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Offshore Wind Project Production System: Reducing Construction Duration Through Planning

PhD dissertation

Jon Lerche

Aarhus BSS
Aarhus University
Department of Business Development and Technology

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Jon Lerche

Department of Business Development and Technology
Aarhus University

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List of Acronyms

CPM	Critical Path Method
IGLC	The International Group for Lean Construction
LBMS	Location-Based Management System
LCoE	Levelized Cost of Energy
LPS	Last Planner System
OM	Operation Management
PDCA	Plan Do Check Act
TFV	Transformation Flow Value
ToC	Theory of Constraints

List of Publications

Peer-reviewed publications included in this thesis:

Journal Paper	I	Lerche, J., Neve, H., Wandahl, S., & Gross, A. 2019. Categorization of the offshore wind production system. *International Journal of Operational Research*. Forthcoming. DOI: TBA
Journal Paper	II	Lerche, J., Neve, H., Enevoldsen, P., Wandahl, S., & Gross, A. 2020. Reasons for offshore wind project delays. *Journal of Marine Engineering and Technology*. In review.
Journal Paper	III	Lerche, J., Neve, H., Wandahl, S., and Gross, A. (2020). Continuous improvements at operator level. *Journal of Engineering, Project, and Production Management*, 10(1), 64–70. https://doi.org/10.2478/jeppm-2020-0008
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Journal Paper	V	Lerche, J. Neve, H. Ballard, G., Teizer, J., Wandahl, S. Gross, A. 2020. Application of Last Planner System to modular offshore wind construction. *Journal of Construction Engineering and Management*. In review.

Peer-reviewed publications included for reference purposes only:

Conference Paper	VI	Lerche, J., Neve, H., Pedersen, K. B., Wandahl, S., & Gross, A. 2019. Why would Location-Based Scheduling be applicable for offshore oil and gas construction? Paper presented at the Proc. 27th Annual Conference of the International Group for Lean Construction (IGLC), Dublin, Ireland. https://doi.org/10.24928/2019/0120
Conference Paper	VII	Leth, S., Lerche, J., Neve, H. H., & Wandahl, S. 2019. Lessons for construction: Delivering mega project on time through culture and Hoshin Kanri. Paper presented at the Proc. 27th Annual Conference of the International Group for Lean Construction (IGLC), Dublin, Ireland. https://doi.org/10.24928/2019/0139
Conference Paper	VIII	Neve, H., Wandah, S., and Lerche, J. 2019. Feedback loop: The missing link in activity analysis. In Proc. of The 10th International Conference on Engineering, Project, and Production Management. (Forthcoming, 2020.) Springer.
Journal Paper	IX	Neve, H., Wandahl, S., Lindhard, S., Teizer, J., Lerche, J. 2020. Determining the relationship between direct work and construction labor productivity: Four decades of insights. *Journal of Construction Engineering and Management*. In review.
Journal Paper	X	Neve, H., Wandahl, S., Lindhard, S., Teizer, J., Lerche, J. 2020. Production system behaviours and performance in refurbishment projects. *International Journal of Construction Management.* In review.

Preface

This thesis is the written contribution to fulfilment of a PhD degree from the Faculty of Business Technology, Aarhus University, School of Business and Social Sciences, Denmark. The project has been conducted in collaboration with Siemens Gamesa as industry partner who also funded the project entirely.

During the last three years, I have been so fortunate to collaborate with peers from academia and the offshore industry. These people have provided me with great insights, been outmost helpful, and I am thankful to them. First, I would like to thank Allan Gross for his support and belief in me prior to and during changes in the project. I would like to thank Hasse Neve, who gave his time on a Saturday in July 2017 and elaborated on lean construction philosophies and guided me while changing direction. Since then we have travelled three continents and shared ups and downs during the experience and journey of achieving the PhD degree, which I am highly grateful for. Thank you to Søren Wandahl, who provided guidance during the transition from modelling into construction management. Thank you to Olli Seppänen for his great patience with me, insights, valuable inputs, and engagement in future prospect. I also feel highly honoured that he allowed me to visit Alto University and obtain different perspectives from his research community. Thank you to Glenn Ballard, who has been an inspiration through literature and in person; I have been blessed with his collaboration and insights during my latest project. Further I would like to thank Trond Bølviken for his question at IGLC 2019, which inspired me to further investigate the topic of process dependencies. A special thank-you to Kristian Birch, who has been a good friend and collaborator, further provided me with great knowledge about utilizing technology in the construction industry, and contributed to my future research.

Thank you also to my colleagues, those directly and indirectly involved in my research and everyday job. Thank you for the understanding and patience with me. It has been insightful and a lesson for life to work with these colleagues. Particular from the industry side I would like to thank Jane Berthelsen for her inspiration and good mood during tough times and Evald Kristensen for co-developing, shielding me from tasks, and inspiration for new ideas. I also owe Søren Leth a big thanks for inspiring me to do better, find my "inner duck" and continuously strive for perfection when working with people.

Also, a thank-you to the operational people who have been part of my lab, providing insights and questioning my thoughts. I am sure that the final result only became better based on your inputs.

Finally, I would like to thank my family and friends. Maybe I wasn't attentive at all times, but the cheering and comments have been valued throughout the entire period. Patience is a virtue. I have learned the meaning of postponing needs in favor of a goal with high personal value or importance.

Jon Lerche
Hamburg, 2019

Abstract

This thesis demonstrates the importance of understanding a production system, to increase its productivity through preparation and planning. First categorizing the system, second understanding its failure modes. As planning was a major contributor to the offshore failure modes this guided the further research within the field. Investigating what processes planning methods that would be applicable. Four field studies were conducted to collect empirical data throughout 2017, studying the relation between products, processes, layouts, resources and failure modes. Two longitudinal field studies were performed in 2018, investigating the applicability of Takt planning and Last Planner System within the environment of offshore wind construction. The results showed that the offshore wind construction industry could be perceived a hybrid between standard products as within production and operational similarities to construction. Further, it was possible to standardize the failure modes within this production system through logical network analysis. Planning and controlling these dynamics required investigations of application. The artefact development and evaluation of the planning methods Takt planning, Last Planner System, and location-based scheduling, adapted for offshore wind projects. Results showed that project construction durations can be reduced with 20% through changing the planning methods from current critical path method practices. The expansion of knowledge challenged the perception of offshore wind construction as a novel hybrid production system. As its similarities with another novel domain in the literature; modular construction became evident. The contributions from this thesis within the offshore wind project context is the categorization and standardization of the failure modes. The contributions to construction community within the overall operations management domain includes the usefulness of Takt planning, Last Planner System, and location-based scheduling in the offshore wind environment and applicability for modular construction.

Sammenfatning (Danish summary)

Formålet med dette ph.d. projekt var at undersøge produktions systemet for byggefasen indenfor offshore wind projekter fra et ledelses perspektiv. Det er set i forhold til den nuværende debat omkring nedbringelse af de overordnede omkostninger for offshore wind energy, mange emner i den debat har drejet sig om teknologi, logistik og finansielle modeller (Esteban et al., 2011, Heptonstall et al., 2012, Rodrigues et al., 2015, Lacal-Arántegui et al., 2018, Enevoldsen and Xydis, 2019). Der har ikke tidligere været en kategorisering af produktionssystemet eller årsagerne til forsinkelse i byggefasen. Yderligere har der ikke tidligere været andre perspektiver på offshore byggeri planlægning end brugen af kritisk vej metoden, derfor blev alternative planlægningsmetoder tilpasset og evalueret.

Undersøgelses området i dette projekt er geografisk primært foretaget i Europæiske lande, i løbet af 2017 blev der foretaget feltstudier i henholdsvis England, Tyskland og Finland. Hvor i 2018 blev der foretaget et længere varende feltstudie i Belgien i forbindelse med et last planner system implementerings eksperiment. Samt yderligere et studie af takt planlægning i Tyskland. Observationerne, interviews, workshops, indtastet data og fremdrifts rapporter danner grundlaget for resultaterne, som blev analyseret med to verdenssyn. Henholdsvis konstruktivisme og pragmatisme blev benyttet til anskuelserne, samtidig med at Taylors, Fayol, Mcgregor og Koskela blev brugt som de teoretiske lænser til at danne forståelsen. Analyse arbejdet blev foretaget som case studier ved hjælp af både kvalitative og kvantitative metoder, indenfor forsknings rammerne af design science og blandede metoder.

Det var nødvendigt at kategoriseere produktions systemet for at danne en forståelse af produkterne, processerne, områderne og ressourcerne som der indgår (Lerche et al., 2019a). Den fælles forståelse af hvordan tingene passer sammen og hvorledes de indgår i systemet var inspireret af byggeriets opgør med produktion i slut 1990’erne. Kategoriseringen viste et produktionssystem hvor produkterne er standardiseret som ved produktion, men operationelt ligner det byggeri. Undersøgelserne ledte videre imod hvad der hindrede fremdrift i dette produktionssystem, årsagerne til at byggeriet blev forsinket

blev derfor undersøgt og dokumenteret i Lerche et al. (2020b). Fejl kilderne blev analyseret ved brugen af logisk netværks analyse, hvilket førte til en kategorisering af forsinkelserne for byggefasen på land og til vands. Det kunne under disse undersøgelser konstateres at kritisk vej metoden var den dominerende planlægningsmetode indenfor offshore litteraturen. Desuden blev perspektivet for forståelsen, af tidligere "antagelser", "konstanter" og "variabler", identificeret som værende udefra-ind, hvor dette studie tog indefra-ud perspektivet. På baggrund af resultaterne vil det for industriens praktikere og akademikere være muligt at danne sig en nuanceret forståelse af årsagerne til projekt forsinkelser. Planlægning blev identificeret som en dominerende fejlkilde for offshore aktiviteter, hvilket motiverede for den videre undersøgelse af proces planlægning for offshore wind projekter. Den videre forskning af planlægnings metoder i offshore miljøet foregik indenfor det videnskabelige verdenssyn design science. Udviklingen og evalueringen af de tre artefakts, viste at både lokations-baseret planlægning (Lerche et al., 2019c), Last Planner System (Lerche et al., 2020a) og Takt (Lerche et al., 2020c) kunne benyttes som alternativer til kritisk vej metoden. Disse applikationer og evalueringer udfordrede den indledende forståelsen af offshore wind som værende uudforsket hybrid produktions system. Da har adskillige sammenligneligheder med modul byggeri, som er et nyligt voksende emnefelt indenfor bygge litteraturen. Resultaterne viste yderligere at det var muligt at reducere tiden for byggefasen med mere end 20%.

Dette ph.d. projekt bidrager til offshore wind litteraturen med en forståelse af projekt produktions systemet og dets fejlkilder. Det bidrager samtidig med en brugbar forståelse om applikationen af alternative planlægnings metoder indenfor offshore wind, som yderligere er relevant for udviklingen af planlægnings teorierne, samt emnefeltet modul byggeri.

