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OPERATIONS SESSION

Challenging Shallow Water DP Jacking DP - Design and Operational Feedback

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Abstract

For decades the critical importance of functions offered and ensured by electrical or software based systems. This paper aims to present a challenging project where DP technology is critical for the success of the operations. It lies indeed in the building of the largest viaduct worldwide, currently built in La Reunion, French island located in the Pacific Ocean. Built by a consortium between VINCI Construction Grands Projets (authorised representative), Dodin Campenon Bernard, subsidiaries of VINCI Construction, Bouygues Travaux Publics, a subsidiary of Bouygues Construction and Demathieu Bard Construction, the mega barge Zourite is a key element of the project. Zourite is a DP jack-up barge over 100 metres long with 8 legs designed to carry cargo items of up to 4,800 tonnes and 23 m in diameter.

The on-board DP delivered by Sirehna incorporates unique control algorithms and the operation carried out demonstrated the extreme precision of the system allowing the jack-up barge to maintain its position very accurately from its target position. Strong and efficient teamwork of all actors has been enforced and necessary for the success of incident-free operations.

In this paper, we will review the design of the jack-up barge, focusing on the innovative developments required for DP system and we will demonstrate how efficient marine operations planning and strong teamwork of all participants (crew, contractors, OEM staff, ...) have lead to maximize the values in order to achieve very challenging operations.

Introduction and Context – The Road

La Réunion is a french island located in the Indian Ocean, approximately 450 miles east from Madagascar, 100 miles southwest from Mauritius and is the most prosperous island of the Indian Ocean. This island is about 1000 square miles with a population around 850,000 people in January 2016 [1].

Figure 1 - La Reunion in the world

This very hilly and rough volcanic island is exceptional with a wide varitey of wildlife while the Reunion National Park, covering more than 40% of the island area belongs to UNESCO World Heritage Site since 2010.

Figure 2 - La Reunion a UNESCO World Heritage Site

The presence of the two volcanos -Piton des Neiges and Piton de la Fournaise (still in activity) - impose naturally to diffuclt topographic conditions leading naturally to major road network constraints. Moreoever, more than half of the population live in the north-west quarter of the island between Saint-Paul and Saint-Denis the capital and can be connected by only two road. One of this road,the Costal Road (Route du Littoral), is as indicated by its name along the coast and is often the prey of several hazards and unsafe situations

- Rocks fall
- Bad weather with strong winds and/or waves over the road

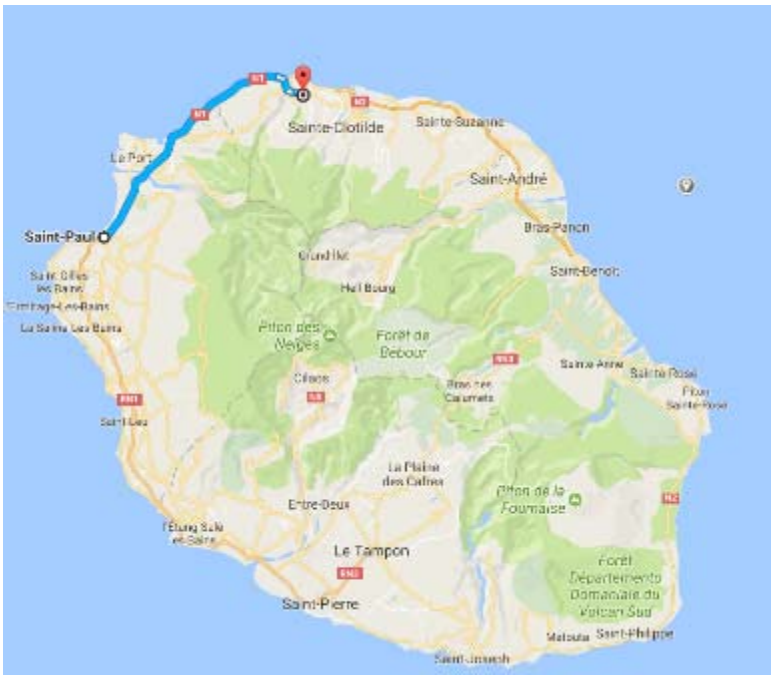


Figure 3 – Location of NCR, Saint-Paul and Saint-Denis

Figure 4 – Location of NCR, Saint-Paul and Saint-Denis From [2]

In 1999 and confirmed in 2006, the construction of a road over the sea has been validated to cope with the different challenges and answer the future needs of the island [3]. This road called New Coastal Road ("Nouvellle Route du Littoral") is hence a gigantic project with many technical challenges. This new 12.3km highway will be composed of three lanes in each direction and will connect Saint Denis, the administrative capital of La Réunion, with La Possession. This project is being carried out by French

consortium Bouygues Travaux Publics, VINCI Construction Grands Projets, Dodin Campenon Bernard and Demathieu Bard Construction. Once complete, this will be the most expensive road/km funded by France and an impressive demonstration of mastering and technologies.

