33rd European Modeling & Simulation Symposium
18th International Multidisciplinary Modeling & Simulation Multiconference

ISSN 2724-0029 ISBN 978-88-85741-57-7 © 2021 The Authors.
doi: 10.46354/i3m.2021.emss.051

Discrete-event simulation for risk management in the overlap of two offshore wind manufacturing projects

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Abstract

An innovative use of Discrete-Event Simulation (DES) is proposed in this paper as a cutting-edge technology for analysing the risk in the possible overlapping of two projects in the field of offshore wind. In this context, we tackle the difficult of identifying and quantifying the impact and probability of the risk in the tendering procedure of a new project. For that purpose, a 3D digital model has been developed to represent in a virtual environment the currently manufacturing process of semi-submersible platforms combined with a new proposal of jackets. Afterwards, we formulated different scenarios according to the level of overlap between the two projects. This way, an equation was implemented as our target profit function to be optimised subject to certain model parameters. Therefore, the simulation model carried out in this study will be able to assess the risks in terms of schedule and costs, considering the variability inherent to stochastics fabrication systems, minimising the impact of the high penalties due to the delays in the delivery milestones. Overall, this work is an evidence how DES gives us an unprecedent advantage in project management, providing with a decision-support tool that allow us to improve process efficiency and maximise our earnings.

Keywords: Discrete-Event Simulation; Risk Management; Manufacturing Project Overlapping; Tendering Process; Offshore Wind.

1. Introduction

Nowadays, the increasing global demand for renewable energy as an alternative to fossil fuels and a solution to the worsening of climate change effects, has led to an interest in the construction of offshore wind farms (OWF). However, despite holding very high expectations regarding installed capacity and planned investments, offshore wind energy is currently facing important challenges because its elevated costs lead to a high degree of uncertainty.

To accomplish this, most governments around the world are more concerned than ever and continue its efforts trying to align offshore wind with the levelised cost of energy (LCoE) of other renewable energy sources to make it a competitive resource. Thereby, being competitive in this market is critical, so long-term vision regulations, efficient supply chains and technology improvements are essential for the success of offshore wind.

In this context, and as part of the revolution of Industry 4.0, discrete-event simulation open up the adequate technique to modeling the behaviour and performance of any process, as well as forecast the demand of each fabrication stage. Furthermore, its flexibility and 3D interface strengthen the process model validation, becomes a digital twin of the real system that assists in the decision-making procedure.

In the light of above, we aimed at putting Discrete-Event Simulation (DES) at offshore wind's disposal, developing a 3D model with the objective of maximise the profit by analysing the feasibility of carrying out a new project which is still in the bidding process. Thus, the simulation model implemented works as a quantifying risk tool based on DES that allow to assess the risk, considering the variability of them as stochastics systems.

All in all, in a context of an industry in expansion whole role even remains uncertain due to a certain lack of competitiveness, this study suggest an innovative method to increase the earnings.

2. State of the Art

2.1. Offshore Wind Industry

The massive amounts of pollution caused every day by fossil fuels and the already noticeable effects of climate change, demand for an urgent transition to renewable energy sources.

In this context, offshore wind energy is believed to be the key for decarbonizing the power sector and is consolidating its position in the global generation mix. In this sense, offshore wind is being offered a once-in-a-lifetime opportunity to become a main industry at the forefront of the energy transition. According to (Lee J., & Zhao F., 2019), wind sector is continuing to see consistent development, after having unequivocally established itself as a cost-competitive energy source worldwide.

Currently, offshore wind market is recording increasing trends concerning the number and size of connected-farms, as well as the capacity of the installed turbines. In the middle of this transition, Europe deserves a special mention as to be leading the global offshore wind market, returning to growth after a slowdown in 2018, with record installations in 2019 (IEA, 2020).

As reported by (Komusanac I., 2021), Europe added 2,9 GW during 2020, in line with the pre-COVID-19 forecast, when eight new offshore wind projects reached final Investment Decision (FID) in four different countries (Ramírez et al., 2021).

Nevertheless and regarding to (IEA, 2020), despite positive breakthroughs and cost reductions, growth must accelerate for the technology to get fully on track with the Sustainable Development Scenario (SDS). In this sense, offshore wind annual capacity additions need to more than quadruple by 2030; more specifically, the installed power estimation for 2025 and 2030 is 47,4 and 76 GW, respectively (Soares-Ramos et al., 2020).