1. Introduction

This paper-based thesis contributes to the body of knowledge within the management and offshore wind construction domain by a comparative review of the related peer-reviewed papers and existing literature. Focusing on expanding the knowledge about productivity through technical and managerial input-output relations within offshore wind projects. The research delimitates financial and commercial aspects. Offshore wind as a production system has existed commercially since 1991 without clear definitions of rules, principles, and existing objects from a managerial perspective. From a literature perspective the phenomenon of offshore wind investigations has intensified from supply chain, engineering, logistic, political, and managerial perspectives. Rodrigues et al. (2015) presented offshore wind farm development from 2001 to 2015, showing a yearly expansion of 36.1 percent on average for the overall capacity in megawatts. From a technical perspective Enevoldsen and Xydis (2019) revealed that wind turbine components for both onshore and offshore have increased in dimensions and weight over the last 35 years. Koh and Ng (2016) supports this trend for turbine designs and predicted a similar change in foundations as the distance to shore was expected to increase. Lacal-Arántegui et al. (2018) argued that despite increasing components' sizes and distances to shore, the following remains to be answered "what increased project productivity and reduced the duration measured in days per installed megawatt". Whether it is planning, processes, variables, or a combination requires further investigation. This research seeks to expands on these topics in particular and provide both practitioners and academics with insight to this from an operational level.

The offshore wind projects have similar contractual conditions to what Yeo and Ning (2002) in the construction domain address as Engineering-Procurement-Construction projects. But where construction develops unique structures from alternative commodities, the offshore wind projects are developing with defined commodities such as substations, cables, foundations, and turbines (Rodrigues et al., 2015, Bilgili et al., 2011). Without consistency, the project production system processes have been divided between different project phases and operations, they have also been handled from different commodity perspectives, including some of the turbine, foundation, or overall assembly, which includes cables, foundations, and turbines.

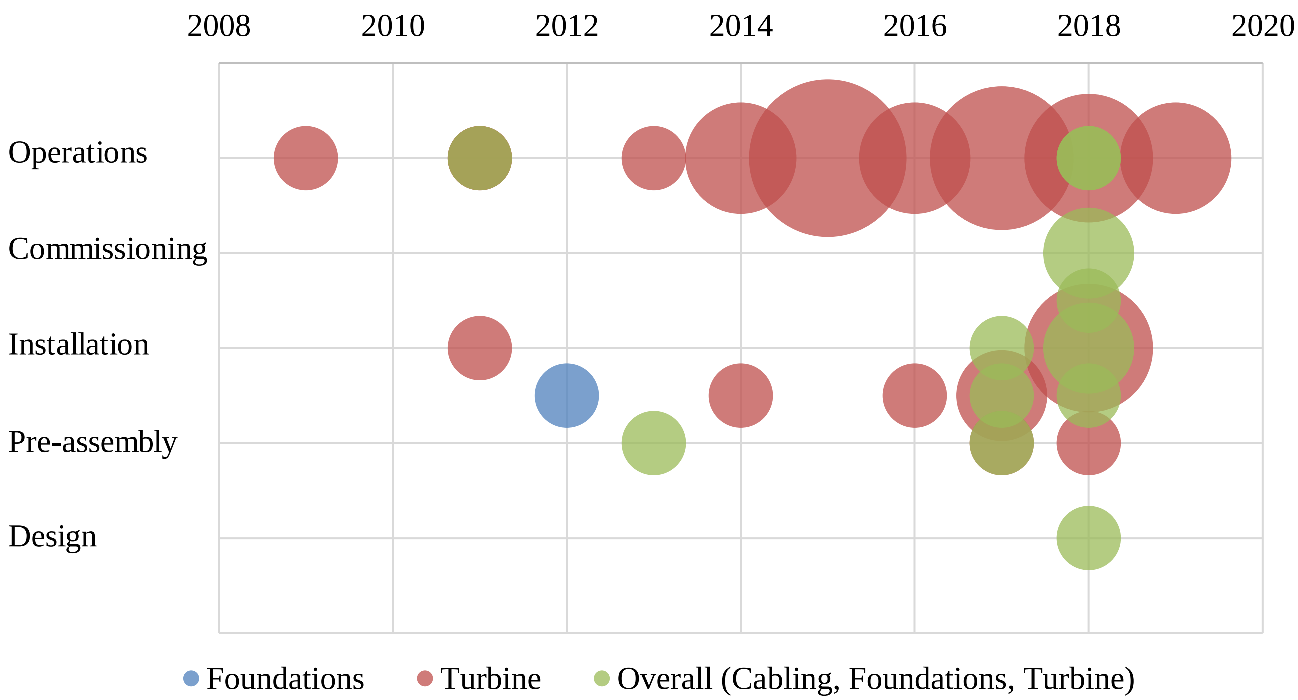

Figure 1: Commodity and project phase planning; size of circle indicates number of papers.

Figure 1 illustrates how 75 journal papers from 2008 to 2019 are distributed between project phases, seen in relation to the wind farm commodities considered as earlier mentioned. From the total population, the overall category covers 32 percent, and 65 percent of the population considers turbines solely. This research takes the turbine perspective, as the review revealed that a common literature understanding is that the turbine perspective is generalizable across the commodities of foundations and cables. An interesting learning from the review was that less than 5 percent of the journal articles considered pre-assembly, installation, and commissioning together. Another interesting finding was the absence of literature expanding the knowledge of wind turbine production or manufacturing planning. Alla et al. (2013) wanted to reduce the vessel cost considering the complete construction phase of cables, foundations and turbines, isolating the pre-assembly harbor activities as a warehouse with constant delivery of components to the vessels. Ursavas (2017) took a similarly broad perspective, considering the availability of structures as constraints but without incorporating the harbor processes as such. Barlow et al. (2018) based their model on Barlow et al. (2015), both considering pre-assembly activities as a part of the installation phase, but as high-level sub process only. To sum up, literature has considered pre-assembly, installation, and commissioning both individually and together. Pre-assembly has been determined as a warehouse or a constraint solely providing loading capacity for the vessels without considering the activities. This research will reveal the importance and complexities of pre-assembly from a process perspective.

As both the construction and the production community, the offshore wind community is considered part of the operations management domain. To develop the understanding of the offshore wind projects, it was necessary to narrow the research field and focus on the aspects or phases within offshore wind projects. To understand the individual production systems with similarities and variables, has been considered important within both construction and production. For production this was addressed by Schmenner (1993) with process-product relations. Hopp and Spearman (2001) later expanded this, focusing on its physics and variables, as this would equip practitioners and researchers with a common language. Gann (1996) showed that the greatest similarities between construction and production are found when comparing modular unit housing with car manufacturing. Still Ballard and Howell (1998b) questioned what categorized the construction production system, as also they perceived this as the initial understanding for how to control its physics. As this exercise had not previously been conducted within the offshore wind domain Lerche et al. (2019b) compared offshore wind to both construction and production.

This led to the focus on the construction phase, with its activities from pre-assembly until end of commissioning. It is recognized that this focus has limitations, as the project phases—design, production and operations—are not considered. This requires assumptions based on the contractual structure, design-built contracts as Lerche et al. (2020a) describes these. Further that production provides the installation phase with modular components, which Vis and Ursavas (2016) supports. The design will not be taken into further consideration, as the focus will be on planning. McNamara (1983) expanded on the productivity and addressed it as a managerial problem. Figure 2 revealed that processes from a high-level perspective change characteristics between the project phases. Lerche et al. (2019b) initiated this understanding, which was then later expanded by Lerche et al. (2020a) to what is displayed in Figure 2. This shows the processes shift understanding between the activities at the port facility with a batch approach to offshore with single piece completion. Later investigations made it evident that these changes in processes and locations also affected the probable causes for delays leading to lost productivity (Lerche et al., 2019b, Lerche et al., 2020b).

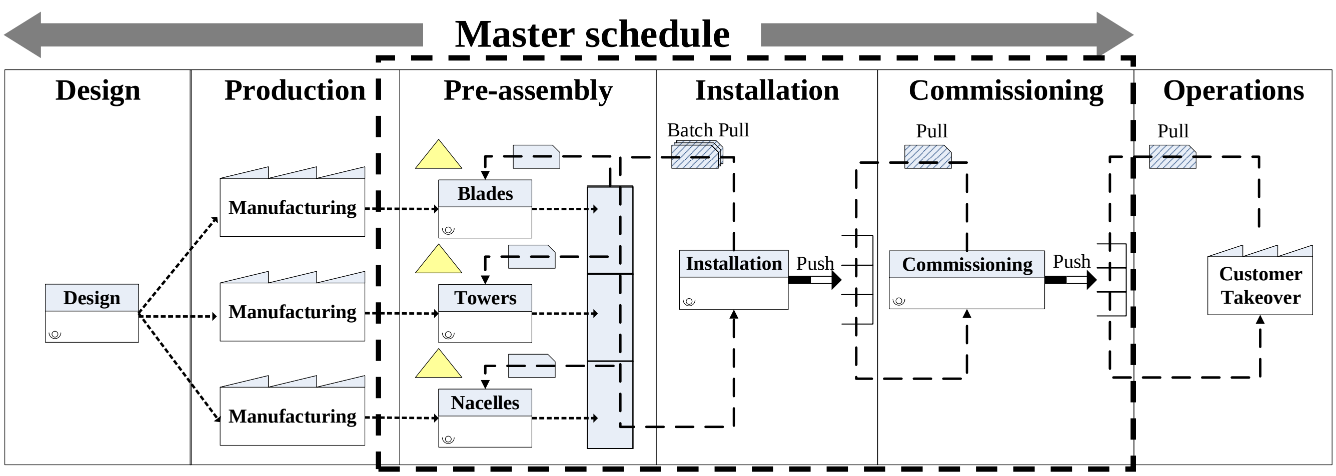

Figure 2: High-level project process map with focus area within dashed square (Lerche et al., 2020a).

Throughout the case studies (Lerche et al., 2020b, Lerche et al., 2019b), a change in processes between harbor and offshore was observed. These changing conditions for processes and locations developed the understanding of what affects productivity within the different sub parts of offshore wind project production systems. This increased the curiosity about the processes and later Lerche et al. (2019c), Lerche et al. (2020c), Lerche et al. (2020a) confirmed these observations which are elaborated in Chapter 4 and 5. Chapter 4 will illustrate the current inconsistency in aspects considered from offshore wind planning perspective. As Lerche et al. (2020b) investigated the variables resulting in lost productivity and developed a network diagram of failure modes from four different cases. These findings revealed planning as a major contributor to lost productivity for installation and commissioning. From a construction perspective Ganesan (1984), emphasized the planning and design as the most critical decisions regarding resource cost of a project. Which supports the later work in Chapter 5, investigating the managerial aspects through planning method application.

Returning to the managerial perspective for increasing productivity, both production and construction agrees that planning resource utilization is crucial. For planning and optimizing the offshore wind projects, the critical path method (CPM) has been the dominant approach, which the literature trend graph in Chapter 3 will further elaborate. Another thing surfacing from the literature review was that the majority of the papers consider vessel performance. According to Sovacool et al. (2017), vessels are perceived as critical factors for offshore wind project performance and risk, and identifies vessels as the differentiating factor between offshore wind farm construction and onshore wind farm construction. But as vessel utilization and daily rates contribute to both cost and complexity, this could explain some of the attention. The construction planning of vessel utilization is considered interdependent with offshore wind overall project cost. E.g. Alla et al. (2013) developed a mathematical model with fixed dependencies for construction of cabling, foundations, and turbines. Their results showed that activities are highly repetitive and affected by weather independent of the commodity. From a turbine developer perspective, Barlow et al. (2017), Barlow et al. (2018) showed models for optimizing vessels and the construction phase. Assuming that the process have fixed durations affected by predetermined variables and weather windows. Ursavas (2017) took a similar approach and verified their model at two North Sea wind farm projects. This models showed different entities in the wind farm projects, which have similar process constraints and identical layout constraints, Irawan et al. (2017c) confirmed this. The literature review made it evident that there is inconsistency between the assumptions and planning aspects considered (Lerche et al., 2020b). As mathematical analysis is currently the dominant practice for planning verification, the field studies Lerche et al. (2020c), Lerche et al. (2020a) opposed this common practice. Lerche et al. (2019c) adapted a third planning methods and evaluated through an analytical study. The thesis with its operation managerial perspective from inside the industry and outward was novel for planning within the offshore wind community.