Figure 5 – Illustration of New Coastal Road from [3]

Figure 6 – Illustration of Road Elevation from [2]

The road is scheduled to be constructed between 2014 and 2019/2020.

Schedule of construction work
End 2013 : Start of preparatory work (access to construction site) and signature of contracts for construction of large scale maritime structures (dikes/viaducts)
Starts 2014 : Construction work lot N°2 (dike of La Possession supporting the junction of the RD41 road) and lot N° 4 (viaduct of Grande Chaloupe: Start of construction of large scale marine structures (dikes/ viaducts), after a preparatory period of approximately one year for mobilisation of exceptional equipment that will be necessary (for example offshore platforms). It is estimated that construction of large-scale maritime structures will take approximately 4 years.
2019 / 2020 : Opening of the New Coastal Road.

Figure 7 – Construction schedule from [3]

This road contains especially a 5,400m offshore viaduc designed to resist to a 100-year swell event. This section is composed by 48 huge piles of concrete which are built in Le Port in a dedicated work area. Designed to resist cyclonic events, the road will be between 20 and 30 meters above the sea. The piles, which can be more than 4,500 tons are conveyed to the site by a DP Jack-up vessel specially built on-purpose for the construction. The construction is represented on the next figure.

Figure 8 – Piles Construction area

Constructed on a sensitive area, numerous studies have been driven in order to assess all components and prevent the hazards and for example ship collisions with one of the pile as represented on the next figure.

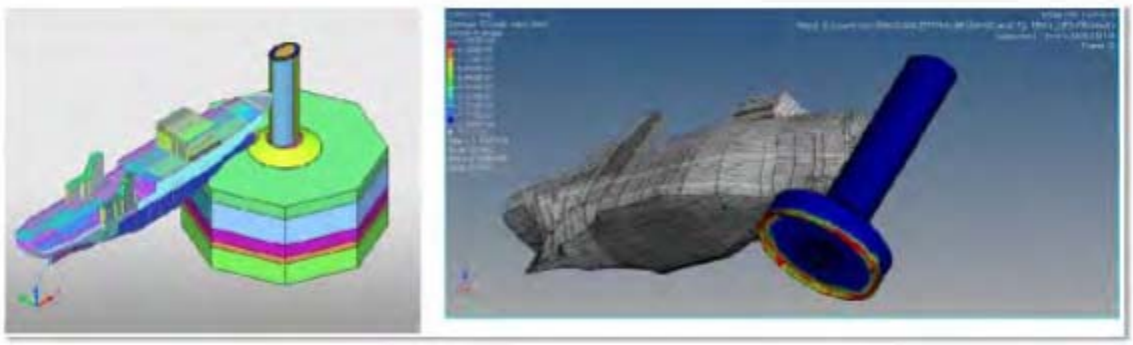


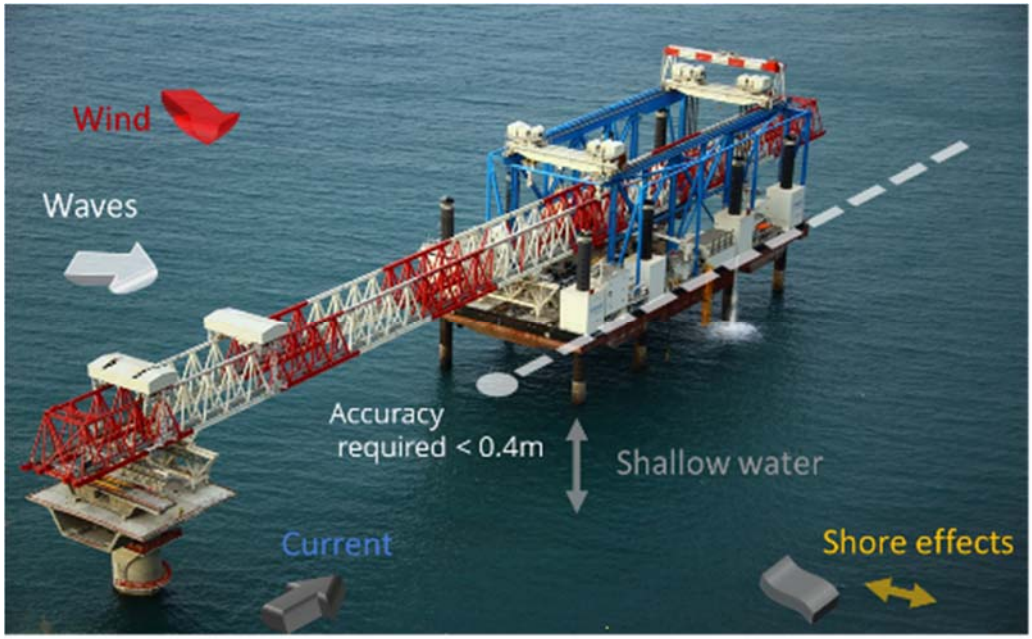
Figure 9 – Numerical simulations of ship collision with the piles

