted or skidded onto a barge for further transport to the installation site while a ship can start operations as soon as it has been launched. Larger shipyards have the facilities to construct both ships and offshore structures. However there are yards specialised in offshore structures that have no ability to build ships. Thus another large CAPEX of an offshore structures project is the T&I phase, this phase is rather specific to offshore platforms while the fabrication process also applies to general shipbuilding. T&I owe the risk of tying down potential revenue, when otherwise functioning equipment cannot be commissioned. Due to the complex and specialised operations needed related to the structures sheer size and weight, holistic scheduling based on information is essential. However research on the subject of marine operations tends to focus on industry examples, lessons learned and detailed calculation methods e.g. weather forecasting and structural aspects [9], [10], [11]. By questioning conventional methods and learning from other industries about logistical issues and their solutions, the research area of marine operations would not only benefit the marine industry but other industries as well.

2. METHOD

The framework used to develop this research is based on Blessing and Chakrabarti's "Design Research Methodology", DRM [12]. The findings found in this work are based on an inductive approach, meaning that facts and empirical evidence form the theory [13].

The goal of this research was to identify gaps in the research body connected to shipbuilding and offshore structures EPC processes. By combining literature review and a case study interview series, gaps were identified and further verified by observed phenomena.

Presupposition and misinterpretation are among the more common and obvious sources of err in analysis of qualitative data, but to completely objectively analyse results is not possible, nor is it necessary, from a hermeneutic point of view [14].

2.1 LITERATURE REVIEW

Journals and conferences contributions connected to large engineering projects and complex products was studied in general and those connected to publications on ship fabrication and installation in particular based on their titles and keywords.

Concepts related to the research topic but not solely found in the marine and offshore business were reviewed to expand and verify identified issues, in some cases shed light on possible solutions from other industries.

2.2 CASE STUDY

Two offshore structures projects where treated as units of analysis based on the framework developed by Yin [15]. The two projects were both in the offshore wind industry ti serve as high voltage direct current connections. A high voltage direct current (HVDC) platform is similar to an oil and gas offshore platform when it comes to methods of construction, installation and appearance. It is the essential equipment and function of the HVDC platform that is different from that of an oil or gas platform. As an increasing number of wind farms are being commissioned offshore and further out at sea, due to stronger winds, HVDC transmissions from the farms to shore is becoming the preferred choice over high voltage alternating current (HVAC), due to transmission efficiency. The HVDC transmission link require a larger and heavier platform offshore than an HVAC equipment and so the projects tend to become more complex. Both studied projects where HVDC platforms with similar power converter capabilities 800-900MW. However the designs differed where one is a jacket – topside and the other a gravity based structure. In order to gain an understanding of the project and their encountered problems associated to the fabrication and installation process semi-structured interviews where held with:

- Project Manager (1)
- Engineering Consultant (1)
- Supply Managers (2)
- Lead Engineers (2)
- System Engineer (1)
- Commissioning Engineer (1)
- T&I Manager (1)

Where all was in involved in the jacket-topside project but only supply and lead engineers had worked on the gravity based structure project.

Table 1. Data Collection Information

Data Collection	No.	Duration [min]
F2F Interview	8	44 – 67
Telephone Interv.	2	50 – 54
Log book observations	11	N/A

Interviews were summaries or recorded and transcribed, thereafter analysed based on the methods described by Hycner [14], delineating units of meaning relevant to the given research out of the interview material to form empirical evidence.

The logbook was kept on day to day basis, noting information from:

- Document Observations
- Informal Discussions
- Meetings
- Unrecorded Interviews

Interview testimonials were verified, when applicable, by archival data and through repeated dialog with interviewees to validate conclusions made based on their answers.

3. RESULTS

The results from the literature review are presented first and followed by findings from the case study. The analysis was performed with a linear-analytic structure and triangulation of collected data [15] and presented as part of the conclusions.

3.1 LITERATURE REVIEW RESULTS

Comparing offshore structures to ships, they typically house advanced equipment e.g. oil drilling tool, process plants or electrical converters and or transformers, this further complicate production as that equipment comes with high technical requirements. In addition, the later phases of offshore structures projects are often more advanced than that of a ship. Lifting and mating modules, sometimes offshore, are complex projects in their own right [1].