1.1 Objective

As this PhD project is a constellation between an industry partner and academic institution, it has had a focus on being relevant to both. From the industry perspective relevance is measured in time reductions during execution and construction. From the academic perspective relevance was measured in contributions to the body of knowledge for offshore wind within the operations management domain. The aim was to establish a baseline for the offshore wind project production system: to understand its process dynamics and investigate if alternative planning methods would be applicable, effect of this measured in time. The analyses in this study are based on data collected sequentially. 1) Exploratory field studies during 2017, visiting four independent offshore wind project sites, which represented 32 percent of the global installed capacity this year. This led to understanding of the offshore wind production system and its reasons for lost productivity. 2) Developing system-specific improvements as artefacts in cooperation with different project teams at two independent offshore wind projects. Longitudinal field studies were organized to evaluate these artefacts during 2018 in the offshore wind construction environment. Finally, the findings were interpreted, compared and presented here. Last an opportunity to transfer knowledge to the offshore oil and gas domain was pursued.

1.2 Theoretical background

The explanations, predictions and directions have been developed through understanding past managerial concepts and principles, guiding the understanding through this research.

Defining the production system perspective:

A production system is an organism of inputs and outputs that are transformed through multiple processes, generating value for a customer.

To understand the production system, the Transformation-Flow-Value (TFV) theory by Koskela (2000) provided a way to perceive its compositions from a conceptual perspective. Transformation is related to the inputs-outputs of resources to an activity. Where flow could be perceived as transformations or activities moving through time and space in order to generate value for a customer. Product or commodity cost, price set by the provider, leading to value measured subjectively by individual receiving customers in the value stream. The value propositions will not be further pursued through this thesis.

Defining the productivity perspective:

The measurable relationship between outputs over inputs per defined transformation.

Here productivity was perceived as the relation between time planned over time added. Labor productivity was by Taylor (1911) defined as relation between input and output in activities, standardizing these to reduce the individual energy consumptions and thereby increasing output. From a construction perspective Neve et al. (2020) revealed the relation between direct work and labor productivity. Emphasising the importance of increasing direct work by hindering flow obstructions or increasing labor productivity in each transformation.

Defining the managerial perspective:

A way for managers to understand their reality, motivating their employees, providing direction, evaluating performance and making decisions.

Some of the general principles of management captured in that sentence are described by Fayol (1949), focusing on performance through organizing, planning, and controlling resources of various sorts while also addressing that managers under given circumstances have to be knowledgeable about forecasting, planning, or organizing activities. Whereas Taylor (1911) had a perspective on measurable performance on the production line, these principles developed the understanding of efficiency and productivity through standardization, but with little trust in the workers. MacGregor (1960) perceived this as conventional management, categorizing workers' lack of interest and motivation to work as theory X. He then developed theory Y, where workers are individuals who have needs and motivational factors that affect their performance.

Defining the constraints perspective:

Measurable delays that affect activity time and project durations.

Time from the project triangle (Atkinson (1999), Kerzner and Kerzner (2017) contributed to this in combination with capacity constraints from Goldratt's (1999) theory of constraints. The capacity constraints affect both the conceptual and managerial perspectives. For further categorization these will be addressed as equipment, location, flow, or transformation constraints. These are also known as waste, constraints, or bottlenecks (Koskela, 2000b, Goldratt, 1999, Ohno, 1988).

2. Research Approach

The following section will introduce the research approach for the thesis and briefly introduce how the papers are related and from what the structure was inspired. Goldratt (1999) argued for understanding classifications, correlations, and further causes and effects to threat the roots and not the symptoms. This could be perceived an approach to develop the understanding of the environment as described by Simon (1996). Based on the previous discussion, the research problem for this thesis is formulated as follows:

What alternative approaches would increase productivity in offshore wind projects?

The broad problem is then broken into three interrelated questions:

Q1: What defines the offshore wind project production system?

Q2: Why is productivity lost in offshore wind construction?

Q3: How could offshore wind construction productivity be improved?

The papers correlate to the research questions in the following order. Q1 is answered through Lerche et al. (2019b), where Q2 is answered through Lerche et al. (2020b) and further expanded through Lerche et al. (2020a) data collection. Q3 is answered through Lerche et al. (2020c), Lerche et al. (2019c) and Lerche et al. (2020a).

2.1 Epistemology

The initial phase takes the constructivism worldview, predetermining the systems' relation to well-established phenomena within the operations management domain. Different philosophical descriptions from each phenomenon's production, management, and construction will be influential to the offshore wind field. Constructivism is what Kuhn (1962) describes as "normal science" developing understanding of the phenomenon of offshore wind construction through comparison with conceptual, principle, and methodological layers. These being found in alternative research fields and domains, recognizing the novelty in the offshore wind domain. The initial thoughts led to Lerche et al. (2019b) questioning what paradigm had most similarities to that of offshore wind projects. They investigated the causations for delays, acknowledging Rosenthal and Rosnow (1991) and that cause-effect patterns from the investigation would be defined as probable causations for the production system failure modes and delays. Inputs were retrieved from multiple sources, constructing understanding of the causations in the identified patterns and comparing results across multiple cases and other philosophical standpoints (Lerche et al., 2020b). This developed the offshore wind environment understanding of its objects, rules and natural laws existing here, with the objective of investigating dynamics. Continuing with questioning how these objects could be controlled by applying known planning and control methods. The application of these known theories and methods in the offshore construction environment led to a switch in paradigm, moving from a belief that truth could be found toward an understanding that utility could be generated and how it would work in this new context (Lerche et al., 2019c, Lerche et al., 2020c, Lerche et al., 2020a).

Changing from the constructivism viewpoint toward a pragmatic viewpoint as co-development and collaboration became a necessity to ensure utilization and relevance. The initial constructive investigations developed the understanding of the environment. From a pragmatic paradigm, Simon (1996) argued for the environment being the "mold" for the artefacts, which are man-made, recognizing the necessity of understanding the objects, phenomena, and embedded natural laws—but also understanding that natural laws cannot be ignored or violated.

2.2 Research designs

A mixed-methods research design combining quantitative and qualitative data sources was inspired by Creswell and Plano Clark (2018). Following the exploratory sequential by obtaining qualitative data first before following up with quantitative data sampling. Lerche et al. (2019b), Lerche et al. (2020b) applied this as the dominant design while investigating the production system and its objects, rules, and laws. While taking the pragmatic worldview, the research design was changed to design science inspired by Hevner et al. (2004), using mixed methods for evaluation (Lerche et al., 2019c, Lerche et al., 2020c, Lerche et al., 2020a). The evaluations were both field study implementations and analytical investigation of the artefact utility within the offshore construction domain.

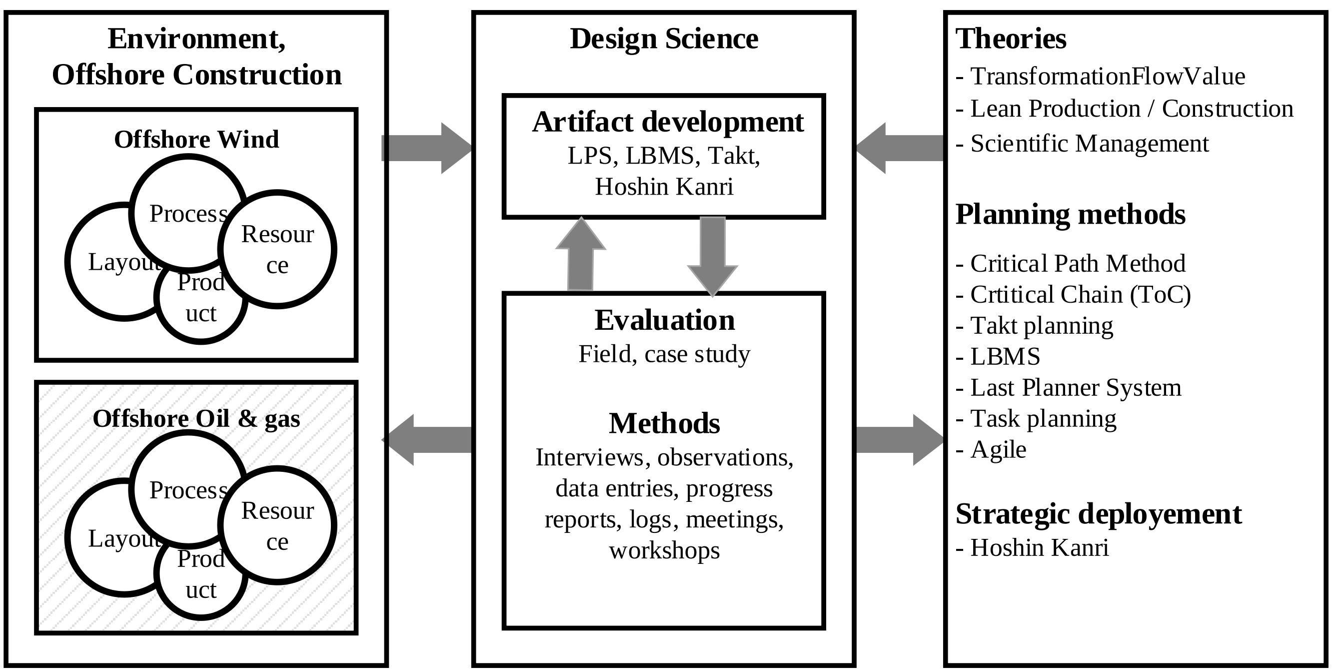

Figure 3: Model for application and evaluation, inspired by Hevner et al. (2004).

Figure 3 illustrates the design science model that was fundamental for the research conducted with a pragmatic worldview. The environments were the offshore construction industries, the primary focus was the wind turbine construction domain. The oil and gas domain was explored due to opportunity and increasing the diversity in understanding. The artefacts in Figure 3 not segregated even though each individual artefact (Lerche et al., 2019c, Lerche et al., 2020c, Lerche et al., 2020a) were during the development and evaluations. Developing on past experiences and learnings build and tested known theories in this alternative environment context, contributing to the literature through relevance.

2.3 Methods

Each paper contributing to this thesis contains a thorough method section, describing how literature was reviewed and how data collection with analysis was conducted. Inconsiderate of the paradigm shifts, the data-generating method involved case studies inspired by Yin (1994), Yin (2014), Voss et al. (2002). It took an exploratory approach from qualitative data and verified through quantitative data to generate a production system comparison. Lerche et al. (2019b) investigated through multiple cases, recognizing the perspective of Eisenhardt and Graebner (2007). Lerche et al. (2020b) had a similar approach to determine failure modes through comparison. Through quantitative data patterns and enriched with qualitative data to understand how these patterns were correlated. The single-case investigations Lerche et al. (2019c), Leth et al. (2019), Lerche et al. (2020a), Lerche et al. (2020c) were supported by the perspective of Flyvbjerg (2006). Who recognized that a single case be generalizable through case selection, data triangulation and a rigorous design. Identical for both types of case studies was the effort to ensure rigor through design and data collection. Based on Yin (1994) and encouraged by Gibbert et al. (2008), there was a focus on constructed, internal, and external validity, besides the reliability. In particular, data triangulation, through workshops with industry experts, interviews, entered data (daily logs, protocols, summaries) and longitudinal observations, made this possible.

