Simulation-based aggregate Installation Planning of Offshore Wind Farms

ABDERRAHIM AIT-ALLA, MORITZ QUANDT, MICHAEL LÜTJEN

Abstract**—**the offshore wind energy is considered as one of the main sources for renewable and sustainable energy for the future. In addition, it can contribute to the decrease of greenhouse gas emissions and pollution caused by fossil energy. Therefore, the construction and utilization of offshore wind farms (OWF) will increase within the next years [1]. However, during the installation process of a wind farm, the installation planning has to deal with harsh weather conditions and limited vessel availability. This makes the installation of wind farms to a complex planning problem. Furthermore the offshore installation process requires not only short-time scheduling but also medium-term planning. In general, the term of aggregate planning is characterized by its medium-term character, which ranges from months to years. This paper addresses the problem of aggregate installation planning of OWF and proposes a mathematical model in order to generate an aggregated schedule. The objective of the optimization is to minimize the total installation costs by considering different vessel types as well as constraints, like e.g. chartering costs, travel times and weather restrictions for operations.

Keywords**—**Offshore wind farm, Aggregate planning, Mixed Integer Linear Programming (MILP), Maritime Logistics.

I. INTRODUCTION

Theinstallation of offshore wind farms is far more challenging than its onshore counterpart. Higher wind speeds, waves and the salty air contribute to the harmful environment at sea that significantly reduces the accessibility of an offshore wind farm [2].

Besides the harmful environment, higher costs for foundation structures, complex logistics processes and the connection to the electricity grid lead to higher total project costs compared to an onshore wind farm project [3]. As a consequence, the cost proportion for logistics during the installation can be estimated at about 15% of the total costs of an OWT installation [4]. Therefore, optimized logistics processes can contribute significantly to the economical installation of an OWF.

Currently, most of the renewable energy is generated from wind power, as vast wind resources are available and the technology reached a high maturity [5]. As suitable areas for onshore installation of further wind energy turbines isscarce, the expansion of wind energy moves offshore. The installation of OWF is ascribed great potential, because of higher wind speeds and wind availability and the numerous areas of high wind energy potential at sea [6] [7].

At the end of 2010, a total of almost 3 GW of offshore wind power capacity had been installed in the European Union. The European Wind Energy Association expects that by 2020 offshore wind power will account for 4 to 4.2 % of Europe's energy demand with an installed capacity of 40 GW [8].

Nevertheless, there is only little research that addresses aggregate installation planning for offshore wind farms. The purpose of this paper is to develop a mathematical model to optimize the installation planning problem for OWF in which an installation plan for a medium-term planning horizon is determined with the minimal total installation costs.

This paper is organized in the following topics: Section II depicts the installation process of the offshore wind farm; Section III discusses related researches in the area of offshore and aggregate planning; Section IV formulates the problem in a mathematical model; Section V demonstrates the feasibility of this mathematical model based on various test scenarios, and finally Section VI presents concluding remarks.

II. Installation process of an offshore wind farm

An OWF project consists of a defined number of wind energy turbines that have to be installed on a suitable construction site at sea during a fixed time span. The decision for a construction site defines the type of foundation structures that have to be installed by water depth, condition of the ocean floor as well as the anticipated wind and wave loads [9]. Apart from the foundation structure an OWT usually consists of the following main components: set of piles, cable, and top structure. The piles are needed to firmly fix the foundation structure to the seabed. Number and type of piles depend on each specific foundation structure and the features of the seabed at the construction site. Therefore, in this case the piles are treated as a set which is suitable to the installed foundation structure. A cable has to be installed to connect the OWT to the electricity grid before the installation of the top structure can be started, because of technical necessity.The top structure is composed of tower, nacelle and a set of usually three rotor blades. The sequence of installation stages is illustrated in figure 1.