In his article on "Innovation and learning in complex offshore construction projects" Barlow [1] explored the problems and solutions to the poor performance of UK's construction industry. Some of the problems Barlow found were:

- Uncertainty due to incomplete information.
- Neglecting user needs.
- Emergence of new system requirements during production.

Barlow's [1] study examined the effect of "partnering" in Complex, Product and Systems-projects, CoPS, and found that this organisational approach mitigates the problems described above, foremost through improved information, or an environment promoting better information. Partnering as a method enables most of the initiatives, described by Gilgeous and Gilgeous [16] below, primarily the first, third, seventh and eighth point.

Gilgeous and Gilgeous [16] investigated the presence of a process, mainly through interviews, towards manufacturing excellence within companies proven exceptionally good at manufacturing strategy. Gilgeous and Gilgeous [16] categorised and conceptualised the answers from their subjects to conclude both the type of initiatives that the companies had taken, and the enablers to reach manufacturing excellence.

The initiatives were:

- Innovation and change.
- Empowerment.
- The learning organisation.
- Customer focus and commitment.
- Commitment to quality.
- First rate management team and belief in the organisation.
- Technology and information systems.
- Win-win relationship.

Flyvbjerg, Bruzelius and Rothengatter [17] has studied the causes of cost-overruns in large and mega sized construction projects and they identified overly positive conception during project planning, they also attribute poor understanding of risks as a source of err in large construction projects.

The CoPS [1] or mega project theories [17] focus on the overall project execution, in the example of a jacket and topside, in figure 1, CoPS and mega projects would include the entire infrastructural endeavour.

Jeargas [18] studied the FEED process of the Alberta oil sands projects of Canada and found that inadequate time and resources spent in the FEED phases directly correlated to less than desirable project execution. The same conclusions are drawn by Love and Edwards [2], in their study of rework in offshore structures projects they identify the following causes of rework that correlate with the inception of a FEED-study, regardless of offshore platform type:

- Scope definition.
- Commencement of construction and installation before engineering is completed.
- Non-compliance to engineering requirements.
- Unrealistic scheduling.
- Lack of resources and planning.

On the more physical side of things a common problem amongst shipyards, connected to fabrication efficiency is their limited space. Often shipyards are established early in urbanising areas, while accelerating the problem themselves as work intensive employers, they find themselves cornered spatially. Much research has been focused on spatial scheduling of shipyard grounds [19], [20] [21]. Lean production tools can be one of the solutions for shipbuilders whom want so utilize more space; this is also supported by Moura and Botter [22] in their study on lean concepts in shipbuilding.

Koeing et al. [6] studied Japanese shipyards with respect to lean philosophies and found several aspects that are considered common lean practice – worker driven process improvements, elimination of waste and pursuit of perfection. Koeing et al. [6] found their observations of Japanese yards so lean that finally asked themselves the question: "Who was the original leader in lean thinking, Toyota or the shipyards?" It could be argued that lean doesn't belong to an industry but is rather a Japanese cultural phenomenon and as such present in most Japanese industries. Pull as a lean concept is present in shipbuilding but at different phases and levels than in e.g. automotive industry, ships and offshore structures are built-to-order and thus pulled by the ship-owner. Another example of pull at a macro production level is the available space in dry docks, which as the most specialized area of a shipyard ought to always be active or occupied. At a higher resolution the presences of lean becomes more scares, most welding operations a sub-assembly is still based on time-schedules [6].

Kolíc et al. [4] proved lean manufacturing principles applied at a shipyard on sub-assembly or plate-stiffener level, resulted in decreased duration, man-hours and required space for manufacturing, many of which aspects one can expect from a lean transformation. Unfortunately as Yamamoto and Bellgran [23] states in their description of how to implement the lean mindset into an organization, many companies are used to implement improvements without risking operations. For companies as shipyards, an understanding of the risks and a contingency plan is recommended, if not for the failure of the lean transition, as a safety in order to be willing to take the leap.