3. Offshore Wind Project Production System

For a production system to move from its novel and immature stage into a more mature phase has been equal to a categorization within operations management. Taylor (1911) developed the principles for scientific management, furthering the understanding of how transformation develops resources from one stage into a new stage. These principles deepened the understanding of standardized work and assembly line production. Fayol (1949) addresses production assembly as technical understanding and planning as managerial understanding. Emphasizing that unity of command cannot exist without unity of direction. This supports that activities and processes require a formalized plan but separates technical from managerial activities. The thesis takes Koskela (2000) TFV perspectives for the categorization of the offshore wind production system during construction of the wind farm. Later, expanding on the process perspective leads the further investigation, contributing to the understanding of process planning and control. The following section will develop the understanding of the offshore wind project production system from these perspectives, answering the question *"what defines the offshore wind project production system?"*.

3.1 Categorization

This section will first compare offshore wind with manufacturing and construction. Schmenner (1993), Hopp and Spearman (2001) argued for the importance of categorizing a production system, understanding its objects and variables, and determining dependencies between activities. Categorization of the phenomenon requires understanding its physics. Schmenner (1993) provided a process-product matrix (Figure 4), which Ballard and Howell (1998a) applied to understand how construction differentiated from production. Koskela (2000) supported these perspectives by formalizing a conceptual way to perceive a production system. Lerche et al. (2019b) developed the understanding of the offshore wind production system in comparison with manufacturing and construction; the elements compared were process, product, layout, and resources. Figure 4 displays the product from utilizing TFV as the data was viewed objectively, then from a transformation and flow perspective. Recognizing how the “value” perspective would be a matter of subjective opinions, this has not been evaluated. The products are standard, produced in medium volumes, assembled by temporary resources, at layouts changing from temporary harbor areas (Irawan et al. (2017c) to final fixed locations offshore. But where these three elements of the production system revealed that the product could be compared to production, the setting and resources would be operating as within the construction domain (Lerche et al., 2019b). The environment description of Lerche et al. (2020a) validated these arguments. Further, it expanded the knowledge about the offshore wind project production, as it was found to be comparable with modular construction (Figure 4).

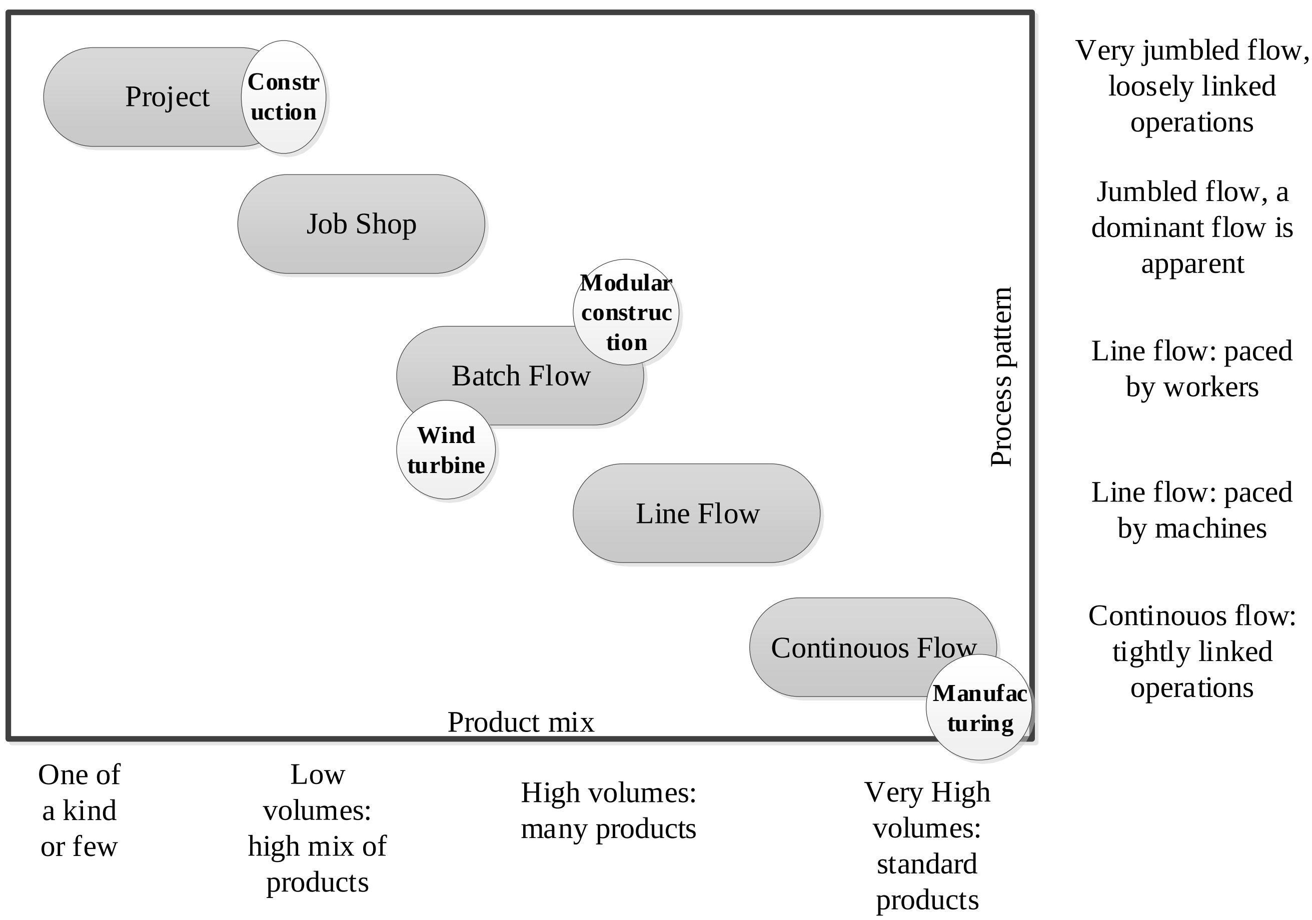

Figure 4: Comparing modular offshore wind construction with manufacturing and construction, modified from (Lerche et al., 2019b).

3.2 Categorization from an alternative perspective

Nam and Tatum (1988) presented the construction characteristics from an alternative perspective: “immobility,” “complexity,” “durability,” “costliness,” and “social responsibility,” which will be discussed below. As the mobility of large ships was an example of what segregated them from construction, this could also be the case for wind turbines when considering floating turbines (Castro-Santos et al., 2018). Seen from a complexity perspective, the wind turbine modules seems more like manufacturing than construction, which Schmenner (1993) matrix agrees with. Lerche et al. (2020a) recognized similarities with modular construction where large pieces are assembled, as Peltokorpi et al. (2018), Choi et al. (2019) describe it. From an offshore operations perspective, Petersen et al. (2016) also identified offshore wind projects modular compositions. Regarding durability, offshore wind resists the forces of nature similar to a high-rise construction (Sacks and Goldin, 2007), but turbines have 20–25 year lifespan, which is perceived less than buildings. Some might argue for it to have similar processes to what Arditi et al. (2002), Sacks and Partouche (2010) describes for high-rise buildings. But the high-rise building process does not have to change between locations, which are spread over a large geographical area offshore. Furthermore, Sacks and Partouche (2010) elaborates common practice with high-rise buildings and it is not to install the individual floors in singular pieces. The durability and complexity brings us to costliness, which Nam and Tatum (1988) argue to be related to design and resource, comparable to vessel cost from offshore wind (Heptonstall et al., 2012). Aspects of social responsibility would be considered similar: specialization of the work force, for one, as both the construction industry and the wind industry require trades trained in certain activities (Lerche et al., 2020a). But it’s also worth mentioning purpose-built vessels and equipment utilized for offshore wind construction and operations (Barlow et al., 2014a, Dalgic et al., 2015b, Zhao et al., 2018, Paterson et al., 2018). The characteristics presented here support the results from Lerche et al. (2019b), that offshore wind project production is a hybrid of production and construction. Lerche et al. (2020a) validate this, but also expand on the products as modules that are sequentially assembled. This allows repetitive activities as seen in manufacturing (Liker and Meier, 2006, Hopp and Spearman, 2001). The complexities, durability, and social responsibilities, though, support that the operational settings are similar to construction. Lerche et al. (2019b) categorized and defined the characteristics. This guided the further investigation of the processes, developing the understanding of how these are planned and controlled in comparison to other parts of the operations management domain.

3.3 Process perspective

The following sub-section compares the relevant process planning methods reported in journal articles from 1984 to 2019 within the operations management (OM) domain. Including but not limited to manufacturing, construction, and offshore wind. This was to understand the unity of command and direction for transformations in OM and specifically the offshore wind production system. During the application studies by Lerche et al. (2019c), Lerche et al. (2020c), Lerche et al. (2020a), the planning and control methods from the offshore wind academic community have been addressed, elaborated, and discussed. Figure 5 displays the following planning methods: “agile,” “critical chain,” “critical path method (CPM),” “Last Planner System (LPS),” “Location-Based Management System (LBMS),” “Takt,” and “task” planning, which Bølviken et al. (2015) also compared for construction utilization. The literature review made it evident that the CPM has been dominant within offshore wind, which is illustrated in Figure 5. Furthermore, Lerche et al. (2019c), Lerche et al. (2020c), Lerche et al. (2020a) made comparisons to the individual cases’ original CPM construction schedules.

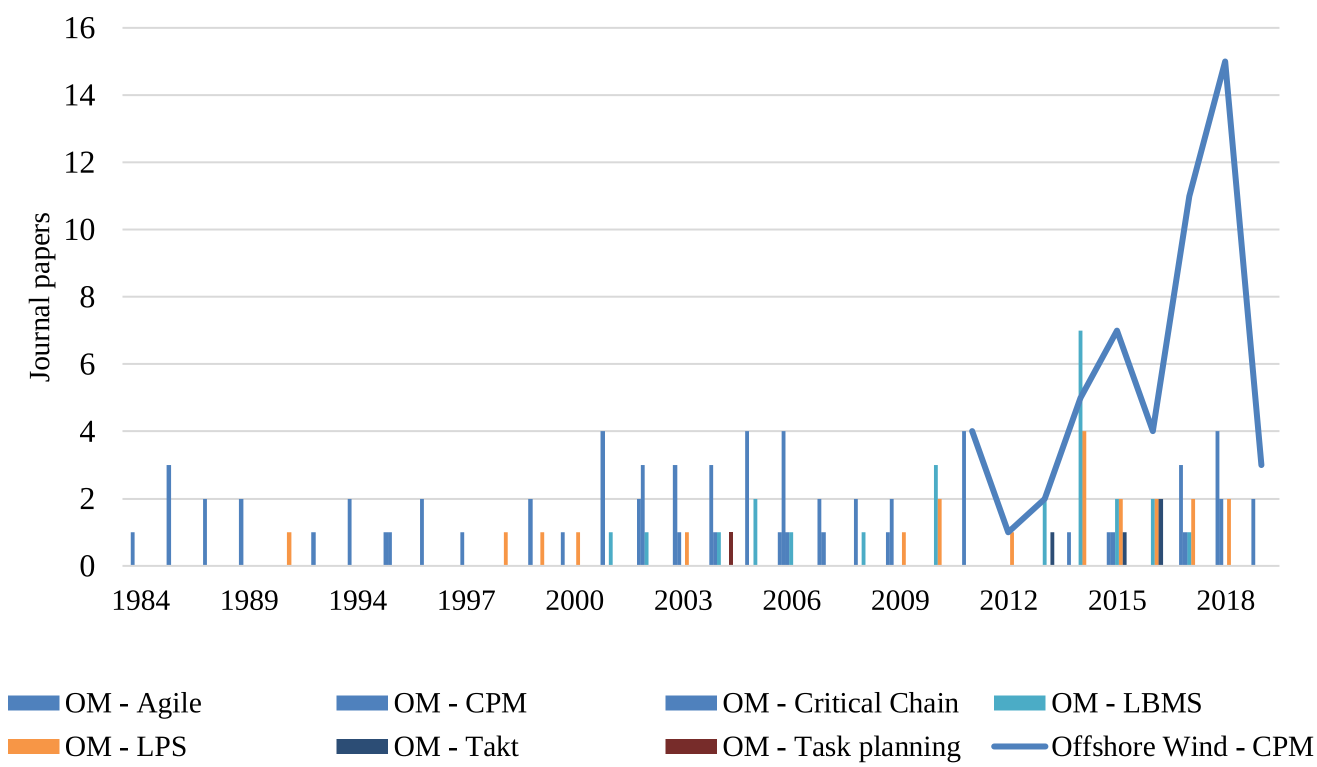

Figure 5: Comparing planning literature trends in OM with offshore wind.