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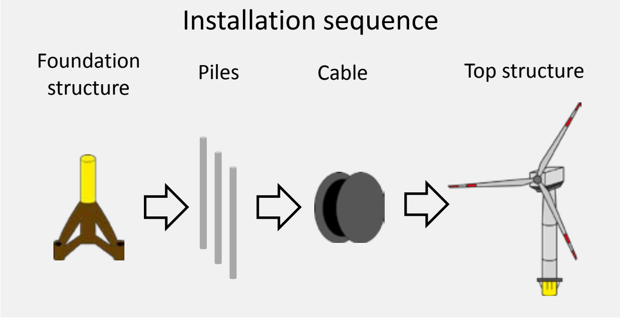

Fig. 1: Installation sequence of an OWT

During the installation process of an OWF several further requirements have to be taken into consideration. The weather conditions at sea and the dimensions of the components have to be considered when choosing a suitable installation vessel. Other factors that influence the decision for a vessel concept are ship performance, operation costs, crane performance and technical risks [8].

Therefore, several types of vessels are used, in order to meet the requirements of the installation process (see figure 2). Even these vessels show a wide variety concerning travel speed, loading capacity and crane performance that define the feasible construction stages per ship. A jack-up platform can conduct all construction stages except for transporting and installing foundation structures, due to its limited crane capacity. Furthermore, the jack-up platform has a limited mobility and travel speed, because it is not equipped with a marine engine and has to be towed by tugboats. The second vessel is a customized jack-up vessel which has sufficient crane capacity to transport and install all components.It's equipped with an own marine engine. A constraint for this vessel is the setup time needed for alternate loading of components. It takes about ten days to change the vessels setup from the load design for foundation structures to the load design for top structure components. The third vessel is a cable vessel that installs cables in order to connect the wind energy turbines to the electricity grid.

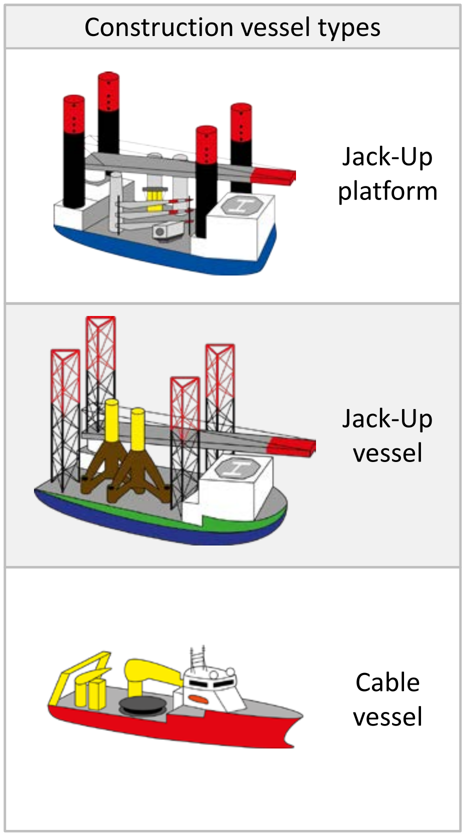

Fig. 2: Construction vessels for the installation of offshore wind farms

III. LITERATURE REVIEW

The installation process of OWFs describes a new type of multi-site construction and transport problem with respect to weather dependencies. There are several publications about installation and maintenance scheduling of offshore wind farms. Typian et al. provided a comparison study of two different mathematical methods for estimating weather downtime and operation times using the Markov Theory and Monte Carlo Simulation [10]. However this approach is limited to one offshore wind turbine and focuses on operation control. A real scheduling approach was given by Scholz-Reiter et al., who developed a heuristic for the scheduling of offshore installation processes [11]. The current weather situations as well as transport capacity limits of the installation vessel were considered. Lütjen et al. presented a further going approach for offshore scheduling, which also integrated the inventory control and supply of the installation port [11].

The problem of offshore maintenance scheduling was treated by Kovácsa et al., who developed a MILP, which constituted a module of an integrated framework for condition monitoring, diagnosis and maintenance [12]. The idea of this approach is to find the best time for maintenance operations in relation to performance of the wind turbine and the availability of the service capacities. Zhang et al. tried to minimize the overall downtime loss of an offshore wind farm due to optimal scheduling problems of preventive maintenance. For this purpose, he took weather conditions as well as the maintenance personnel, transportation, and tooling infrastructure into account. The mathematical model was solved by a genetic algorithm for an offshore wind farm with 25 turbines [13].

