RISK MANAGEMENT IN JACKETS MANUFACTURING PROJECTS USING DISCRETE EVENTS SIMULATION

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ABSTRACT
This paper presented an innovative parametric tool for quantifying project risks by applying Discrete Events Simulation (DES). This tool has been customized for wind turbine foundations manufacturing projects and will be applied to quantify the risk associated with delays in the supply chain and customer's AFC (Approved for Construction) drawings delays.
The difficult task of identifying risks, quantifying them and proposing mitigation plans to minimize their impact in this type of serial fabrication projects justifies the use of a tool based on DES. The short fabrication period and the high penalties related to the non-compliance of the delivery milestones, makes this tools very useful in project management.
This simulation tool has been validated by a real jacket manufacturing project and has been used in order to identify and quantify the project risks as well as to propose and check the effect of the mitigation plans associated with each project risk.

Keywords: jacket, risk management, mitigation plans, discrete events simulation

1. INTRODUCTION

In the last 3 years the wind energy in Europe has duplicated its installed capacity with a total installed capacity of 12,631 MW from 3.589 wind turbines along 81 wind farms in 10 European countries. As well as, at the end of 2016, 11 projects reached final investment decision, worth €18.2bn, will represented an increase of 4,948 MW in the total capacity installed. Offshore wind is one of the most dynamic renewable energy, in terms of installed capacity and technology development since 2010. (Carmen & Varela-v 2017).
According to (EWEA 2017b), by 2020, offshore wind is projected to grow to a total of installed capacity of 24,6 MW with trends to installing greater capacity wind turbines (4,8 MW average capacity in 2016)and situated in deeper and further away to shore areas (29m average deep and 44 km average distance to shore in wind farms completed or partially completed in 2016).
This trends means a promising future by the jackets market, representing 12 % of all foundations installed in 2016 and 6,6 % of cumulative installed foundations in Europe.
On the other hand, the wind industry has continuously reduced cost in order to make wind energy a competitive energy resource, making nowadays the onshore wind energy the cheapest new power generation in Europe. At the same time, in 2016, offshore wind energy has proven it can be in the same cost range (Ewea 2017a). Offshore wind is also undergoing an increasing cost reduction and technology improvements (Carmen & Varela-v 2017)
In search of this aim Jan Kjærsgaard (CEO of Bladt Industries) proposes the jacket design standardization to contribute to offshore wind cost reduction.
Another important aspect in jackets manufacturing project is the very demanding takt time established by the market which currently requires the delivery of 1 jacket per week.
This takt time implies that the manufacturer company needs to work with more than one supplier in the same project. This reason leads the fabrication company to make an exhaustive risk analysis on possible supply chain and engineering delays.
According to the described jacket manufacturing project needs, a Discrete Events Simulation model has been developed in order to quantify the risks arising from supply delays and to propose different mitigation plans depending on the likelihood associated with the risk. The use of simulation techniques is advised as an effective instrument for supply chain risk evaluation (Klimov & Merkuryev 2008).
Therefore, through the Simulation tool used, is possible to characterize the risk based in quantitative data and determine the appropriate level of detail grade of the mitigation plans depending on the probability of use them. Process risks should be modelled and assessed to account for the uncertainties and their consequences (Shah et al. 2017)
In addition, the simulation tool will perform an economic analysis based on the risk probability and the economic impact of the risk over the project.

2. STATE OF THE ART

The aim of this work will be develop a quantifying risks tool based on Discrete Events Simulation. Most of the literature use the Discrete Events Simulation in order to quantifying risks in supply chain, but applications that quantify risks with simulation models that combines the supply chain and manufacturing process are less frequent. The following paragraphs presents a brief summary of the most relevant studies related to the problem considered:

(Singh & Schmitt 2009), studied the impact on the customer service of disruptions in a customer products service using Monte-Carlo and discrete events simulation. They used their tool in order to assess the level of supply chain disruption risk, test different mitigation plans, can use the tool in case of a disruption in order to validate recovery steps before putting then into action and Identify redundancy in the system.