In consequence, research into supply chain optimisation is needed for offshore wind to finally success aligning itself with the advances of Industry 4.0. Hence, this work proposes an innovative approach focused on enhancing the manufacturing process and be more competitive in tendering procedures.

2.2. Discrete-Event Simulation and Risk Management

Nowadays, although DES is already a common technique for the study and optimisation of almost any manufacturing process, the literature shows a clear lack of applications that combine DES and risk management. However, this last is becoming more frequently and necessary for the companies in order to avoid risk and achieve their objectives, for which the implementation of simulation is advised as an effective instrument for supply chain risk evaluation (Klimov, R., & Merkuryev, Y., 2008).

Therefore, with the simulation, risks can be characterised and assessed based on quantitative data to take account the uncertainties and their consequences. The following paragraphs provide a brief summary of the most relevant studies with regard to the use of DES in risk management.

(Klimov, R., & Merkuryev, Y., 2008) discussed the simulation-based risk evaluation in supply chain and presented in their work a risk analysis example. The simplified model considered allowed the authors to solve it from a mathematical point of view. They also highlight the point that the simulation model can deem expert opinion and that the final goal is provide supply chain managers with powerful simulation-based software.

(Schmitt., A., J. & Singh., M., 2009) presented a model using DES constructed for a large consumer products company to analyse their vulnerability to disruption risk and quantify its impact on the service. Moreover, they implemented various strategies for coping with the risk in order to maintain product availability to the customer. Likewise, the dynamic nature of the risk in the network and the importance of proactive planning was discussed.

(De Landtsheer, R., et al., 2016) provided a software supported method for quantifying procurement risks and establishing adequate strategies for mitigate them at an optimal cost, in contrast to individual estimation of risk and probability which, although is still very rooted in the industry, cannot provide fully reliable assessment. Their main technical contribution lies in the development of an efficient DES engine, together with a query language to measure business risks from the simulation results.

(Cube et al., 2016) designed a tool based on discrete-event simulation for monetary quantify risk and thus allow adjusting the model dependent to the use-case. It provides graphical modeling language equipped with risk assessment probes enabling to capture all risk-relevant aspects. In this way, based on this instrumental model, the framework is then able to compute and report about monetary risk quantification using an efficient DES engine.

(Shah et al., 2017) proposed a process-oriented quantitative risk assessment methodology to evaluate the risk associated with processes using modeling, simulation and decision-making approaches.

Finally, (Lamas, A., et al., 2017) used DES to identify and quantify project risks in the field of offshore wind manufacturing structures to further propose mitigation plans that minimise their impact. This approach takes the risk management methodology of the company at issue and couples it with the evaluation of several stochastic scenarios to study the tradeoffs of non-compliance of customer milestones, so that appropriate risk assessment may lead to better performance.

2.3. Process Overlapping and Risk Mitigation

A well-known practice to accelerate projects is to overlap the design phase activities, which can result in timesaving. However, the cost of these strategies varies significantly depending on the total rework and sophistication they generate. Thus, while some risk responses might be easy validated, overlapping, a commonly outcome in engineering projects, is difficult to analyse because of complex interactions between activities and resources.

Despite this problem, not many references have been found in which process overlapping are integrated with risk management. In the next paragraphs, we put forward a brief summary of de main references on this issue, although some of them focus on the overlapping process as a means of risk mitigation, rather than the appraisal of this last in the aliasing procedure.

(Wang, J., et al., 2008) explored an activity overlapping strategy as a technique for quicker product launch by knowing that the deep interaction patrons between components increase the chance of unanticipated iterations that may lead to late time-to-market. In this sense, the simulation algorithm used in this research allows project managers to design a better approach in order to minimise risks and analyse the impact of process structure on the delivery dates of a complex development project.

(Podean, I., M. et al., 2010) described a comprehensive and structured methodology that focuses on minimising project specific delay risk considering the intrinsic variability of the activities and their overlap. The method may supplement existing cost-based risk analysis combining moderation techniques and it can be regarded as a special case when the timely achievement of milestones is critical. Hence, this pathway encourages the common appreciation of risks by finding out the essence of what can go wrong and where the opportunities can be unlocked.