Apart from the wind farm business, the supply service scheduling of offshore oil installations is part of the ongoing research. Fagerholta et al. described the evaluation of various supply policies for a number of offshore oil installations in the Norwegian Sea that are serviced from an onshore depot by supply vessels [14]. The authors formulated a multi-trip vehicle routing problem (VRP) by integrating the fleet size problem (FSP). The influence of weather dependencies was not part of the research. Aas et al. developed a mixed integer linear programming model for offshore supply services that contains constraints reflecting the storage requirements problem [15]. They tested the model on real-life-sized instances based on data provided by the Norwegian oil company Statoil ASA. Christiansen et al. studied a pickup and delivery problem of bulk cargoes within given time windows [16]. Due to uncertainty of bad weather at sea and unpredictable service times in ports, they developed a scheduling approach, which creates robust schedules in order to prevent example ships from staying idle in ports during the weekend.

The offshore installation process as treated in this paper requires not only short-time scheduling but also mid-term installation planning. The general issue of mid-term planning is a well-known problem in production environments. It is called aggregate production planning (APP) problem. Aggregate production planning is often used in supply chain planning in order to modulate production capacities by preventing inventory shortages [17]. Aggregate production planning is part of a hierarchical planning approach, which uses aggregated information (product families, machine families etc.) for mid-term planning and detailed information (product units, machine units etc.) for short-term scheduling [18]. Mirzapour Al-e-hashema et al. addressed a multi-site, multi-period and multi-product aggregate production planning (APP) problem under uncertainty. It contains multiple suppliers, multiple manufacturers and multiple customers [19]. They developed a robust multi-objective mixed integer nonlinear programming model, which deals with uncertainty of cost parameters and demand fluctuations. The evaluation is done by solving an APP problem in an industrial case study.Stephan C.H. Leung et al developed a two-stage stochastic programming with resource model to determine the production loading plan with uncertain demand and parameters. The focus was on the aggregate production planning problem for perishable products. The objective was the minimization of the cost and the shortage of products [20].Paolucci et al. proposed a system which is devoted to manage the dynamic supply chain determinedby the customer demand with respect to internal and external resources, over a multi-site manufacturing network. They generated an aggregate plan taking into account the capacity of the available resources and minimizing the sum of all the cost incurred [21].

The planning and scheduling models in literature show some interesting aspects to the aggregate installation planning of offshore wind farms, but did not consider all the specific requirements. Due to different time horizons and different handling of weather stochastic, the use of existing scheduling approaches is quite complex, despite the fact that some of these approaches were developed for installation process of offshore wind farms.

IV. PROBLEM FORMULATION

In this paper, a mathematical programming model is developed to describe the aggregate installation planning problem. The goal is the minimization of total installation costs, which consists of vessels utilization costs and fixed project costs during runtime.

A. Hypothesis

The following assumptions related to the installation processes are considered by the model:

- Given an OWF of *N* wind turbines, each wind turbine consists of four installation operations. Each operation belongs to an installation sequence which can be built by an appropriated vessel type under specific weather restriction.
- The components are available at any time in the harbor.
- The components will be built in a predefined scenario, i.e. first the foundation structure, secondly the piles to fix the foundation structures firmly to the seabed, then the cable to connect the OWT to the electricity grid, and finally the installation of the top structure.
- The construction site of the OWF is known and all wind turbines in the OWF have the same coordinates (x,y).

B. Parameters

In the following, the parameters for the model are defined.

N	number of wind turbines.
V	set of vessels;
F	set of types of vessels;
f	index of type of vessels; f=1, 2, 3.
V_f	set of vessels of type f.
C	set of the components (foundation, pile, cable and top-structure).
c	index of a component.
LS_f	set of loading scenario of vessel type f.
Δt	time interval unit (12h).
T	set of planning periods.
t	index of the planning period.

- WC Set of weather condition categories :{ Cat1, Cat2, Cat3, Cat4, Cat5} (very good=Cat1, good=Cat2, medium=Cat3, bad=Cat4, and very bad=Cat5).
- LT_c loading time of a component c.
- TT travelling time of vessel from harbor to wind farm.
- $Setup_f$ setup time of vessel type f.
- IT_{cf} installation time of component c installed by vessel type f.
- Cf_t fixed rent cost for using vessel of type f in planning period t.
- CP_t fixed project cost in planning period t.
- WI_c weather condition category to install component c.
- WL_c weather condition category to load component c from harbor.
- NF_{if} number of foundations in loading scenario i of vessel type f.
- NP_{if} number of piles in loading scenario i of vessel type f.
- NC_{if} number of cables in loading scenario $i$of vessel type f.
- NT_{if} number of top structures in loading scenario i of vessel type f.
- $NComp_{if}$ index of number of components in loading scenario i of vessel type f.
- M_{it} number of occurrence of weather condition category i in planning period t.
- M_t vector of the occurrence of different weather condition categories in planning period t.
- $Capacity_{fc}$binary parameter which indicates if the vessel type f can build the component c.