3.4 Process planning

Within the construction domain, CPM has been subject to criticism from multiple perspectives. Perspectives presented are related to the planning of activities and resources. Critical path activities are centrally planned, predetermined, and sequenced by given dates. Durations have fixed predecessors and successors relations, which categorizes it as push planning (Hopp and Spearman, 2004). Lerche et al. (2020a) summarized especially the limitations of predetermined activities and restricted response to constraints. Chua and Shen (2005) acknowledge this and that productivity increases through solving constraints and reducing bottlenecks, which CPM does not accommodate. Theory of constraint (Goldratt, 1999) and critical chain (Goldratt, 1997) especially took a constraint perspective, focusing on resource constraints and applying resource and project buffering instead of individual activity buffering, thereby reduced overall project durations. But as Koskela et al. (2010) point out, critical chain is still a centralized push mode of management in comparison to LPS, for instance (Ballard, 2000). This is a decentralized mode of management relying on the social interaction and commitments between actors. Another thing with CPM is that it lacks the ability to dynamically respond to uncertainties in the production. From a LBMS perspective, Kenley and Seppänen (2010) addressed this as lack of rhythm and continuous production in the schedules. From a pull perspective in construction it has particularly been criticized for its distance to actual execution and dynamics of the work (Ballard, 2000). Where from a production perspective Takt is seen as an alternative, this method sought to reduce the duration and resource variety (Hopp and Spearman, 2004). Returning to the resources in a CPM schedule, Olivieri et al. (2018) argued that such would follow the critical path activities and non-critical activity related resources would be smoothened according to float in the schedule. LBMS and CPM resource leveling could be considered similar, but CPM would not adjust to all non-critical and critical activities. In contrast, LPS focuses on shielding the production (Ballard and Howell, 1994, Ballard and Howell, 1998a) through workflow stability. As look-ahead and week plans ensure preconditions are prepared before production starts (Ballard and Howell, 1998a, Koskela, 2000b, Koskela, 2004). Chapter 5 in this thesis will further elaborate on planning and control, by utilizing Takt, LBMS, and LPS in offshore wind project production (Lerche et al., 2019c, Lerche et al., 2020c, Lerche et al., 2020a).

It was evident from the offshore wind literature that the majority of the CPM schedules for offshore wind projects were developed for estimation and forecasting purposes. Chapter 4 will expand on this, investigating the different planning aspects considered while generating project outcome estimations, calculating productivity, and utilizing resources.

4. Lost Productivity Within Offshore Wind

From a CPM perspective, activity delay or failure would be measured in time. To protect the project schedule, time is added to the duration of each individual activity and handled as assumptions or variables while calculations predict or forecast outcomes. Within the production domain, Ohno (1988) addressed it as waste when a transformation was obstructed. Within the construction domain, Koskela (2000), Koskela (1999) addressed flow-delaying factors as preconditions. The question addressed in this section is *"why is productivity lost in offshore wind construction?"*

4.1 Planning aspects

While investigating offshore wind planning literature, the constraints, obstacles, and considerations in this field revealed a dominant outside-in perspective. But it also revealed that waste or preconditions for the offshore wind project production had not previously been investigated. Figure 6 illustrates the factors that have been considered delaying factors for offshore wind farm construction schedules and models. Figure 6 reveals that the lines for "weather periods" have been considered throughout the reviewed period and wind or waves separately first occurred in 2014. Lerche et al. (2020b) and Figure 6 reveal the lack of consistency among the variables, which leads to activity or project delays.

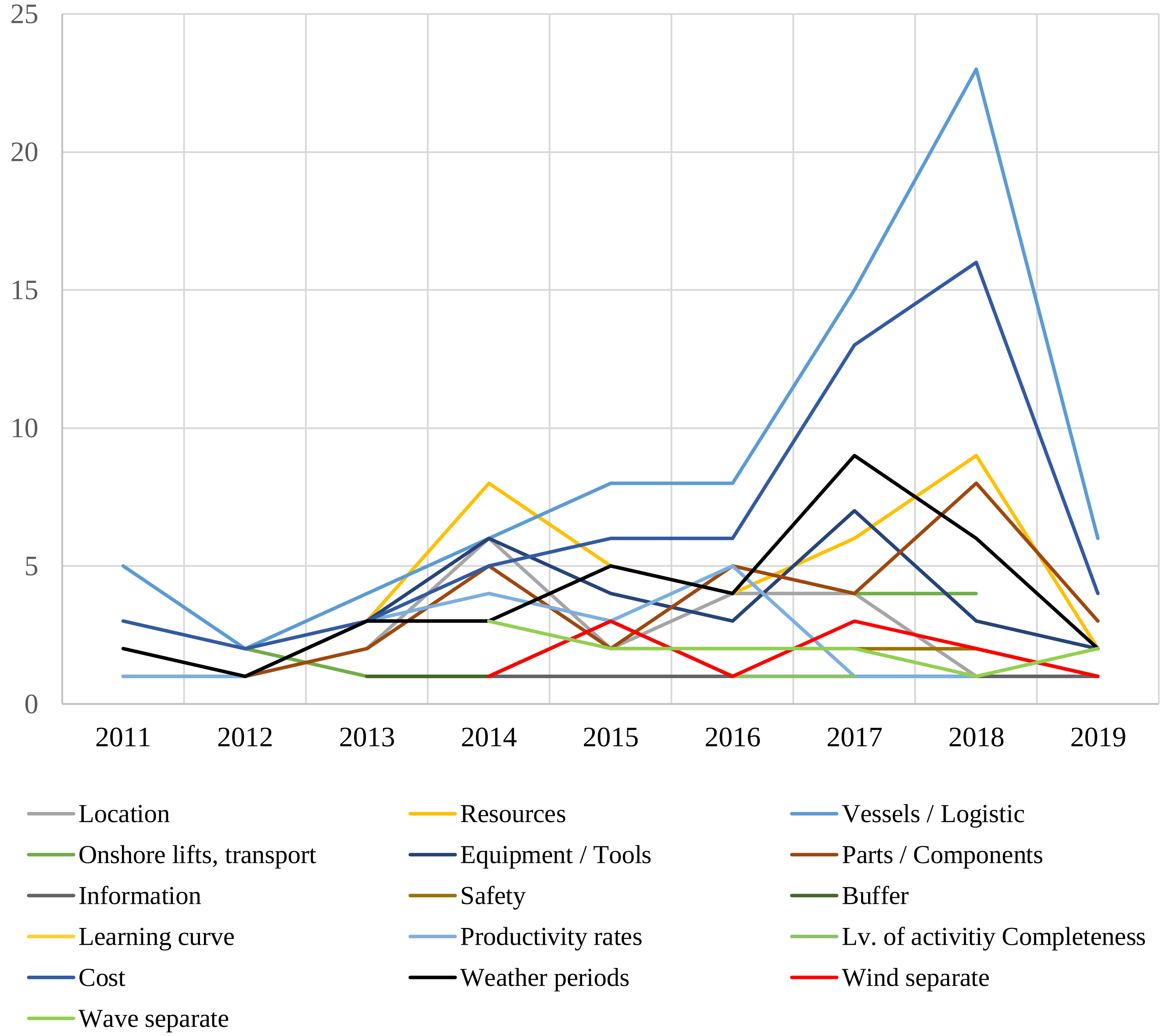

Figure 6: Trends for failure aspects considered in the literature (Lerche et al., 2020b).

The failure trends in Figure 6 illustrate different aspects. The majority of the journal articles considered vessels/logistics and weather as their main failure modes or reasons for delays when planning. The increased interest in vessels and logistics could be considered to follow the increasing industry interest and development reported by Rodrigues et al. (2015), Enevoldsen and Xydis (2019).

4.2 Offshore wind project delays

Lerche et al. (2020b) investigated data patterns for delays in four individual projects executed in different European countries. These patterns revealed a shift between shore and offshore positioned activities, expanding the potential failure modes related to the offshore locations. Figure 7 illustrates probable causations for production delays in a cross-case comparison. Cases 1–4 in Figure 6 represent Lerche et al. (2020b) findings and the “planning” failures where all failures related to the task; for Case 5 these were segregated individually. Case 5 presents findings from Lerche et al. (2020a) where the LPS principles followed the preconditions and therefore certain failure modes were adjusted by the project team. To benchmark Cases 1–4 with 5 in Figure 7 required that Case 5 installation and commissioning failures were combined in an offshore category.