(Yang, Q., et al., 2013) highlighted that the iteration and overlapping are the main causes of uncertainty and ambiguity in the product development (PD) process. Based on DES modeling and analysis, their empirical research provides a quantitative method to reveal how the uncertainty and ambiguity related to the overlap impact on the project timeline. Simulation experiment results reinforce several managerial insights, such as the relationship between uncertainty and levels of overlapping, and how to control project schedule and hedge the resulting risk.

(Grèze, L., et al., 2014) implemented an evaluation model to measure the effectiveness of overlapping strategy as a risk response in terms of additional cost and total maximum time reduction. The results generated emphasise the relevance of the factors in the effectiveness of an overlapping strategy, the maximum aliasing amount allowed and the level of resource constrains.

(Dehghan, R., et al., 2015) built a methodology based on the principles of genetic algorithms (GAs) with the aim of be able to answer which activities have to be overlapped and to what extent to reduce the project duration at the minimum cost. Their algorithm can optimise multi-path networks and handle all types of activities dependencies, taking both non-critical and critical activities into account. The computer tool was also developed to run and validate the overlapping optimisation algorithm, thereby achieving the improve of a real-world project schedule.

3. Manufacturing Process

3.1. Construction Strategy of Floaters

The manufacturing process considered here consists in the assembly of 18 semi-submersible foundations (floaters) each of which one wind turbine will be installed on. The process, which takes place in a shipyard, is performed by means of fabrication workshops that gradually sub-assemble the small components provided first, and then, a final assembly operation these parts together forming the entire floater (Figure 1). This presents a high degree of prefabrication and a close-to-Lean methodology.

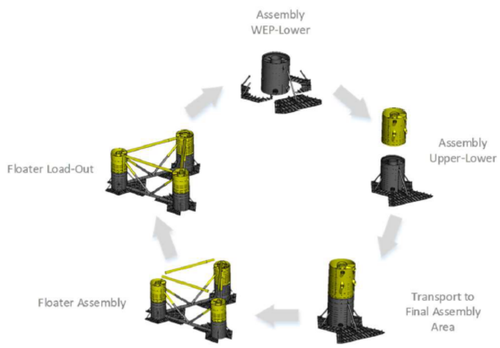

Figure 1. Main components of a floater.

Semi-submersible foundations are made up of three columns which are connected by tubular trusses (bracings) that consist of diagonal and horizontal tubes linked by nodes. The part of the construction strategy deemed here starts with the assembly of lower semi-column (Lower) and the Water Entrapment Plate (WEP) at its bottom that provides motion control to the whole platform. Then, the upper semi-column (Upper) is placed together with the rest of the floater. All this work is carried out in Berths with the help of a gantry crane and is called Assembly 1 (A1).

It should be noted that, although Upper section requires painting process, while the Lower and WEP blocks not need to be painted, this stage will not consider in this study.

Afterwards, when the entire column is assembled, a SPMT (Self-Propelled Modular Transporter) moves each of them to Piers, where the assembly of three columns (Assembly 2, A2) takes place (firstly, the column 2 with 3 and then, the whole set with column 1, where the turbine tower will be installed). Finally, floaters are transported to their finally location to perform the Load Out. An overview of all these processes is shown in Figure 2.

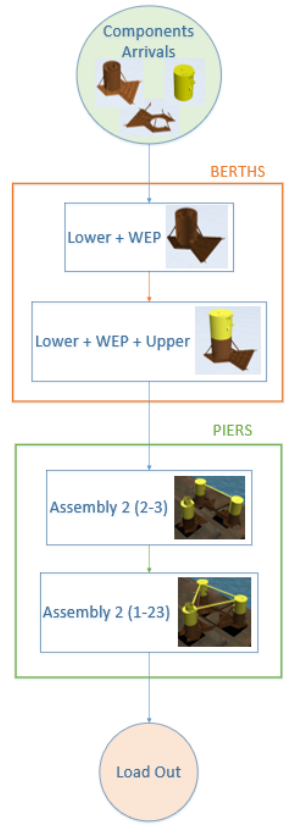

Figure 2. Simplified Process Flow of floater assembly.

3.2. Construction Strategy of Jackets

Jackets can be mostly divided into three parts (Figure 3): Lower Block (JLB) and Upper Block (JUB), which make up the main body of the structure, and the Transition Piece (TP) between the jacket body and the wind turbine tower.