C. Variables

The following decisions variables are set by the MILP and are also described:

- XF_{vt} number of foundations to be built by vessel v in planning period t.
- XP_{vt} number of piles to be built by vessel v in planning period t.
- XC_{vt} number of cables to be linked by vessel v in planning period t.
- XT_{vt} number of top-structures to be built by vessel v in planning period t.
- $XComp_{vt}$ index of number of components to be built by vessel v in planning period t.
- EC_{vt} effective cost for using vessel v in planning periodt.
- BL_{cj} binary variable equal to 1 if the loading of component c can be only performed under weather condition category j (j= WL_c), 0 otherwise.
- BL_c loading binary vector of component c.
- BI_{cj} binary variable equal 1 if the installation of component c can be only performed under weather condition category j (j= WI_c), 0 otherwise.
- BI_c installation binary vector of component c.
- $BSet_vt$ binary variable equal to 1 if the vessel v has been set up during the planning period t, 0 otherwise.
- Ω_{vt} estimated time needed for travelling and setting up of vessel v in the planning period t.
- α_{vt} integer coefficient related to Ω_{vt}.

D. Objectives

The objective is to minimize the sum of vessels costs during the total planning horizon. The model is formulated as follows:

$$\text{Minimize} C_{cost} \tag{1}$$

where $C_{cost} = \sum_{\forall t \in T}^{T} \sum_{v=1}^{N_f} EC$

E. Constraints

The objective is subject to the following constraints:

$$\forall\, t \in T, \forall\, f \in F, \forall\, v \in V_f$$
$$EC_{vt} = \begin{cases} C_{ft} + C_{pt}, & if\ \exists c \in C,\ XComp_{vt} > 0 \\ C_{pt}, & otherwise \end{cases} \tag{2}$$

$$\forall\, t \in T, \forall\, f \in F, \forall\, v \in V_f, \forall\, c \in C$$
$$If\ capacity_{fc} = 0 \quad then\ XComp_{vt} = 0 \tag{3}$$

$$\forall\, t' \in T, \sum_{t=1}^{t'} \sum_{v=1}^{V_f} XP_{vt} \leq \sum_{t=1}^{t'} \sum_{v=1}^{Vf} XF_{vt} \tag{4}$$

$$\forall\, t' \in T, \sum_{t=1}^{t'} \sum_{v=1}^{V_f} XC_{vt} \leq \sum_{t=1}^{t'} \sum_{v=1}^{Vf} XP_v \tag{5}$$

$$\forall\, t' \in T,\ \sum_{t=1}^{t'} \sum_{v=1}^{V_f} XT_{vt} \leq \sum_{t=1}^{t'} \sum_{v=1}^{Vf} XC_{vt} \tag{6}$$

$$\forall\, t \in T, \forall\, v \in V$$
$$\sum_{t=1}^{T} \sum_{v=1}^{V} XF_{vt} = N \tag{7}$$

$$\sum_{t=1}^{T} \sum_{v=1}^{V} XP_{vt} = N \tag{8}$$

$$\sum_{t=1}^{T} \sum_{v=1}^{V} XC_{vt} = N \tag{9}$$

$$\sum_{t=1}^{T} \sum_{v=1}^{V} XT_{vt} = N \tag{10}$$

$$\forall\, t \epsilon T, \forall\, v \epsilon V,\ \forall\, i \epsilon LS_f, \forall\, c \epsilon C$$
$$\alpha_{vt} = Max[XComp_{vt} / NComp_{iv}] + 1 \tag{11}$$

$$\forall\, t \epsilon T, \forall\, f \epsilon F, \forall\, v \epsilon V_f$$
$$BSet_{vt} = \begin{cases} 1, & if\ XF_{vt} > 0\ and XT_{vt} > 0 \\ 0, & otherwise \end{cases} \tag{12}$$

$$\forall\, t \in T, \forall\, f \in F, \forall\, v \in V_f$$
$$\Omega_{vt} = \alpha_{vt} * (TT + Setup_f * BSet_{vt}) \tag{13}$$

$$\forall\, t \in T, \forall\, v \in V, \forall\, j \in WC, \forall\, c \in C$$

$$\sum_{\forall j\in WC}^{WC}[XC_{vt}(BL_{ci}LT_c+BI_{ci}IT_c] + \Omega_{vt}\leq M_t \qquad (14)$$