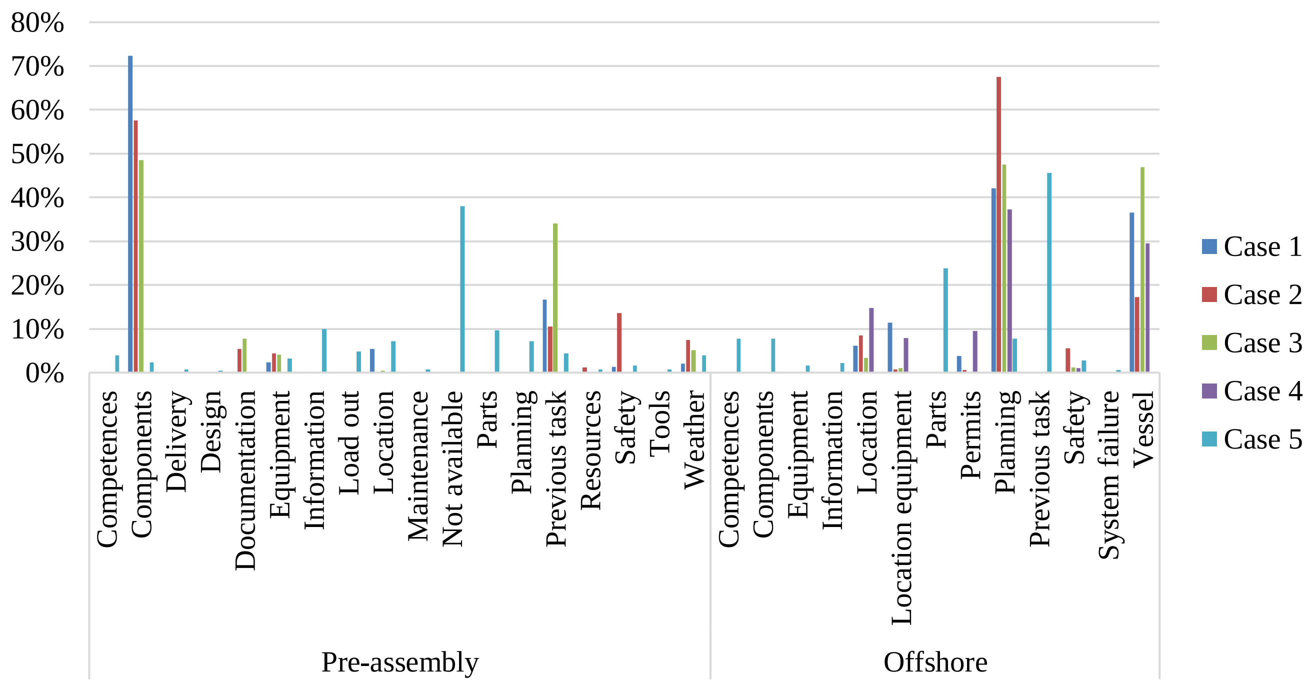

Figure 7: Comparison of probable occurred causations (Lerche et al., 2020b, Lerche et al., 2020a).

The failure mode differences in Figure 7 are recognized as sub-categories, contributing to the logical networks presented in Lerche et al. (2020b). These differences in failure mode categories for pre-assembly were "competences," "delivery," "design," "loadout," "maintenance," and "not available." Case 5 showed that loadout delayed the pre-assembly activities, which could also be considered another dependency to the location category from Cases 1–4. Further, "not available" differences in Case 5 were categorized according to failure descriptions. The logical network presented in Lerche et al. (2020b) was validated through the empirical data from Case 5. As the categories from Figure 7 were sorted, this led to the visualization in Figure 8. As earlier addressed, the offshore failures categories in Cases 1–4 related to the task were solely sorted into "planning". The data set from Lerche et al. (2020a) supported this, and Figure 8 reveals that Case 5 failure segregation led to expansion of the knowledge about how the offshore failure modes are distributed.

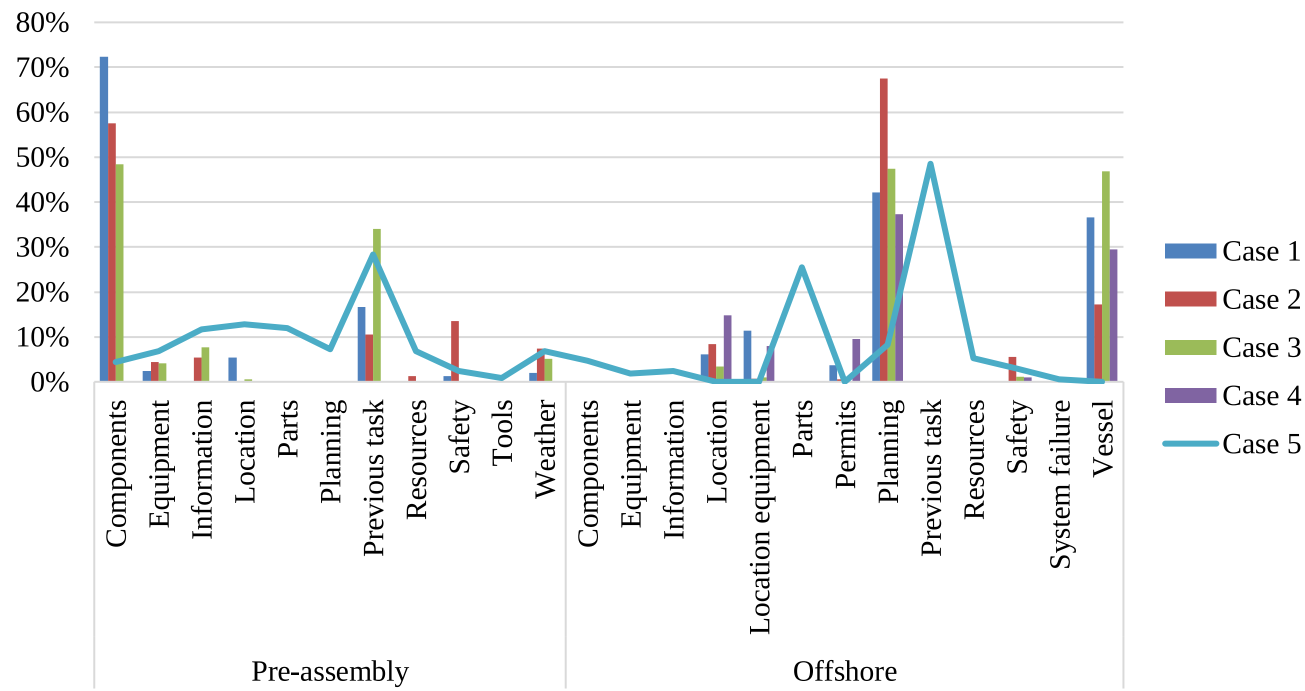

Figure 8: Distributed percentages of occurred causations for offshore wind project delays.

The overall case 1-4 data in Figure 8 illustrates large peaks in occurrences with components for pre-assembly and planning for offshore. For case 1-4 to 5 pre-assembly experienced a shift from "components" to "previous task" in number of occurrences, they registered with an alternative perception of upstream production. From a planning perspective, “component” and “vessel capabilities” are required inputs for the transformation, but outside scope for this thesis, whereas the planning perspective is the main issue for the offshore phases supported the further investigation in the following chapter.

4.3 Offshore wind project delays: “waste” or “preconditions”?

The empirical data also rejects a common understanding of weather as single or main reason for lost production or delays in offshore wind. However, with the vessel category offshore, it is recognized that weather capabilities are important factors. It also addresses that offshore wind construction lost production has more similarities with preconditions seen from a flow perspective than with waste from a transformational perspective. Lerche et al. (2020b) presented the logical networks that provided understanding of offshore wind project delays and later discussed these findings in relation to both waste and preconditions. In relation to waste as presented by Ohno (1988), Lerche et al. (2020b) find the results to be compatible to a limited extent. For pre-assembly, the pre-conditions were found to be similar to what Lindhard and Wandahl (2014) describe as reasons for construction delays. Table 1 displays these findings and how the preconditions for offshore construction related to either the task or the location. This segregation between task and location for offshore activities contributes to both the knowledge of preconditions and the understanding of what causes project delays in offshore wind. It could be argued that the offshore location-dependent preconditions are an extension of Lindhard and Wandahl (2014) “surrounding conditions.”

(Koskela, 2000) Preconditions construction	(Lindhard, 2014, Lindhard and Wandahl, 2012) Reasons for delays in construction (Pre-assembly)	Reasons for delays at offshore construction (Installation and commissioning)	Related to task	Related to location
1. Construction design	1. Construction design	1. Documentation	x	
2. Components & materials	2. Components & materials	2. Components & materials	x	
3. Workers	3. Workers	3. Resources	x	
4. Equipment	4. Equipment & machinery	4. Equipment & machinery	x	
5. Space	5. Space	5. Space	x	
6. Connecting works	6. Connecting works	6. Previous Task	x	
7. External conditions	7. Climate conditions	7. Permits to work	x	
	8. Safe working conditions	8. Safety	x	x
	9. Surrounding conditions	9. Vessel durability		x
		10. Location availability		x
		11. Location equipment		x
		12. Permits to access		x

Table 1: Construction pre-conditions compared to reasons for delays in offshore wind (Lerche et al., 2020b).

5. Offshore Wind Planning Applications

This chapter will describe applications of planning methods alternative to CPM, adapted for and evaluated in the offshore wind environment. As Figure 5 revealed, CPM planning is dominant in offshore wind planning, and empirical data in Section 4.2 revealed “planning” as a major contributor to lost productivity. The planning failures were related to resource management and leveling, and further individuals pointed out that plans were generated centrally but decentralized units independently had to plan according to the daily challenges. Bølviken et al. (2015) asked “*What is a good plan?*” which inspired the question answered through the following section, *“How could the offshore wind construction productivity be improved?”*

Unity of command and direction, described by Fayol (1949), still requires managerial levels to ensure that decisions are made and the direction kept. To answer the question, the process perspective has been dealt with from different methodological perspectives. The perspectives changed from central to decentralized planning positions and construction and production perspectives. Therefore, first utilization of central planning perspectives: Takt, known as a production planning perspective, and LBMS, representing a construction perspective. The last alternative, LPS, was chosen as it is a recognized decentralized construction perspective. Each individual planning method was handled as individual research projects within the offshore wind environment.

5.1 Application within offshore wind

Dividing the activities between the project phases of pre-assembly, installation, and commissioning is established practice both within the literature and in industry. The literature review made it evident that wind farm installation optimization has recently been approached from a vessel performance perspective. Also, the pre-assembly activities are perceived as an on-time process step that provides components for each vessel loadout as a modular prefab manufacturing facility (Barlow et al., 2018, Barlow et al., 2015, Alla et al., 2013, Ursavas, 2017, Irawan et al., 2018, Paterson et al., 2018, Tekle

Muhabie et al., 2018). As the turnaround time between loadouts is defined by the installation vessels, this increases uncertainty and neglects its complexities. Pre-assembly and installation are here considered one interdependent system instead of individual systems. This argument is supported by Figure 9, illustrating the process steps for the modular offshore wind construction. The backlogs represent available unstructured activities that are without hard technical dependencies for pre-assembly. Whereas the activities for installation (Figure 9) and commissioning (Figure 10) are closely attached due to hard technical dependencies. It could be argued that the sequence for installation is determined due to technical dependencies and gravity. This modular architectural understanding is what Peltokorpi et al. (2018) refer to as sectional. It is recognized, but not further elaborated how national legislations influence especially the lifting, electrical, and offshore activities.