In line with the many improvements suggested by the implementation of lean concepts, flexibility and agility is the next evolutionary step for many manufacturing companies. The increased demand of customized products is one of the driving factors towards flexible manufacturing systems [23]. Rao and Gu [24] wrote on the importance of scientific methods to guide the design process of new agile and flexible manufacturing systems, while in the article providing both a design method and an integrated design approach. For manufacturing industries that have always been producing one-off-products this is an opportunity to make use of a coming larger body of research relevant to their businesses. Moura and Botter [22] argues that a key factor for shipyards to reach success in agile manufacturing is the integration of product and planning functions, be it internal or external, pointing in the same direction as Rao and Gu [24].

In the context of offshore structures fabrication it is important to include the T&I phase as those phases contribute as much to the overall completion of a project as fabrication alone.

Crowle [10] gives an insight into T&I projects using HTVs to transport modules for offshore structures, the different types of HTVs that are used in industry and discuss module prerequisites among other things. In his part on modules aspects to be considered at the design phase are established along with information on grillage and sea fastening design. Ayaz et al. [9] present a similar report to that of Crowle for a case of on and off loading of modules offshore using a HLV, where both technical and operational aspects are covered.

Zhang et al. [11] write that the availability on heavy transport vessels drive the need for scheduling and as part of the lessons learned section Crowle [10] mention the importance of detailed scheduling based on modular requirements, thus looking upstream in the fabrication process and the necessity of preventing carry over work from one fabrication, transport and installation phase to another.

3.2 CASE STUDY RESULTS

The complexity described by the interviewees regarded the product, process and organisational aspects. From a product point of view the different types of platforms that is feasible for the same site makes informed decision making crucial. The number of sub-systems, sub-contractors and scheduling implications complicate the project process of offshore structures. Contracts, requirements, regulations, competence and manpower are indicated by the participants of the study, to add to the complexity from an organisational point of view.

In the case studied all respondents acknowledge the need for well-established inter-project information across participating companies as a success factor. Obstacles in the way of this preferred way of working were:

- Company cultural differences
- Scope split and contractual loopholes
- Software compatibility problems

Many of the stakeholders in the project are driven by different goals as that is how contracts are written. Some partnering and bridge agreements had been signed; the downside to that however is an impaired supply and acquisition process.

A majority of the respondents of the case study mentioned the importance of a well-documented FEED-study together with an established scope split to avoid complications due to responsibility issues in projects downstream.

In the case that revision of the design is needed the time to correctly agree on the rework, is often more time consuming than the redesign itself. One of the respondents said that:

"One main concern during the FEED phase is to have competence and capacity that is expected in project organisation as a whole, otherwise there will be imbalances of influence over the FEED and customer requirements probably will not be fulfilled in the end."