Constraint (2) sets the effective cost for using vessel *v* in planning period *t* as equal to the fixed rent cost for using the vessel if it handles at least one component during the planning period *t* plus the fixed project cost, otherwise it is set to the fixed project cost of the planning period *t*. Constraint (3) ensures that the vessel type *f* can only install components which belong to its loading scenarios. Constraint (4) ensures that the sum of installed piles by all vessels does not exceed the sum of installed foundations.

Constraint (5) ensures that the sum of installed cables by all vessels does not exceed the sum of installed piles. Constraint (6) ensures that the sum of installed top-structures by all vessels does not exceed the sum of installed cables.

The constraints (7) to (10) restrict the sum of the built components during the planning periods to the total number of wind turbines *N*. Constraint (11) denotes the estimated number of possible trips carried out by the vessel *v* in the planning period *t*. Constraint (12) indicates if a setting up of the vessel has taken place in the planning period *t*. Constraint (13) indicates the estimated time for travelling and setting up of vessel *v* in the planning period *t*. Constraint (14) guaranties that the required time to install different components in different weather categories is available in the planning period*t*.Note that because of the fact that the weather categories are estimated and embedded in the mathematical model (constraint 14), the constraints (11,12, and 13) take this uncertainty in the forecasting von weather categories into consideration.

V. PROBLEM SOLUTION

In this section we analyze the behavior of the model. Since the aggregate planning is defined as medium term- capacity planning over 2-18 month planning horizon [17], the weather conditions have to be forecasted for this planning horizon. To this end the arithmetic mean is used to forecast the number of different weather categories for the next 12 months, regarding to the historical weather data from the last 50 years (see table 1). The solver (e.g. SCIP or CPlex) solves the mathematical model and gives an aggregate plan. It takes the weather conditions and the number of different vessel types into considerationwhich are available during the total planning horizon. In fact, the establishment of an aggregate plan provides the number of components that must be installed by each available vessel over the medium term planning horizon to meet the weather forecast. Furthermore different operational constraints are taken into account. In addition, table 2 shows the classification of different operations (e.g. traveling and structure installation) with respect to wind speed and wave height. The weather categories are ranked as follows: very bad=cat5, bad=cat4, medium=cat3, good=cat2, very good=cat1.

Month	Cat1	Cat2	Cat3	Cat4	Cat5
1	2	6	21	5	27
2	2	7	22	5	20
3	2	9	26	5	18
4	4	13	28	4	10
5	4	15	32	4	6
6	4	16	30	3	5
7	4	17	31	3	5
8	4	17	29	4	7
9	3	12	27	4	13
10	3	8	25	5	21
11	2	5	21	5	27
12	3	6	20	5	26

Tab. 1: number of occurrence of different weather category per month for the next 12 months.

Operation	Max wind speed [m/s]	Max wave height [m]	Weather category
No operation possible (stay at port)	**>12**	**>4,8**	**very bad**
travelling	**<12**	**<4,8**	**bad**
installation of foundations	**<11**	**<3,5**	**medium**
installation of piles	**<11**	**<3,5**	**medium**
linkage of cables	**<11**	**<3,5**	**medium**
installation of top structures	**<6,5**	**<2,5**	**good**

Tab. 2: threshold weather classification for each possible operation.

The configuration of the simulation experiment is summarized in Table 3.