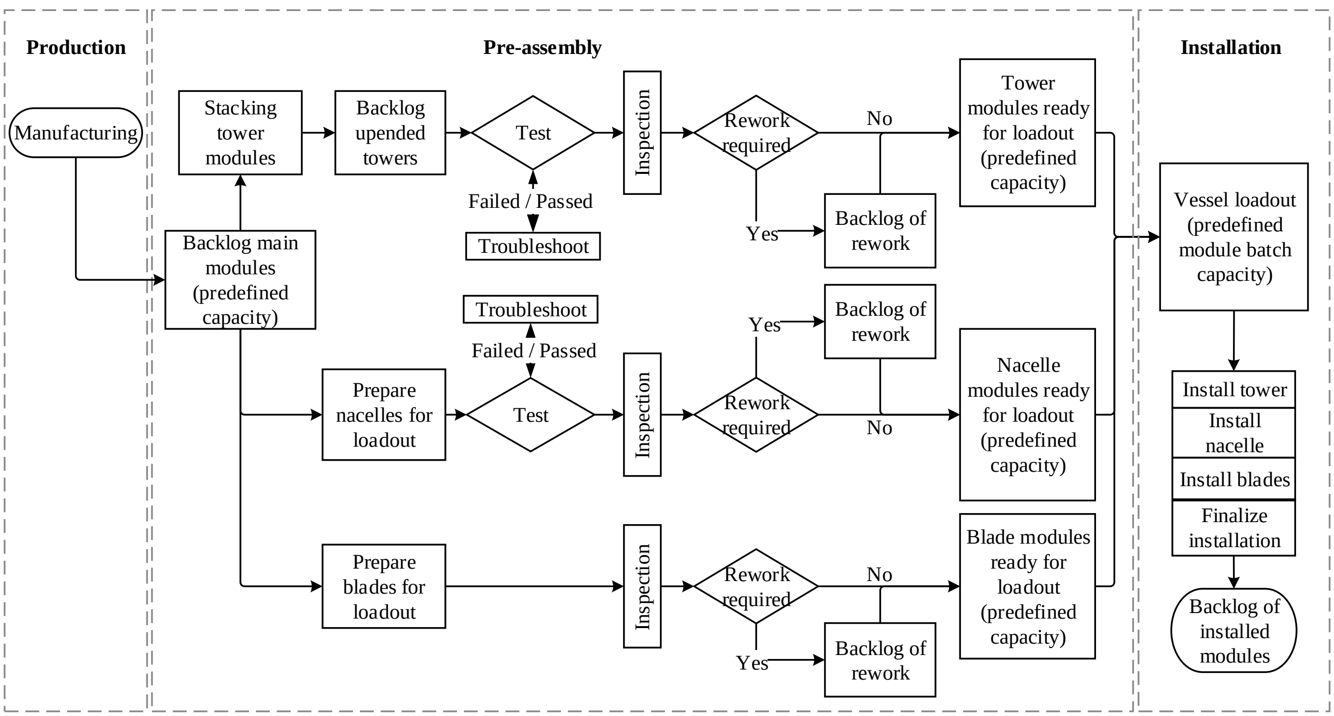

Figure 9: Pre-assembly and installation process overview (Lerche et al., 2020a).

Vis and Ursavas (2016) describe “bunny ear,” “full rotor star,” and “separate parts” as the three different types of component compositions that determine the installation processes. Figure 9 takes the perspective of what Vis and Ursavas (2016) describe as “separate parts” composition and which is similar to what Sarker and Faiz (2017) refer to as Method 4. Had it been “full rotor star” composition, the “prepare nacelle for loadout” track in Figure 9 would have been two parallel lines, one for “rotor assembly” and one for “nacelle preparation.” Besides this, the “prepare blades for loadout” would be incorporated in the “rotor assembly.” The last composition, “bunny ear,” seems less feasible, as Enevoldsen and Xydis (2019) report a significant increase in offshore wind turbine rotor diameters. Single blades today exceed 75 meters length and 30 tons of mass.

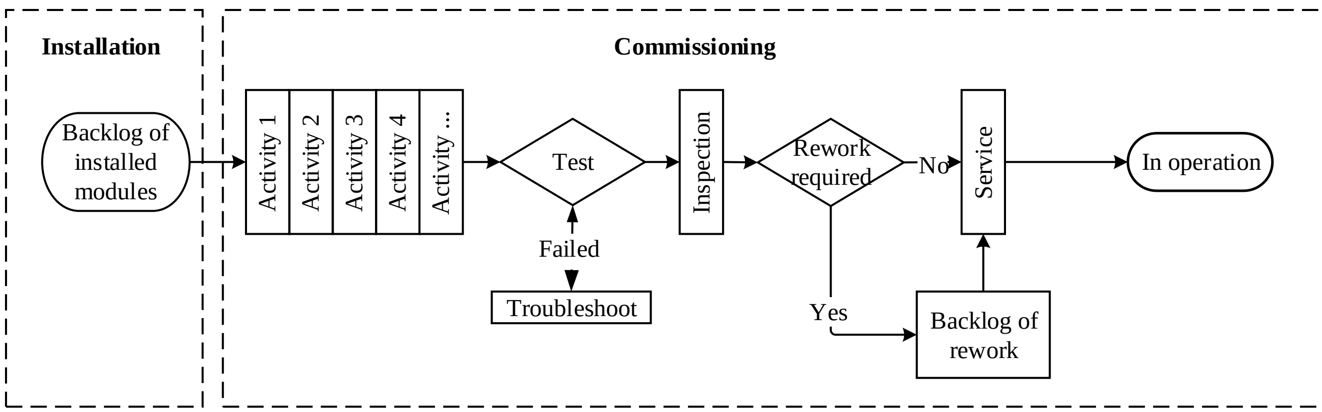

Figure 10: Commissioning process overview (Lerche et al., 2020a).

Figures 9 and 10 could be considered expansions to the models developed and applied through Barlow et al. (2015), Barlow et al. (2017), Barlow et al. (2018), as the pre-assembly and installation processes are interlinked and defined. Rework is identified as a potential outcome of the quality inspections, which requires attention prior to vessels receiving the batch of turbine modules or operations receiving the final products. In Figure 10 the technical dependencies are supported, as activities 1–5 have a predetermined sequential order. This is supported by, e.g., Barlow et al. (2018), making it evident that the CPM schedules consider the activities as either “true” or “false” in their predetermined sequences. This is inconsiderate of changes in dependencies or constraints between the activities. For example, as Vis and Ursavas (2016) consider, the installation vessel transfer actions as jacking out of the water and weather limits are dominant. An interviewee addressed during Lerche et al. (2020a) that he as captain would not consider jacking into the water if the weather was above the limits Table 2 expands the knowledge of constraints and dependencies identified in Figures 9 and 10. This will be further expanded in the section below.

5.2 Dependencies

CPM predetermines dependencies between activities by activity as Start-Start, Start-Finish, Finish-Start and Finish-Finish (Kerzner and Kerzner, 2017, Vollmann et al., 2004). The module construction transitions from soft logical sequence dependencies at pre-assembly to hard technical sequence dependencies offshore (Lerche et al., 2019b). Table 2 shows relations between task dependencies and constraints at each project that impacted the planning artefacts during utilization.

Task dependencies	Pre-assembly	Installation	Commissioning
Logical sequence (soft)	x		
Technical sequence (hard)		x	x
Location constraints	x	x	x
Resource constraints	x	x	x

Table 2: Dependencies related to project phases.

Understanding the offshore wind environment dependencies and constraints accommodated the utilization in comparison to CPM. This comparison was inspired by Tenhiälä (2011), who from a production perspective elaborates on planning methods in relation to this. Here LPS benefited from the logical sequenced activities at the pre-assembly while Takt and LBMS during installation and commissioning benefitted from the fixed technical dependencies here. The most significant difference identified was between process sequencing comparing CPM and LPS (Lerche et al., 2020a). The decentral planning required social interaction with the performing team leaders, while in central specialized planning little interaction was detected.

Utilizing LBMS (Lerche et al. (2019c) and Takt (Lerche et al. (2019c), the technical dependencies became evident as the tasks could be fixed unit wise. Lerche et al. (2020a) supported this, as offshore module construction sequencing was difficult for the project teams to incorporate in their LPS week plans. Both Takt and LBMS were enabled through the clear sequencing and the repetitive durations within each location. To mitigate the hard dependencies, Last Planner System had to be adapted for the modular offshore wind environment. The locations structure from Lerche et al. (2019c) revealed repetitive activities moving through physical locations with resource constraints, which also changed from pre-assembly to offshore. Takt required a utilization of multiskilled technicians, as the locations are less accessible, which is different from what has previously been reported within construction (Frandson and Tommelein, 2014).

5.3 Planning artefacts

This section presents the three different artefacts utilized, based on LPS, Takt, and LBMS, which was adapted for the modular offshore wind construction environment. Simon (1996) describes the adaption as the artificial being "molded" within the environment. In opposition to what Kuhn (1962) describes as "normal science," the models don't seek the truth. The purpose of the models is to be useful in the actual or similar modular construction environments and relevant to the academic community.

5.3.1 Modular offshore wind construction LPS model

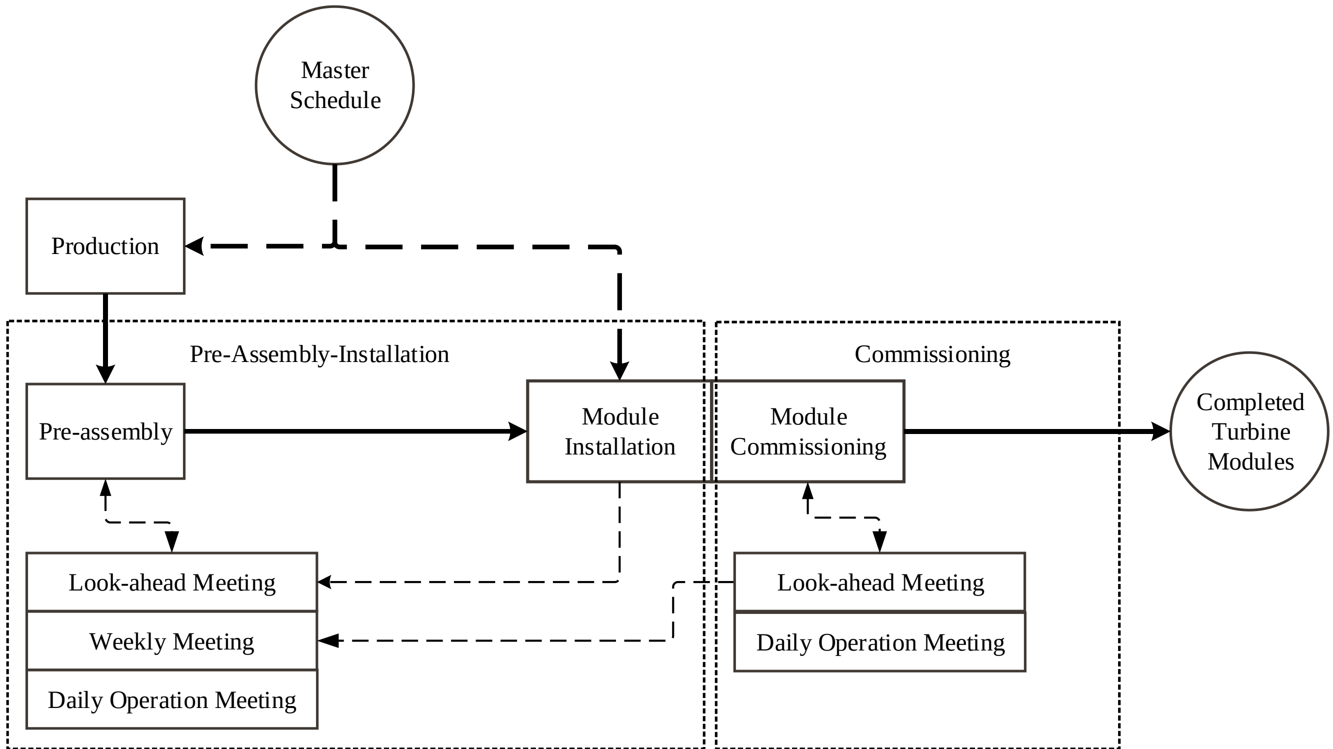

Figure 31: Modular offshore wind construction LPS model (Lerche et al., 2020a)

Figure 11 represents the model that was developed with the case team, implemented, and later evaluated by Lerche et al. (2020a). Following the approach described by Hevner et al. (2004), which is elaborated in Chapter 2 of this thesis. The master-schedule fat-dashed line in Figure 11 indicates that once the contract is signed and the installation vessel period determined, the "production" time is calculated according to amount and manufacturing pace of modules. Then the fat lines illustrate the modules' transition through the model from start of construction at "pre-assembly" to "complete turbine modules," which is when operations take over. The thin-dashed lines indicate the information flow from the construction phases and how these and the meeting structure are interlinked. The module "installation" and "commissioning" production are connected as these are required for each module to be completed. The model contributed by building on LPS theory about how to apply it for modular construction, especially the changes Lerche et al. (2020a) made to the five elements, eight functions, and twelve principles thoroughly described by (Ballard, 2000, Ballard and Tommelein, 2016).