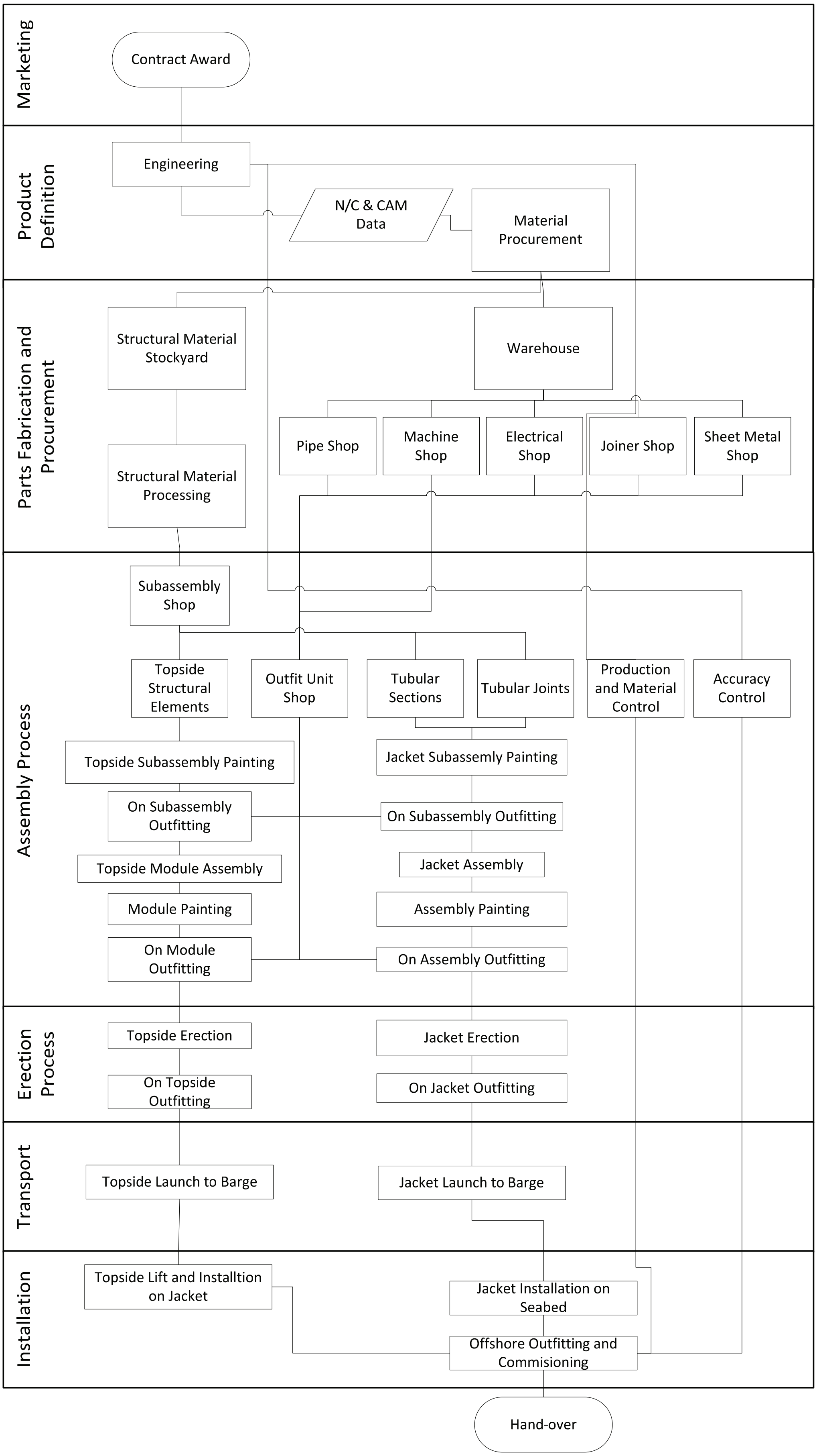

Figure 1: Fabrication process of a jacket and topside platform.

On-site engineers interviewed and observations at site visit gave a frustrated impression, having the tools at their hands to manage problems but due to slow decision making processes their hands were often tied. Software compatibility and project management in-house understanding of the on-site problems were suggested as culprits.

One T&I manager gave witness of how difficult it is to establish roles and responsibilities both internally and externally within the project organisation despite contractual agreements. Contractual agreements naturally vary between suppliers, the T&I manager said:

"One contract for these type of projects alone is tough to comply with, add to that that different suppliers contracts differ the slightest form the end clients specification – and that is of course unacceptable"

Based on the work of Storch [5] the steps of fabricating a jacket topside platform have been established in figure 1. The different areas of research going into shipbuilding or fabrication of offshore structures can be discussed with figure 1 as the basis.

Lean principles apply in large to the mass production characteristics of sub-assembly fabrication, in terms of what has been observed as part of this study. FEED is the prevalent method in research and industry, being part of the planning process for both T&I and Engineering.

Theories with a holistic perspective often consider the processes shown in figure 1 as part of something larger, the entire project campaign where the platform is only a part. In figure 1 based on Storch's work [5] the T&I process has been added, due to this phase importance to the overall project completion for offshore structures.

4. DISCUSSION

The interviewees held as part of the case study contain a limited sample size and project scope of the interviewed. One could always argue that more individuals from a broader range of disciplines would enrich the material, and this is of course true. However given the envelope of this research the interviews are still regarded sufficient in complementing the literature review and act as verification.

The literature study was primarily based on publications by RINA and SNAME with regards to ship production and offshore installations. Certain conference proceedings had to be omitted due to limited access of the researchers; surely a larger literary sample size would be even more enlightening on the subject. In addition other research areas as large engineering structures and complex products and systems were used as complement to the study and exposed common problems across product types. Traditional manufacturing literature and theory was also included in the study to enrich and enable cross industry knowledge.