Vessel Type	Operations	Foundations	Piles	Cables	Top-Structures
Type "Jack-up vessel"	Loading scenarios	3	0	0	0
		0	0	0	5
		0	10	0	0
	Installation time	2	2	0	1
	Installation restriction	cat3	cat2		cat2
	Loading time	1	1		1
	Loading restriction	cat3	cat3		cat3
Type "cable installation vessel"	Loading scenarios	0	0	10	0
	Installation time	0	0	2	0
	Installation restriction			cat2	
	Loading time			1	
	Loading restriction			cat3	
Type "pile installation vessel"	Loading scenarios	0	10	0	0
	Installation time		2		
	Installation restriction		cat3		
	Loading time		1		

Tab. 3: configuration of simulation experiment.

Three scenarios are considered in this simulation experiment. The objective is to find the best vessel configuration between the considered scenarios which can minimize the total cost of the project respectively the cost per offshore turbine.

The input data of the simulation experiment are: N=30, T=12 months. The first scenario consists of three vessels from different types, one cable installation vessel, and one pile installation vessel (figure 3). The second scenario is composed of four vessels, two Jack-up installation vessels, one cable installation vessel, and one pile installation vessel (figure 4). The last scenario consists of five vessels, three Jack-up installation vessels, one cable installation vessel, and one pile installation vessel (figure 5).

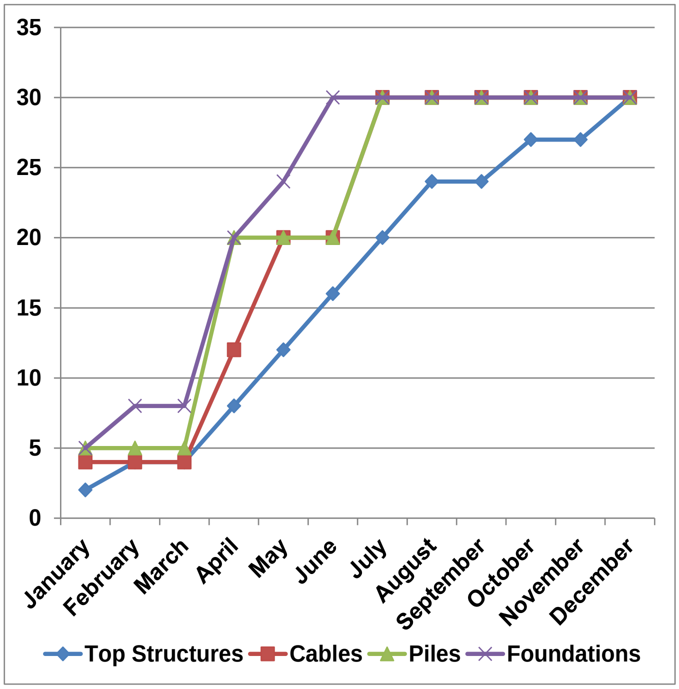

Fig. 3: aggregate planning to install 30 wind turbines (first scenario)

In the first scenario, the installation time needed for the complete installation of all wind turbines is 12 months. The project has a total cost equal to 5250 cost units, which means that the cost of installing a wind turbine is valued at175 cost units. In the second scenario the time needed is 6 months, the total cost of project is 5050 cost units, and the estimated installation cost of oneOWT amounts to 168 cost units. In the last scenario the planning time horizon needed to complete the installation is 5 months; and the total cost of project is 5100, which means that the installation cost of a wind turbine is 170.

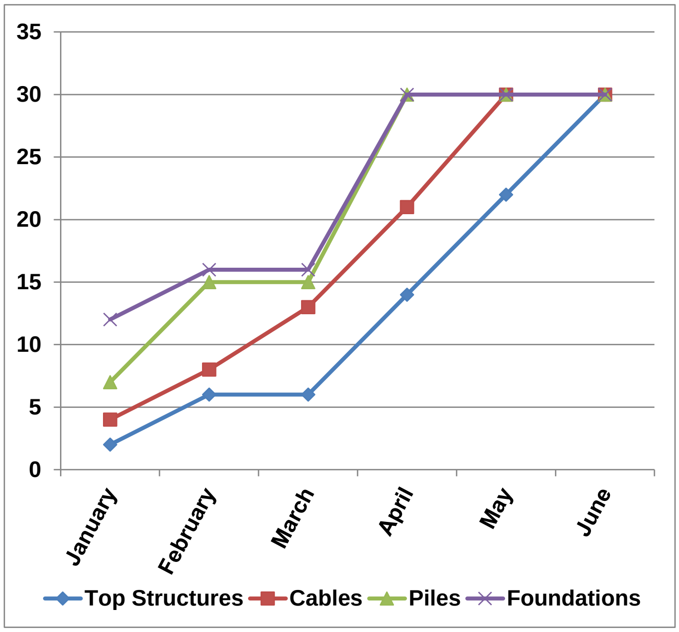

Fig. 4: aggregate planning to install 30 wind turbines (second scenario).