More specifically, the JLB and JLB are in turn made up of a series of arms (X-Bracings) that will be in charge of joining the different legs (Legs), a tubular elements connected by transition nodes on which the jacket is supported.

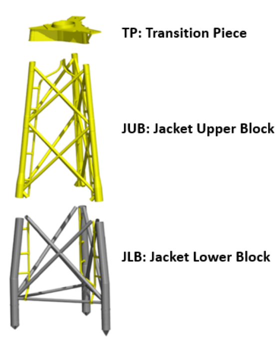

Figure 3. Main parts of a jacket.

The first step in the manufacturing process is painting all the components of the part of the jacket that protudes from the surface of the water for aesthetic reasons. Later, components will be assembled as the existing workstations in Berths making up, in the first place, the Rows (faces of the jacket) and then the entire block.

Once JUB are completed and the corresponding TP has arrived, this last component is arranged on top of the JUB through a gantry crane to perform the Assembly 1. Then, the entire block A1 (TP + JUB) are loaded and moved to the other Berth in order to carry out the Assembly 2 (A1 + JLB) as indicated in Figure 4.

Finally, the Load Out of jackets takes place in Piers, whenever possible, that it to say, there is enough space in them and the three stations pertinent to the same floater must be idle.

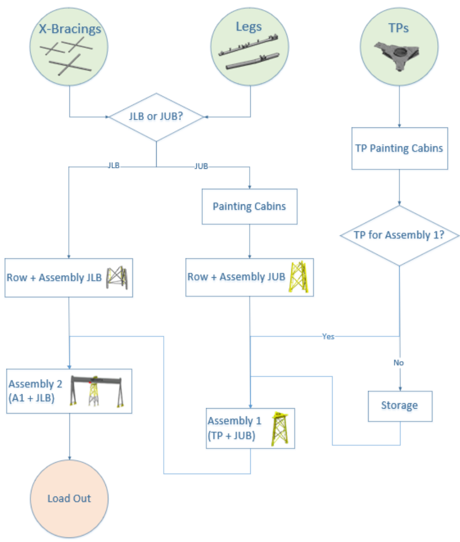

Figure 4. Process Flow of jackets assembly.

4. Methodology

4.1. Problem Description

The problem addressed in this paper lies in the risk of overlapping the assembly of 18 semi-submersible foundations with a jacket project which is still in tendering procedure. Hence, the aim is to manufacture as many jackets as possible without incurring in any risk for the current project of floaters.

Thus, we seek to avoid possible penalties in the delivery dates of foundations, at the same time we are able to maximise the total income from jackets assembly. For achieve this goal, a target function has been implemented as a global profit measure, which we will try to maximise by formulating different scenarios according to the level of overlapping between the manufacturing process of floaters and jackets.

First of all, we have coarsely defined 3 main scenarios:

- Scenario 1: non-overlapping or sequential scenario.
- Scenario 2: conservative scenario.
- Scenario 3: aggressive scenario.

The non-overlapping or sequential scenario (Figure 5) is the base line of the project, where the jackets will not begin to assemble until all floaters' deliveries are fulfilled. This supposes that there will be a certain amount of time in which some berths and piers are completely unoccupied and, thereby, we are not adequately utilizing the whole shipyard's capacity.

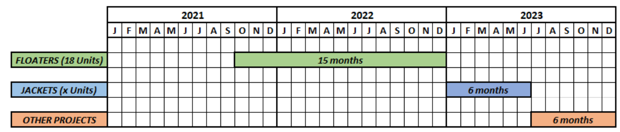

Figure 5. Characterisation of the non-overlapping scenario.

It must be taken into account that the beginning of the project time concerning jackets refers to the start of assemblies in berths, since the previous painting process has no relevance to the analysis because different painting cabins are utilised in both projects. In fact, the construction of columns of semi-submersible foundations has been modeled without their painting procedure.

As mentioned before, we have designed an overlapping strategy in order to assemble the maximum number of jackets. This is a very common casuistry in the market, where a certain customer may grant us a new agreement for a manufacturing project that is difficult for the company itself to handle due to limited availability, change-over times, etc., so we have to be able to find out the maximum quantity of a product or workload we could keep at the moment. Likewise, it is necessary to study the existing overlap with other projects, the benefits brought to the enterprise by the compliance of this assignment or the possible delays that may arise; in short, the risk involved in tackling the new order.