5.3.2 Takt and Deming combined at operator level in offshore wind construction

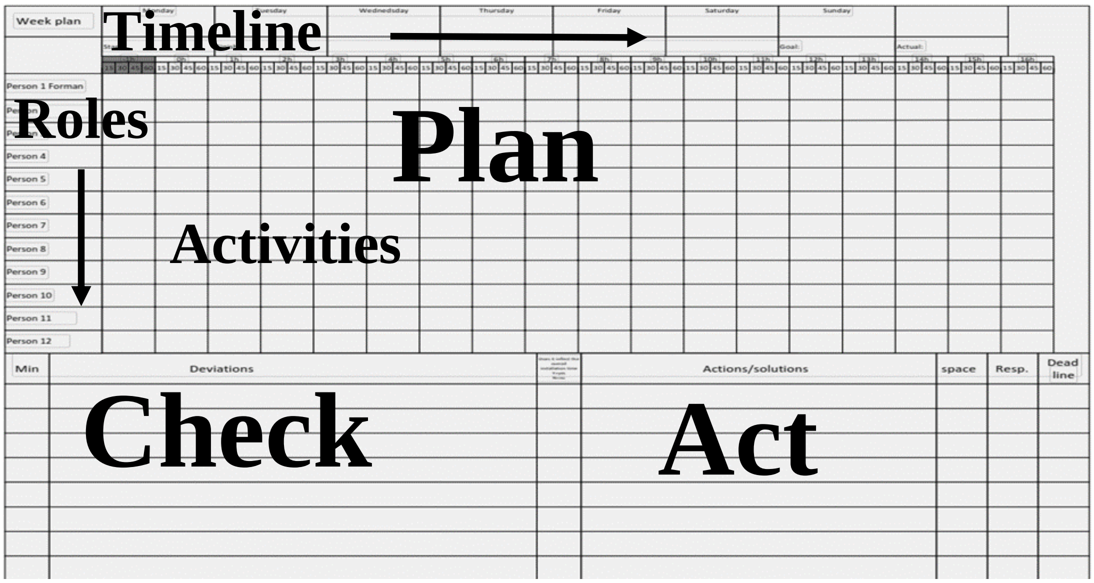

Figure 42: Offshore wind Takt and Deming model (Lerche et al., 2020c)

Figure 12 displays the visual expression of how Takt planning (Liker and Meier, 2006) and Deming cycles (Deming, 2000) were combined in Lerche et al. (2020c). As earlier addressed, the logical dependencies for pre-assembly limited the application in this part of the offshore wind construction project. This meant that the model and its visual management approach was adapted and evaluated in the installation and commissioning part of the offshore wind construction environment. Koskela et al. (2018) addressed the importance of visual management as lean production tool for reducing time for decision making. The model evaluation was conducted through a field study, revealing the potential of visual management and continuous improvements in a construction environment. The primary contribution from this research project was the combination of Takt and Deming; secondly, the visual management utilization contributes to the discussion about “why visual management.”

5.3.3 Location structure for LBMS in offshore wind construction

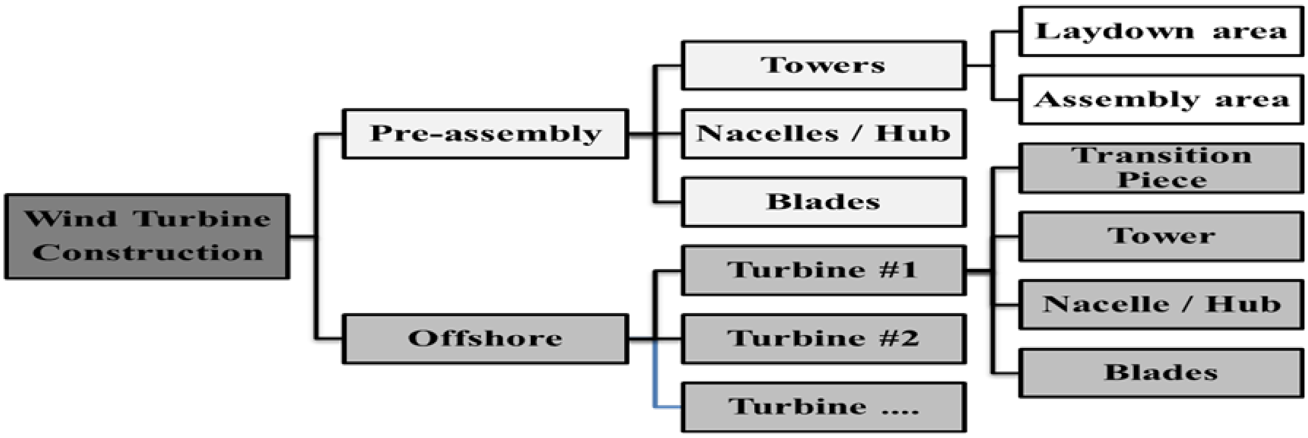

Figure 53: Location breakdown of structure in offshore wind construction (Lerche et al., 2019c).

Figure 13 displays the location structure that was applied to utilize LBMS within the offshore wind construction environment. Lerche et al. (2019c) build on the theory of LBMS explained by Kenley and Seppänen (2010) with this and tested it within the offshore wind context through an analytical case study. With this particular location structure, a loop between pre-assembly and the offshore phases was required. The analytical study revealed that it would be possible to evaluate offshore wind CPM schedules, and it further showed that location and resource constraints would be possible to identify visually. This could enable validations of, e.g., Barlow et al. (2018), Ursavas (2017), Irawan et al. (2017b) from an alternative planning perspective. Lerche et al. (2019a) support this argument as the analytical evaluation of CPM converted to LBMS within the context offshore oil and gas also required adaption of its location structure. The main contribution from this application is the location structure and CPM conversion to a LBMS schedule. Future research could investigate how offshore construction safety would be affected by an increased understanding of the location constraints.

5.4 Achieved results from utilization

The following section will provide an understanding through comparison of the artefact evaluations, which was not possible in the individual papers. As earlier mentioned, some might argue that legislations, project teams, interface design, and vessels could affect these results. Generalizability of the results might be difficult even when looking beyond each project's variables, but utilization is proven through individual system improvement. The artefact comparisons operate with different evaluation perspectives based on (Hevner et al., 2004), considering either field study with implementation or an analytical study, which was a transformation of existing plans. For both (Lerche et al., 2020c, Lerche et al., 2020a), the evaluation was conducted through field studies, where (Lerche et al., 2019c) was evaluated analytically. Table 3 compares these time reductions in percentages with the original as planned CPM schedules with P90 confidence. Both LPS and LBMS are improvements through reduction of duration on project level, combining pre-assembly with installation separate from commissioning, where the Takt improvements are lead time reductions on the individual turbine level. It is recognized that Takt generated significant improvements for individual turbines and supported the project delivery for (Lerche et al., 2020a). But the overall project impact of takt was not measurable.

<table>
<tr><th>Method</th><th>Pre-assembly</th><th>Installation</th><th>Commissioning</th></tr>
<tr><td>LPS</td><td colspan="2">25%</td><td>28%</td></tr>
<tr><td>Takt</td><td>N.A.</td><td>28%</td><td>55%</td></tr>
<tr><td>LBMS</td><td colspan="2">30%</td><td>23%</td></tr>
</table>

Table 3: Construction phase reduction in comparison to original CPM schedules (Lerche et al., 2019c, Lerche et al., 2020c, Lerche et al., 2020a).

6. Conclusions and Perspectives

The ongoing debate about reducing offshore wind projects costs reveals a necessity for bringing new considerations into the discussion about offshore wind. Understanding the production system and how to increase productivity can provide new perspective to this ongoing discussion. This research contributed to the body of knowledge within the domains of management and offshore wind. Through the categorization section, the gaps in the body of knowledge were made evident, as the pre-assembly, installation, and commissioning processes had not earlier been considered from an operational perspective. Further, the planning perspectives existing within the offshore wind domain have dominantly taken the CPM perspective, which made our alternative planning perspectives relevant to both the industry and literature.

The literature review made it evident that foundations, cabling, and turbines are generalizable as standard products, with highly repetitive activities being prepared on land and finally assembled offshore. The standard modular components are comparable to production line assembly, but the assembly processes, resources, and temporary layouts are similar to construction conditions. Overall it could be argued to have similarities with modular construction, but further research would be necessary to understand this.

One reason for lost productivity is the preconditions for offshore wind construction not being achieved. First investigation led to probable causations for lost productivity and generated a logical network. Second larger field investigation led to a verification of the initial logical diagram with minor adjustments to the sub-categories. It became evident that the patterns are applicable and could have implications for both future forecasting and planning models. Besides the implication for academia, industry would be able to prepare these categories and increase productivity as seen with LPS look-ahead processes in construction and Lerche et al. (2020a). As planning was a main reason for lost productivity offshore, this directed the further investigation in this study toward alternative planning methods. Later the implementation of LPS in offshore wind revealed a positive effect on this failure mode offshore.

Answering the question of what can make a good plan was done through evaluations in the offshore domain. The results made it evident that the three different planning methods reduced durations for both project and cycle times. The LPS and Takt implementations both required social interaction with the project teams, while the LBMS was evaluated through data analytical comparison. To fully understand the LBMS potential field evaluation and investigation of the location structure would be part of the future perspectives. An alternative future perspective would be to understand the impact of the critical chain approach in the wind domain.

The study suggests two main conclusions to the overall problem statement. First, through controlling the preconditions for the activities and preparing these at the operational level, it would be possible to increase productivity. Controlling the preconditions has been investigated in construction as method for successfully shielding the production and stabilizing the workflow (Ballard and Howell, 1998a, Ballard and Tommelein, 2016). Further research could develop the understanding of the offshore preconditions among other commodities in the offshore wind and search for generalizability in the oil and gas domain.

Second, increased productivity can also be achieved by changing planning paradigm from CPM to Takt, LPS, or LBMS. The artefact developments revealed that the methods are not applicable in their original form, which made this a contribution in terms of theory building the origin and testing these in a new domain. The improvements increased productivity, but further testing and evaluations would be required to identify whether a single method or a combination would be optimal for offshore wind projects. It is recognized that the operational perspective here had limited insight in how the political and social economies across borders affect the project performance in offshore wind. It would be useful as a future research topic, as standardization across national legislations and terms could mature the industry further. With Leth et al. (2019), Hoshin Kanri was proven applicable within a large international project from the offshore oil and gas industry. This research could potentially be expanded to understand if this would be applicable for offshore wind.

A perspective could be to validate the presented artefacts from operational managerial level within the offshore project to strategic level. This could drive further application within oil & gas, investigating Hoshin Kanri here and within the offshore wind domain. It would be interesting to understand how a combination of strategic deployment and optimized operational planning would affect the offshore projects as we know them.

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Appended Articles

Article I

Article II

Article III

Article IV

Article V