(Deleris 2005), designed a tool to assess uncertainty in supply networks based on Monte-Carlo Simulation. They have focused their tool on a method to estimate the losses in a supply network.

(Klimov & Merkuryev 2008), discussed the simulation-based risk evaluation in supply chain, and presented in their work a risk evaluation example with a simplified supply chain system.

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

(Ingalls 2014), based in his paper called The Value of Simulation In Modeling Supply Chains (Ingalls, 1998) presents the advantages and disadvantages of simulation use as analysis methodology to evaluate supply chains.

(Cube et al. 2016), designed a tool based on discrete events simulation for monetarily quantify risks independent of the depth of information and thus allow adjusting the model dependent on the use-case.

3. DESCRIPTION OF THE MANUFACTURING AND SUPPLY PROCESS IN A JACKET MANUFACTURING PLAN

To elaborate the study of this paper, we have used jackets whit three legs, which are differentiated into four principal parts (Transition Piece, Jacket Upper Block, Jacket Lower Block and Piles). The jacket decomposition is represented in the Figure 1.

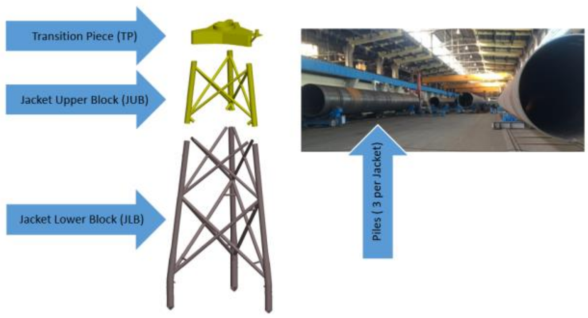

Figure 1: Main Parts of the Jacket.

The manufacture process used in this paper uses as input the four principal parts of the jacket. Figure 2 presents the manufacturing process flowchart.

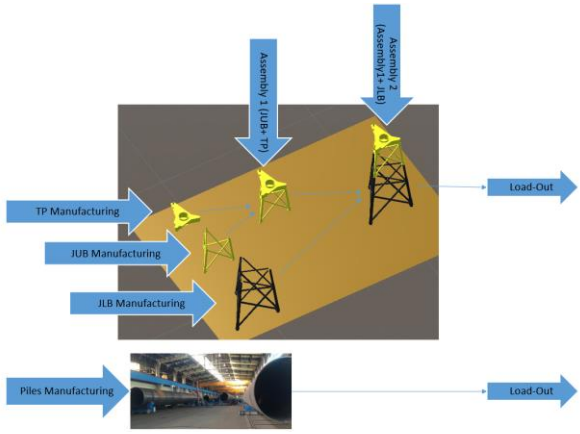

Figure 2: Flowchart of Jacket Manufacturing Process.

For simplify in this paper the experimental results, we go to use a manufacturing Piles Simulation model. This Simulation Model will represent the supply and manufacturing process in a piles manufacturing plant. This process it is not a trivial supply chain problem due to the first supplier is also the customer i.e., the customer marks the beginning and end of the project.

The supply and manufacturing process flowchart is represented in Figure 3.

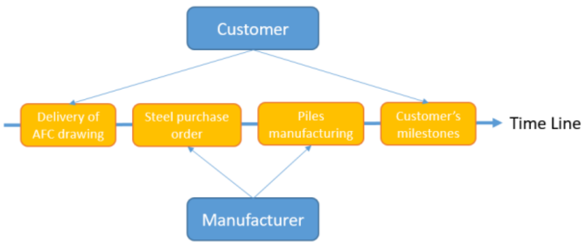

Figure 3: Supply and Manufacturing Process of the Piles.

At the same time, in jackets manufacturing projects is important to take into account the high penalties due to non-compliance customer milestones, which can be about 150.000,00 €/ (day and jacket).

4. PROBLEM DESCRIPTION

In the manufacturing jackets projects the risks quantifying analysis can be apply in the project planning phase or in the manufacture phase. If we do the risks analysis in the planning phase, the aim will be assess the level risk of break the customer milestones, and test the different mitigation plans proposed. On the other hand, if we do the risk analysis in the manufacture phase, our aim will be used the tool in case of appears the risk of break the customer milestones along the manufacturing plan.