For this reason, we roughly consider a second (conservative) scenario where the manufacturing of jackets on berths starts when the last column of the ultimate float is transported to piers or, in other words, without any overlapping on berths (Figure 6).

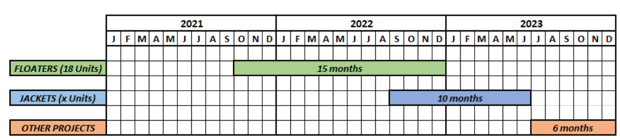

Figure 6. Characterisation of the conservative scenario.

Finally, we formulated the third and more aggressive scenario (Figure 7):

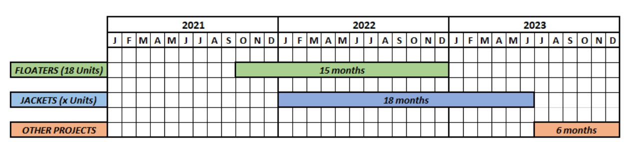

Figure 7. Characterisation of the aggressive scenario.

This latter represents the case that the assembly of jackets begins with the end of the assembly of the first column of the initial floater and its transport to piers.

4.2. Data Collection

Personnel of the Production and Engineering Division (PED) provided us with a detailed description of the construction strategy and cycle times of each stage of fabrication. In addition, information from previous projects served as data source during the model conceptualisation phase.

Regarding cycle times, each of them has been approximated to a continuous uniform distribution, which will take into account the variability of different processes. This is extremely important since the intrinsic variability in the duration of stochastics project tasks is crucial to be able to analyse the possibility of an overlap.

The uniform distribution presents a cumulative distribution function (CDF) such as (1):

$$F_X(x) = \begin{cases} 0, & x < a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ 1, & x > b \end{cases} \tag{1}$$

Where:

- $X \sim U(a,b)$ is a random variable with uniform distribution.
- $a, b \in \mathbb{R}$ are the parameters of the distribution.
- $x \in [a,b]$.

The following table (Table 1) is a summary of all parameters of this uniform distribution considered for each process.

Table 1. Duration of process tasks considered.

Activity	a (days)	b (days)
Assembly 1 Columns	53	56
Assembly 2 C2-C3	43	46
Assembly 2 C1-C23	78	82
Assembly Row JLB	7	9
Assembly Row JUB	9	11
Assembly JLB	9	11
Assembly JUB	15	17
Assembly 1 Jackets	20	23
Assembly 2 Jackets	34	37
Load Out Jackets	2	4

Finally, it is important to highlight the effect of learning curve in the task times of the assembly processes. Based on historical data of similar projects, we have observed that exists a reduction of 5% in the last third of the manufacture. Hence, this last issue has been considered in our DES model in FlexSim.

4.3. Model Verification and Validation

The verification of the model implemented, which represents the base line of floaters construction, was performed with the supervision of planning, programme and commercial department, thoroughly examining the behaviour of it through visual checks and an exhaustive revision of the code.

Subsequently, company's personnel validated the model checking and comparing if the lead times and delivery dates of the floaters and jackets outputted matched with the schedule data included in a MS Project file for each of the scenarios developed.

4.4. Measure of Performance

One time our DES model has been verified and validated, we proceed to formulate several scenarios with the aim of find where the best moment is to get started with the assembly of jackets.

To sum up, we need to develop a methodology be able to measure quantitatively the performance of each scenario, so that we could decide which is better than another. For this reason, a target function was designed to evaluate the degree of efficiency in terms of cost, because at the end, is the top manner of performance by considering different parameters of the simulation model. Thus, we will select the scenario that maximise this formula as a measure of the global profit of all the project.

The function we will optimise is the (2:

$$GP_i = aF_i + bJ_i - c\sum Delay_i - dWIP_i - eAvgFab_i - f\sum Travel_i - gBuffer_i \tag{2}$$

Where:

- GP_i: Global profit of the project estimated for the scenario i.
- a: Profit of one floater delivery in thousands of euros (k€).
- F_i: Number of floaters delivered on scenario i.
- b: Profit of one jacket delivery.
- J_i: Number of jackets delivered on scenario i.
- c: Cost per day of a floater delay in thousands of euros (k€).
- $\sum Delay_i$: Total delay of floaters' deliveries on scenario i.
- d: Parameter associated with the cost of one component per day.
- WIP_i: Measurement of work in progress on scenario i.
- e: Parameter associated with the cost of fabrication per day.
- $AvgFab_i$: Average fabrication time of floaters on scenario i.
- f: Parameter associated with the cost of one meter traveled by the SPMT.
- $\sum Travel_i$: Total distance traveled by the SPMT on scenario i.
- g: Parameter associated with the cost of one component in buffers per day.
- $Buffer_i$: Number of jacket components in buffers per day on scenario i.