Manufacturing and shipbuilding have much in common and a lot to learn from each other and the contemporary research show that efforts are being made on the behalf of both sides. Lean principles is as dominant in ship production literature as manufacturing as a whole, with a surge of the applicability of agile and leagile principles of research to follow. As for offshore structures project the business – to – business interfaces and client – contractor – sub-supplier integration need more research, new development project within manufacturing industries as the automotive could be used to shine new light on old issues faced by the offshore and shipbuilding industry.

The benefits of doing a thorough FEED-study are well document. Front loading of project and engineering efforts has for long been the focus of companies looking to mitigate risks during project execution. Similarly, planning is a recurring subject connected to productivity, and rightfully so. But as Ross et. al [25] wrote on the subject of robustness, a concept comparable to flexibility and agility:

"The desire for "robustness" stems from the fact that change is inevitable, both in reality and perception."

A system is only as efficient as the contingency in the event of failure, which directly corresponds to planning. But as stated by Love and Edwards [2] one of the reasons of rework is the start of fabrication prior to completed engineering efforts. Some engineering firms even suggests having pre-FEED, this likely seem to be a curing of a symptom not the cause of rework.

To establish information cross project phases a prerequisite is that the information of the one phase e.g. T&I is functional to begin with. This holds true also for other project disciplines. T&I operations can account for a substantial part of a project. Research written in this area form a good source of reference that can be extended both into operational conditions to come and processes that precede the T&I phase

The authors humbly acknowledge that the extent of issues related to shipbuilding and offshore fabrication are wide and many. This has been an attempt at highlighting some of the work performed previously and connect that to underlying causes.

5. CONCLUSIONS

Research from traditional manufacturing disciplines and offshore fabrication share common interest and obstacles and both industries do benefit from each other's contribution but this exchange can be further developed.

The dynamic nature of shipbuilding and offshore fabrication should be explored in terms of manufacturing aspects, as changeability often is treated as a project management problem. The unplanability of certain manufacturing processes need to be better understood both by project managers and contractors. The need for agility as the next step in production evolution from lean principles is another factor showing the need from industry to become more flexible in their manufacturing process.

It can also be concluded that there is little research that focus on how to enable information transfer across project phases, and holistic frameworks for project execution. There seem to be a research gap to be filled by academia, as industry has developed their processes out of an economy based on competition rather than overall project success. Academia can play the role of patching the gaps and providing concepts and frameworks. It will be an academic responsibility to prove these concepts and frameworks better than today's best practises from an overall project completion perspective. If successful both industry and academia concerning naval architecture will stand to gain against competition from other shore-based industries. Love and Edwards [2] lay the ground work by identifying reasons for rework in offshore projects, and this is where the need for research to reduce project impairing factors is proven best.

Love and Edwards [2] touch upon another conclusion that can be drawn based on this research and that is the dynamic nature of large engineering projects, the changeability, the need for adaptability, agility the management of uncertainty. In a project environment with unrealistic scheduling the ability to adjust the course in real time is a must. This is a field of research that can be expanded with experience from the shipbuilding and offshore fabrication industries. Much of the work on understanding the issues in this field has been performed, but this needs to be followed by tools, mind-sets and novel business models for industry to implement in the future.

6. ACKNOWLEDGEMENTS

The authors would like to thank the interviewees, of the case study, for their insightful answers and the company that allowed for full access data collection during the entire case study. The conclusions of this research represent the work of the researchers, not necessarily those partaking in neither the interviewees nor their employer.