In both cases, previously described, to elaborate the risks analysis, the project team needs to quantify the probability that the risk may exist and, at the same time, evaluate the impact of this risk in the project.

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Depending on the risks analysis, the project team will develop with more or less detail the mitigation plans associated with each risk. At the same time, the parameters to elaborate the mitigation plans will be different if the risk is detected in the planning phase or in the manufacture phase.
In this point, and as main reason for the developed tool presented in this paper, we should take into account the difficulty of quantifying the impact of the risks in the project, and the importance of detecting the risk in the planning phase. i.e., a very likely risk could have not impact in the project and its mitigation plan should have a low detail or a less likely risk could be dangerous for the project and its mitigation plan should have a high detail. At the same time, a risk identified in the planning phase will be easier to solve than the same risk identified in the manufactured phase.

5. RISK MANAGEMENT METHODOLOGY

In this paper, we have based the risk management methodology in a company whose risk management process is represented by flowchart of the Figure 4.

Figure 4: Risk Management Process Flowchart

The simulation model developed in this paper will be used in the points two, three and four of the previous flowchart.

5.1. Risks Criteria

The risk quantification methodology used in this paper is based on the probability of occurrence of the risk-causing activity and the effects of the risk on cost and schedule.
To assessment the risk occurrence probability we are going to use a probability index (PI) represented in Table 1. This index is related to the occurrence of the risk.

Table 1: 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	$90\% < P \leq 100\%$

An assessment of the impact of a risk shall be performed in accordance with the Table 2.

Table 2: Impact Index

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

To obtain the Impact Index (II) for a risk, we use as a reference the Table 3 and Table 4.

Table 3: Cost Thresholds

Cost Impact [€]				
Very low	Low	Medium	High	Very High
<50000	<75000	<150000	<300000	≥300000

Table 4: Schedule Thresholds

Schedule Impact [days]				
Very low	Low	Medium	High	Very High
<5	<15	<30	<50	≥50

The assessment of the Impact Index (II) for each risk shall be whichever is the highest of the values estimated for both criteria.

5.2. Risks Assessment Matrix

Once the Probability and Impact Indices have been defined, the Criticality Index shall be defined as the product of both:

$$CRITICAL\ INDEX\ (CI) = PI \cdot II. \quad (1)$$

Table 5 represents all possible values for the Criticality Index. At the same time, we have used a colour code in order to separate the thresholds in terms of mitigation or contingence actions.

Table 5: Critical Index Matrix

Critical Index (CI)		Impact				
		Very Low	Low	Medium	High	Very High
Probability	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

Risk Level (LOW): CI = 1, 2, 3, 4, 5, 6
Risk Level (MEDIUM-LOW): CI = 8, 9, 10, 12
Risk Level (MEDIUM-HIGH): CI = 15, 16, 20
Risk Level (HIGH): CI = 25

5.3. Simulation model development

The piles simulation model developed for this paper consist in five inputs (delivery of AFC drawings, customer milestones, plant capacity, construction strategy and task simulation times) with the flowchart represented in Figure 5.

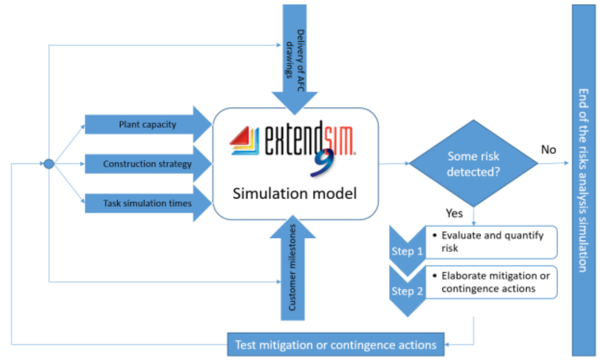

Figure 5: Simulation Model Flowchart

This simulation model uses the floating calculation in order to detect the risks, i.e. the model calculate the maximum delay in the project that allows compliance the milestones of the customer.