To calculate the total delay of floaters, the delivery dates of the foundations have been considered with regard to the baseline dates. As for the *e* parameter of the work in progress, it has been calculated from the cost of raw materials and labor, as well as overhead costs incurred for components that are assembling at various stages of the supply chain.

The values of all these parameters can be seen in Table 2.

Table 2. Value of the parameters considered in the model.

Parameter	Value	Units
a	1000	k€/floater
b	300	k€/jacket
c	100	k€/day
d	6	k€/component·day
e	4	k€/day
f	3	€/m
g	50	€/component·day

It should be noticed that parameters *b* and *f* are the same for any project of jackets carried out, while *a* and *c* are determined in the contract of the project in bidding process. However, the rest of them could vary slightly, so a sensitivity analysis may be neccesary in order to assess the risks. In any case, for this study, all parameters were previously calculated and provided by the company.

4.5. Risk Management

The risk management methodology used in this paper is based on the probability of occurrence of the risk-causing events and the effects of it on cost and schedule. However, in this analysis, indeed, we only will consider the risk effects on cost because our performance measure of all the system, referenced throughout the (2, already includes the schedule impact, so that it makes no sense evaluate it in a separate way.

Hence, to be able to quantify these risks we are going to use the probability (PI) and impact indexes (II) represented in the Table 3 and Table 4, respectively.

Table 3. Probability index.

Probability Index (PI)	Denomination	Probability
1	Very Low	$0 < P \leq 10\%$
2	Low	$10 < P \leq 30\%$
3	Medium	$30 < P \leq 60\%$
4	High	$60 < P \leq 90\%$
5	Very High	$90 < P \leq 100\%$

Table 4. Impact index.

Impact Index (II)	Denomination
1	Very Low
2	Low
3	Medium
4	High
5	Very High

On the other hand, the assessment of the risk impact of the cost regarding the different thresholds of the procurement value will be performed in accordance with Figure 8, provided by the company.

COST IMPACT (€)					
Contract Value (€)	Very Low	Low	Medium	High	Very High
< 100.000	< 1.000	< 2.000	< 3.000	< 4.000	≥ 4.000
< 500.000	< 2.000	< 4.000	< 6.000	< 8.000	≥ 8.000
< 1.000.000	< 3.000	< 8.000	< 12.000	< 15.000	≥ 15.000
< 5.000.000	< 5.000	< 10.000	< 25.000	< 50.000	≥ 50.000
< 10.000.000	< 10.000	< 25.000	< 50.000	< 75.000	≥ 75.000
< 50.000.000	< 25.000	< 50.000	< 75.000	< 150.000	≥ 150.000
< 150.000.000	< 50.000	< 75.000	< 150.000	< 300.000	≥ 300.000
≥ 150.000.000	< 75.000	< 150.000	< 300.000	< 500.000	≥ 500.000

Figure 8. Cost Impact thresholds.

Likewise, once the probability and impact indexes have been defined, we can estimate the critical or criticality index (CI) as the product of both, as shown in (3:

$$CI = PI \cdot II \quad (3)$$

Where:

- CI: Criticality index of the risk.
- PI: Probability index of the risk.
- II: Impact index of the risk.

Figure 9 represents all possible values for the critical index and therefore, in accordance with it, we will take on a certain risk level (RL) as stated in Figure 10.

CRITICAL INDEX (CI)					
Probability Index (PI)	Impact Index (II)				
	Very Low	Low	Medium	High	Very High
Very High	5	10	15	20	25
High	4	8	12	16	20
Medium	3	6	9	12	15
Low	2	4	6	8	10
Very Low	1	2	3	4	5

Figure 9. Critical index matrix.