7. REFERENCES

1. BARLOW, J., 'Innovation and learning in complex offshore construction projects', *Research Policy, 29*(7), 973-989, 2000.
2. LOVE, P. E. D., & EDWARDS, D. J., 'Curbing rework in offshore projects: systemic classification of risks with dialogue and narratives', *Structure and Infrastructure Engineering, 9*(11), 1118-1135, 2013.
3. WOMACK, J. P., JONES, D. T., & ROOS, D., '*The machine that changed the world: The story of lean production--Toyota's secret weapon in the global car wars that is now revolutionizing world industry'*: SimonandSchuster. com. 2007.
4. KOLIĆ, D., FAFANDJEL, N., & ZAMARIN, A., 'Lean Manufacturing Methodology for Shipyards, *Brodogradnja', 63*(1), 18-29, 2012.
5. STORCH, R. L., 'Improving flow to achieve lean manufacturing in shipbuilding', *Production Planning & Control: The Management of Operations 10*(2), 127-137, 1999.
6. KOENIG, P. C., NARITA, H., & BABA, K., 'Lean production in the Japanese shipbuilding industry?', *Journal of ship production*, *18*(3), 167-174, 2002.
7. HEYNES, R. H. and WHEELWRIGHT, S. C., 'Link Manufacturing Process and Product Life Cycle', *Harvard Business Review, 57*(1), 133-140.
8. GOLDMAN, S. L., NAGEL, R. N. and PREISS K., *Agile competitors and virtual organizations: strategies for enriching the customer*, *(8*). New York: Van Nostrand Reinhold, 1995.
9. AYAZ, Z., MCLELLAND G., SMITH P. and McCarthy V., 'Removal and Installation of Modules onto Truss Spar with DP Heavy Lift Vessel', *Marine Heavy Transport & Lift III*, UK, 2012.
10. CROWLE, A. P., 'Marine Design Aspects for Large Modules on Heavy Transport Vessels', *Marine Heavy Transport & Lift III*, UK, 2012.
11. ZHANG, D., SUN, W., & FAN, Z., 'Application of a newly built semi-submersible vessel for transportation of a tension leg platform', *Journal of Marine Science and Application, 11*(3), 341-350, 2012.
12. BLESSING, L. T. M. and CHAKRABARTI, A., *DRM, a Design Research Methodology,* Springer, 2009.
13. ARBNOR, I. and BJERKE, B., *Methodology for Creating Business Knowledge,* Sage Publ., 2008.
14. HYCNER, R. H., 'Some guidelines for the phenomenological analysis of interview data', *Human studies, 8*(3), 279-303, 1985.
15. YIN, R. K. *Case study research: Design and methods*, Vol. 5, Sage, 2009.
16. GILGEOUS V. and GILGEOUS M., 'A framework for manufacturing excellence', *Integrated Manufacturing Systems 10*(1), 33-44, 1999.
17. FLYVBJERG, B., BRUZELIUS, N., & ROTHENGATTER, W., *Megaprojects and*

risk: An anatomy of ambition, Cambridge University Press, 2003.

18. JERGEAS, G., 'Analysis of the front-end loading of Alberta mega oil sands projects', *Project management journal, 39*(4), 95-104, 2008.
19. CHO K. K., CHUNG K. H., PARK C., PARK J. C., AND KIM, H. S., 'A Spatial Scheduling System for Block Painting Process in Shipbuilding', *CIRP Annals-Manufacturing Technology 50*(1), 339-342, 2001.
20. LEE J. K., LEE K. J., PARK H. K., HONG J. S. AND LEE J. S., 'Developing scheduling systems for Daewoo Shipbuilding: DAS project', *European Journal of Operational Research 97*, 380-395, 1997.
21. PARK C., PARK J.-C., BYEON G.-G., KIM H.-G. AND KIM J., 'Steel stock management on the stockyard operations in shipbuilding: a case of Hyundai Heavy Industries', *Production Planning & Control: The Management of Operations 17*(1), 1-12, 2006.
22. MOURA, D.A. and BOTTER, R. C.,'Can a shipyard work towards lean shipbuilding or agile manufacturing?', *Sustainable Maritime Transportation and Exploitation of Sea Resources*
23. YAMAMOTO, Y. and BELLGRAN, M., 'Improvements towards lean production', *Assembly Automation 30* (2), 124-130, 2010.
24. RAO A. H. and GU P, 'Design methodology and integrated approach for design of manufacturing systems', *Integrated Manufacturing Systems 8*(3): 159-172, 1997.
25. ROSS, A. M., RHODES, D. H., and HASTINGS, D. E., Defining changeability: Reconciling flexibility, adaptability, scalability, modifiability, and robustness for maintaining system lifecycle value, *Systems Engineering, 11*(3), 246-262, 2008.