In piles manufacturing projects the model inputs (AFC drawings delivery and customer's milestones) are established by the customer and only can be modified if the risk analysis is elaborate in the planning phase. The impossibility of modified this inputs during the manufacturing phase limits the possibility of elaborate mitigation plans if the risk is identified during the manufacturing phase.

As to the piles construction strategy, in this paper we have used a strategy based on the tasks and the task overlap presents in the Table 6 where notation of task overlap used the Microsoft Project notation.

Table 6: Piles Construction Strategy

Task number	Task description	Task overlap
1	Plates cut and bevelling	
2	Bending of plates	1FC+1
3	Longitudinal Welding	2CC+1
4	Section assembly	3CC+2
5	Circular welding	4CC+2
6	Welding of beds	5FC
7	Non-destructive testing	6FC+1
8	Marking of section	7
9	Final inspection	8

The number of piles that can be manufacturing in parallel is a factor depending on the manufacturing plant, but in this study case we go to consider it a variable parameter, due to in this type of projects the market offer a great number of companies whit capacity for this type of works.

As a last input we have the tasks process time, for this practical work each task time has been approximated to a lognormal distribution. In this case we have used historical data of similar projects in order to elaborate de theoretical lognormal distribution.

This simulation model has been developed in the DES software ExtendSim 9.2 and the Figure 6 presents the model that capture the flow presented in Figure 5. The figure is too small to appreciate the blocks, but with the color-coded presents in the figure is possible identify the different parts.

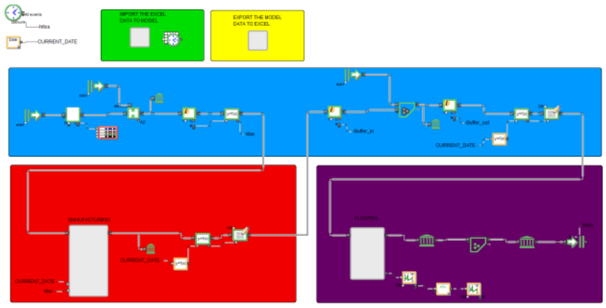
Figure 6: Simulation Model

- The green and the yellow block represents the exchange of data between the Simulation model and the Excel spreadsheet within which are represented the model changeful parameters. The green block occurs in time zero and feeds the simulation model and the yellow block occurs at the end of the simulation and feeds the risks analysis tables.
- The blue block controls the purchase orders, buffer dimensions and Load-Out dates, i.e., controls that the model does not break the restrictions.
- The red block represents the construction strategy and controls that the model does not exceed the real dimensions of the manufacturing plant.
- In the last place, the purple block is in charge of calculate the floating of the manufacturing project, and controls the model replications in order to obtain a floating value whose confidence interval keep a relative error less than 0.01.

6. RESULTS

The results of this paper has been organized in two different experiments. First experiment has been designed in order to detect the start project date with floating value equal to cero. Second experiment represents the risks analysis in the piles manufacturing project, within which presents a numerical example to risks quantification with Discrete Events Simulation, and a brief explain about the possible mitigation actions.

6.1. Start Date Analysis

When we speak of floating value equal to cero, we are referring to the start project date from which the project milestones will be broken.

In this first analysis we have used a range dates of five days up and down from the estimated AFC drawings delivery date.

In this point, we have not taken into account the quantification of risks, because we have focused in find

the latest start project date that assure us do not take early risks.
Table 7 presents the result for this analysis, providing the average floating, confidence interval, and the percentage in each threshold of floating value. In this analysis we have used 200 replications per scenario.

Table 7: Results of Start Date Analysis

Delivery of AFC drawings	Average floating	Confidence interval	Floating (f) [days]			
			<-1	-1≤f<0	0≤f≤1	>1
-5	1.295	0.1332	1.5%	0.0%	57.0%	41.5%
-4	1.220	0.1413	2.0%	0.0%	56.5%	41.5%
-3	0.110	0.2096	10.0%	0.5%	85.0%	4.5%
-2	-1.975	0.3067	45.5%	5.0%	49.5%	0.0%
-1	-1.820	0.3010	43.0%	4.5%	52.5%	0.0%
0	-2.045	0.3048	48.0%	5.5%	46.5%	0.0%
1	-4.480	0.1405	97.0%	1.0%	2.0%	0.0%
2	-5.535	0.1318	100.0%	0.0%	0.0%	0.0%
3	-6.810	0.1919	100.0%	0.0%	0.0%	0.0%
4	-8.815	0.2570	100.0%	0.0%	0.0%	0.0%
5	-10.460	0.1956	100.0%	0.0%	0.0%	0.0%