Risk Level (RL)	Critical Index (CI)
Low	1, 2, 3, 4, 5, 6
Medium-Low	8, 9, 10, 12
Medium-High	15, 16, 20
High	25

Figure 10. Risk level depending on critical index.

5. Results and Discussion

Following the methodology proposed in this work, we implement different scenarios in which we have been bringing forward the workload of jackets project a little more in time.

In this sense, we have created 54 scenarios depending on the degree of overlap, where the scenario 1 matches with the most aggressive scenario (scenario 3 mentioned above) and the scenario 54 is the most conservative scenario (scenario 2 described previously). These 54 scenarios were obtained as a result of iterating the output on berths of each 3 columns of the 18 floaters, so it has been scheduled the beginning of jackets production after the end of the assembly of each column.

The previous consideration is based on the fact that, at first glance, it can be seen that it does not make sense to quantify these 54 events when the columns get in berths, since it would cause inadmissible delays for the initial project. Actually, it has been considered from information provided by the company that it is not allowed for the total delay time of floater deliveries to exceed 20 days, nor for the last structure to be delayed by more than 10 days. It would also make no sense to make reference to the departure of columns from piers because most of scenarios would not reach a feasible level of overlapping.

Hence, we ran a simulation with 100 replications (this same value has been used for the subsequent analyses) of these 54 scenarios comparing them which the base line in order to know the outcome of overlapping. Results of first three main scenarios are shown in Table 5. All of them are average values except the global profit, which is expressed in terms of minimum, mean and maximum, always use a confidence interval of 99%.

Table 5. Performance measures of main scenarios.

Performance Measure	Base Line	SC 1	SC 54
Assembled Jackets	16,40	35,00	30,60
Jackets Cycle Time (days)	38,75	18,08	20,71
Jackets Fabrication Time (days)	87,14	96,93	86,73
Floaters Cycle Time (days)	25,28	27,71	25,32
Floaters Fabrication Time (days)	194,87	196,78	195.08
Total Delay (days)	0,25	156,08	0,64
Work In Progress	661,50	346,00	424,4
Jackets Buffer	8614,00	2188,00	3387,00
SPMT Total Travel (km)	706,80	884,015	827,09
Global Profit – Minimum (M€)	9,41	6,07	18,10
Global Profit – Mean (M€)	9,49	-11,54	18,34
Global Profit – Maximum (M€)	9,57	-23,68	18,58

Therefore, as it can be appreciated, with the most aggressive scenario we are able to assembly an average of 35 jackets in comparison with the base line, where we only reach a maximum production of 17.

However, as mentioned before, scenario 54 results in a total delay of floaters of more than 20 days, so that only scenarios that fulfill this condition will be considered. This way, with the aim of specify a little more, we have adjusted to best scenarios, this is to say, from scenario 25 to 48.

Once again, in Table 6, the results of the best scenarios are displayed.

Table 6. Results of best scenarios.

Performance Measure	SC 31	SC 40	SC 42
Assembled Jackets	34,20	33,60	33,80
Jackets Cycle Time (days)	18,51	18,87	18,77
Jackets Fabrication Time (days)	89,82	87,99	87,71
Floaters Cycle Time (days)	25,52	25,32	25,32
Floaters Fabrication Time (days)	192,75	195,09	195,08
Total Delay (days)	3,38	0,64	0,64
Work In Progress	362,80	373,20	373,20
Jackets Buffer	2946,00	3266,00	3278,00
SPMT Total Travel (km)	873,82	862,55	864,39
Global Profit – Minimum (M€)	20,32	20,12	20,16
Global Profit – Mean (M€)	20,43	20,23	20,27
Global Profit – Maximum (M€)	20,54	20,34	20,38

In view of the previous group of data, scenario 31 maximises the global profit of our manufacturing project with a mean value of 20,43 M€. Despite this fact, it is neccesary analyse the risk level of choosing this scenario due to the intrinsic variability of stochastics task times, so we will follow the methodology described previously.