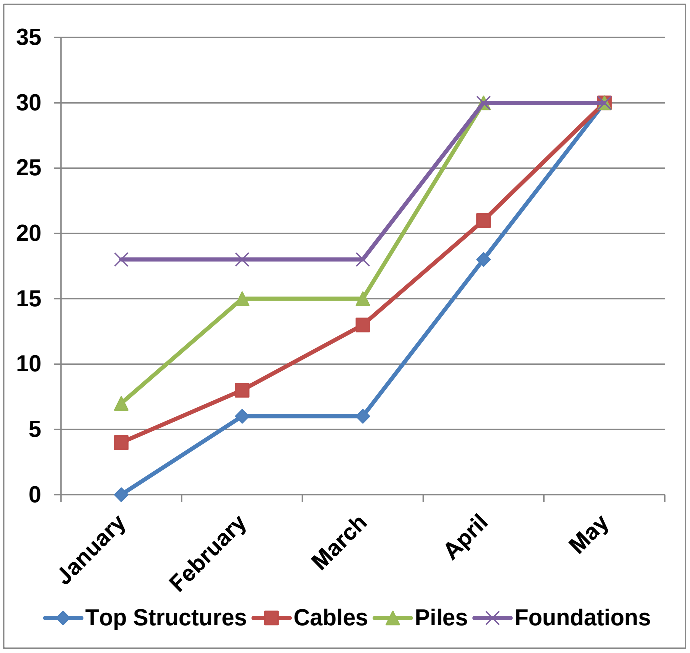

Fig. 5: aggregate planning to install 30 wind turbines (third scenario)

In the first scenario we can observe that the allure of the installation increases in the period between April and August due to the weather condition. This feature can be slightly observed in the second and third scenario due to the fact that several Jack-up installation vessels are collaboratively used to install the components, which leads to adecrease of the total installation time and total project cost.

Based on the results, we find out that the best vessel configuration, in which the total installation cost is minimized, is the vessel configuration of the second scenario. Normally it is expected that the third scenario should be better than the second scenario, since there are more installation vesselsavailable.However, because of limitations in the harbor capacity to serve and perform more than one vessel at a time, it leads toincreased waiting times for installation vessel in the harbor, and the optimal use of the vessels is affected by these waiting times.

VI. CONCLUSION

In this paper we presented the problem of aggregate installation planning of offshore wind farms. This problem is very challenging and complex problem due to its medium term- capacity planning character, the weather restrictions and vessel restrictions. In contrast to the scheduling of offshore operations which focus only on short-term planning problems, the literature dealing with the aggregate installation planning of offshore is still very sparse. The proposed mathematical model solves this problem by generating an estimated medium planning horizon schedule which minimizes the total costs of a given project. Important aspects to the OWF, like weather conditions have been taken into consideration in this model. Different scenarios can be studied and simulated with this model which can be considered useful as a decision tool for medium term planning of OWFs.

REFERENCES

[1] Scholz-Reiter, B.; Lütjen, M.; Heger, J.; Schweizer (Virnich), A.: Planning and control of logistics for offshore wind farms. In: Rogozea, Liliana (ed.): 12th WSEAS International Conference on Mathematical and Compuational Methods in Science and Engineering (MACMESE'10). Advances in Mathematical and Computational Methods, WSEAS Press, Faro, 2010, pp. 242-247.

[2] T. Smit, M. Junginger, R. Smits, Technological learning in offshore wind energy: Different roles of the government, Energy Policy, Vol. 35, 2007, pp. 6431-6444.

[3] Junginger, M.; Faaij, A.; Turkenburg, W. (2004): Cost Reduction Prospects for Offshore Wind Farms, Wind Engineering 28, pp. 97-118.