Interestingly, the real AFC drawings delivery date has a risk for the project whit a probability greater than 50% of break the customer milestones.
In addition, if the AFC drawings delivery date is advanced in 3 days the probability of compliance the customer milestones is about 90% and with an advance of 5 days the probability is increased to 99%.

6.2. Risks Quantification with Discrete Events Simulation

Taking advantage of the identified risk on the previous analysis, in this point we go to quantify the risk in accordance with the risk management methodology described in the point five of this work.
In first place, the simulation model is run again, in order to complete the schedule impact and the cost impact tables (Table 8 and Table 9).

Table 8: Example of Schedule Impact

Schedule Impact [days]						
Average floating	No impact	Very low	Low	Med	High	Very High
	>0	<5	<15	<30	<50	≥50
-2.180	43.5%	47.5%	9.0%	0.0%	0.0%	0.0%

Table 9: Example of Cost Impact

Cost Impact [€]						
Average cost	No impact	Very low	Low	Med	High	Very High
311250.0€	46%	0%	0%	0%	5%	49%

If we based on the schedule impact represented in Table 8, we have two possibilities in order to calculate the critical index (CI).

1. Schedule impact very low, whit an occurrence probability of 47.5%, then, consulting the tables 1, 2 we have a PI=3, II= 1, therefore, according to table 5 the critical index (CI) is equal to 3 (risk level low).
2. Schedule impact low, whit an occurrence probability of 9%, then, PI=1, II= 2, therefore, according to table 5 the critical index (CI) is equal to 2 (risk level low).

On the other hand, if we based the risks analysis by its cost impact, we have another two Critical Index (CI) possibilities.

1. Cost impact high, with an occurrence probability of 5%, then PI=1, II=4, therefore CI=4 (risk level low).
2. Cost impact very high, with an occurrence probability of 49%, then PI=3, II=5, therefore CI=15 (risk level medium high).

According to risk criteria, the mitigation plan shall be developed taking into account the highest CI, in this case is a risk level medium high.
In order to represents the analysis of mitigation plans with the developed tool, we go to study the effect of learning curve in the tasks times of the process. Based on historical data of similar projects we have observed that a reduction of 5% tasks times can be considered in the last third of the manufacture. Applying this reduction at the average value in the lognormal distribution that define the tasks time we obtain the results represented in the Table 10 and Table 11.

Table 10: Schedule Impact with the Learning Curve Effect

Schedule Impact [days]						
Average floating	No impact	Very low	Low	Med	High	Very High
	>0	<5	<15	<30	<50	≥50
0.39	91%	9%	0.5%	0.0%	0.0%	0.0%

Table 11: Cost Impact with the Learning Curve Effect

Cost Impact [€]						
Average cost	No impact	Very low	Low	Med	High	Very High
29250.0€	91.5%	0%	0%	0%	5.5%	3%

With the effect of the learning curve in the tasks times, is not possible eliminate the risk, but as is represented in Table 10 and Table 11 the max CI is reduced to 5, which means that the risk level is low.

7. CONCLUSIONS

Overall, the simulation model developed allows checking the possibility of non-compliance the customer milestones, and allows an exactly quantification as to schedule and cost impacts for each identified risk.
In addition, throughout the project we have observed the importance of detect the risks in the planning phase due to the greater flexibility for elaborate mitigation plans, and the importance of this kind of tools in order to presents the risks analysis to the project manager.
Finally, the simulation model results demonstrate the high economic impact of break the customer milestones, and the importance of fulfil the project schedule.

Likewise, the results of this paper leave an evidence the importance of analyse the risk under different aspects and as a good risk management methodology can help us to finish the project successfully.

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