Hence, the first step is to calculate the probability and impact indexes of the risk, for which Table 3 and Figure 8. Cost Impact thresholds. will be used, respectively. With the aim of estimating the probability index, it is necessary, firstly, to define what probability we will have to consider. Since a target cost function has been implemented to measure the performance of the whole project, it would suffice to study when the chosen scenario presents a lower global benefit than the second best and more conservative scenario, in this case, scenario 42.

$$P_T = P(GP_{SC31} < MGP_{SC42}) \bigcap P(GP_{SC42} > mGP_{SC31}) \qquad (4)$$

Where:

- P_T: Total probability of the risk.
- GP_{SC31}: Global profit in scenario 31.
- MGP_{SC42}: Maximum value of global profit in scenario 42.
- GP_{SC42}: Global profit in escenario 42.
- mGP_{SC31}: Minimum value of global profit in scenario 31.

Thus, we should assess the probability that the global equation could reach a lower profit in scenario 31 than in scenario 42. This latter is equivalent to analysing at the same time the probability that scenario 31 is lower than the maximum of the global profit in scenario 42 and this last scenario presents a higher value than the minimum of scenario 31. This casuistry is cover in (4).

This way, in order to find out these parameters we used FlexSim's histogram tool, which directly provides us with the probability value. Therefore, the resulting probability index for this case is 15%, which corresponds, according to Table 3, to a low risk level.

Moreover, we should estimate the impact index of the cost, this being the difference between the maximum value of the global profit in scenario 42 and the minimum in 31, as shown in (5) below.

$$C_T = MGP_{SC42} - mGP_{SC31} \qquad (5)$$

Where:

- MGP_{SC42}: Maximum value of global profit in scenario 42.
- mGP_{SC31}: Minimum value of global profit in scenario 31.

Once the risk cost value is known, we estimated its impact depending on the thresholds of Figure 11, resulting in a medium level.

COST IMPACT (€)					
Contract Value (€)	*Very Low*	*Low*	*Medium*	*High*	*Very High*
< 50.000.000	< 25.000	< 50.000	< 75.000	< 150.000	≥ 150.000

Figure 11. Cost Impact thresholds according to our agreement.

Finally, through (3) and, in accordance to Figure 9 and Figure 10, the criticality index reaches a value of 6, which means that the risk level associated to tackle this scenario is low and, therefore, is feasible to develop this strategy in reality.

This enables us to reach much more benefit by being able to manufacture more floaters that any other configuration, bringing forward the start of the project in bidding procedure without any significant risk. Hereafter, Figure 12 shows the final distribution of workload and overlapping in berths as a result of carry out the scenario 31.

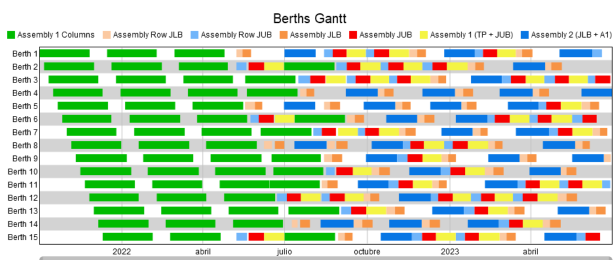

Figure 12. Gantt chart of workload in berths.

Overall, a screenshot of the 3D model during the runtime of scenario 31 is included in Figure 13.

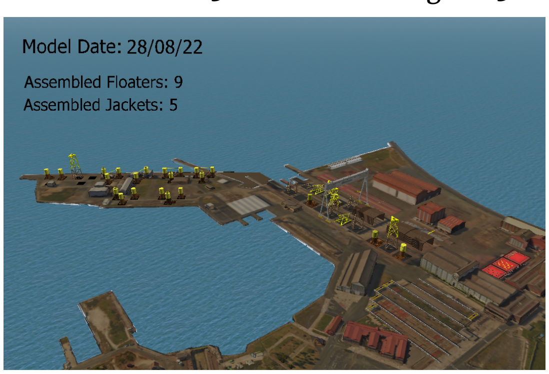

Figure 13. General overview of the 3D DES model.

6. Conclusions

The DES model developed in this paper has successfully served as a parametric decision-support tool for identify and quantify the risks from the overlapping of two projects in the offshore wind industry.

Therefore, the model allowed us to decide during the tendering procedure of jackets project and finally to bring forward the workload, maximising our profits. In addition, we thoroughly checked that this overlap does not lead to a high risk implementing a global equation as our target cost function.

All in all, the results reached in this work leave a strong evidence of the importance of assess risks under a simulation-based cost optimization in such a competitive market.

Acknowledgements

The authors are thankful to the Joint Venture Navantia-University of A Coruña (UMI) and Navantia for their valuable support.

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