[4] K. Lange, A. Rinne, H.-D. Haasis, planning maritime logistics concepts for offshore wind farms: A newly developed decision support system, Computational Logistics Lecture Notes in Computer Science, Vol. 7555, 2012, pp. 142-158.

[5] Dolores Esteban, M.; Javier Diez, J.; López, J.; Negro, V. (2010): Why offshore wind energy?, Renewable Energy 36, pp. 444-450.

[6] X. Sun, D. Huang, G. Wu, The current state of offshore wind energy technology development, Energy, Vol. 41, 2012, pp. 298-312.

[7] S. Breton, G. Moe, Status, plans and technologies for offshore wind turbines in Europe and North America, Renewable Energy, Vol. 34,

[8] J. Moccia, A. Arapogianni, D. Williams, J. Philips, G. Hassan, Wind in our Sails – The coming of Europe´s offshore wind energy industry, The European Wind Energy Association, 2011.

[9] B. Byrne, G. Houlsby, Foundations for offshore wind turbines, Phil Trans. R. Soc. Lond. A, Vol. 361, 2003, pp. 2909-2930.

[10] I. Tyapin, G. Hovland, J. Jorde, Comparison of Markov Theory and Monte Carlo Simulations for Analysis of Marine Operations Related to Installation of an Offshore Wind Turbine, The 24th International Congress on Condition Monitoring (COMADEM), Stavanger, Norway, 2011, pp. 1071-1081.

[11] M. Lütjen, H.R. Karimi, Approach of a Port Inventory Control System for the Offshore Installation of Wind Turbines, The Twenty-second (2012) International Offshore and Polar Engineering Conference (ISOPE). Rhodes, Greek, 2012, pp. 502-508.

[12] A. Kovácsa, G. Erdősa, Z. JánosViharosa, L. Monostori, A system for the detailed scheduling of wind farm, CIRP Annals - Manufacturing Technology, Vol. 60, Issue 1, 2011, pp. 497–501.

[13] J. Zhang, S. Chowdhury, J. Zhang, W. Tong, A. Messac, Optimal Preventive Maintenance Time Windows for Offshore Wind Farms Subject to Wake Losses, 14th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Indianapolis, Indiana, September 17-19, 2012, pp. 1-13.

[14] K. Fagerholta, H. Lindstad, Optimal policies for maintaining a supply service in the Norwegian Sea, OMEGA - The International Journal of Management Science, Vol. 28, 2000, pp. 269-275.

[15] B. Aas, I.Gribkovskaia, Ø. Halskau, A. Shlopak, Routing of supply vessels to petroleum installations, International Journal of Physical Distribution & Logistics Management, Vol. 37, Issue 2, 2007, pp.164 - 179.

[16] M. Christiansen, K. Fagerholt, Robust ship scheduling with multiple time windows, Naval Research Logistics (NRL), Vol. 49, Issue 6, 2002, pp. 611–625.

[17] Baykasoglu, A. (2001). MOAPPS 1.0: Aggregate production planning using the multiple-objective tabu search. International Journal of Production Research, 39, 3685–3702.

[18] A.H.Gharehgozli, M. Rabbani, RTavakkoli-Moghaddam: A Proposed Hierarchical Production Planning Structure for CombinedMTS/MTO Environments. Proceedings of the 9th WSEAS International Conference on Applied Mathematics, Istanbul, Turkey, May 27-29, 2006, pp146-151.

[19] S.M.J. Mirzapour Al-e-hashema, , , H. Maleklyb, , M.B. Aryanezhad, A multi-objective robust optimization model for multi-product multi-site aggregateproduction planning in a supply chain under uncertainty,

International Journal of Production Economics, Vol. 134, Issue 1 ,2011 , pp. 28–42.

[20] Stephen C. H. Leung, W.L. NG, K.K. Lai: A Two-Stage Production Planning Model for Perishable Products under Uncertainty. Proceedings of the 10th WSEAS International Conference on SYSTEMS, Vouliagmeni, Athens, Greece, July 10-12, 2006, pp400-405.

[21] M. Paolucci, R. Revetria, F. Tonelli: An Agent-based System for Sales and Operations Planning in Manufacturing Supply Chains. 6th WSEAS International Conference on SYSTEM SCIENCE and SIMULATION in ENGINEERING, Venice, Italy, November 21-23, 2007, pp 339-345

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