Figure 10 – Road Apron construction

The road apron is constructed from the first installed piles and will go over the piles which are installed by the Jack-up barge. Hence meeting the installation deadlines is more than important to ensure the viability of this mega project.

Our Challenge : Accurate Positioning in Jacking Operations in Difficult Conditions

The "Big Picture"



Photograph by Gwénolé de Kermenguy

Figure 11 – Illustration of the operational challenges

As illustrated on the above figure, numerous challenges have to be faced for the installation of the pile :

- Shallow water – less than 10 meters
- Shore effects – between 60m and 300m (less than 1 ship length).
- Wind and Thermic winds
- Waves and Swell (La Reunion is a famous surf spot)
- Current
- Important accuracy (less than 40cm required from the georeferenced set-point and less than 0.5° in heading)

The Heavy-Lift Jack-up Barge "Zourite"

Why Zourite?

Zourite is the name of a sea animal living in La Reunion and is a reference to the eight legs of the DP vessel. "Civet de Zourite" is also a famous dish from the Island.

Figure 12 –A Zourite

Main Ship Characteristics

Zourite is the first 8-legs DP vessel ever operated and has actually one of the strongest lifting crane in the world, able to lift huge concrete piles of more of 4,500 tons

Photograph by Gwénolé de Kermenguy

Figure 13 –Lifted pile

The main particular of the vessel are given in the next table

CIEMAR

ZOURITE
Heavy Lift Jack-up Barge
Le Havre

HLB Zourite – Data Sheet
Date : 28th March 2016
Revision 01A
Page 1 / 1

Main Charateristics :				**Jacking system :**	
Name of the Vessel:	ZOURITE			jacking system supplier :	Ravestein B.V.
Type of the Vessel :	Heavy Lift Jack-up Barge			Type :	hydraulic
Classification society :	Bureau Veritas			Nomber of legs :	8,0
I ⊕ HULL ⊕ MACH				Legs lenghts :	55,0 m
Offshore self-elevating unit Lifting Accommodation				Legs diameter :	3,0 m
Specific criteria La réunion - coastal area				legs max wall thickness :	60,0 mm
⊕ DYNAPOS -AM/AT				Spud cans dimensions :	5 x 5 m
				Maximum jacking capacity per leg :	4000,0 T
Flag :	French			Elevation range :	16,0 m
Date and registration number under French flag:	25/03/2016	/	FC 062039302	max speed :	0,40 m/mn
Port of registry :	Le Havre	immatriculation :	LH 933184 T		
IMO No:	9777981			**Lifting capacities :**	
Year and place of construction:	2016	/	CRIST S.A. , Gdynia, Poland	Over Head Traveling Crane supplier :	ENERPAC IS
				OHTC maximum capacity :	4 800,0 T
Main Dimensions:				Number of Hooks :	4,0 1200 T/each
Length Overall (including all appendages): abt.		108,0 m		Cable diameter :	52,0 mm
Hull length LOA:		107,0 m			
Length between perpendiculars LPP:		105,00 m		Auxilary Overhead Cranes :	ENERPAC IS
Overall Breadth of the Vessel ((including all appendages): abt.		47,5 m		AOC capacity :	25,0 T
Hull Breadth moulded:		44,00 m		Traveling type :	1,0
Depth moulded :		7,00 m		Fixed type :	2,0
Minimum draft in ballast cond. : abt.		3,95 m	above base line		
Design draught:		5,05 m	above base line	Deck crane Port side :	Global Davit GmbH
Summer Freeboard Draught:		5,085 m	above base line	Deck crane capacity :	6,0 T
Scantling Draught:		5,10 m	above base line	Man riding :	1,0 T
Maximum air draft (legs up):		51,65 m	(at light ballast)		
Weight		13 146 T		Crawler crane :	Manitowoc M1200
Gross tonnage:		9242		Boom lenght :	24,0 m
Net tonnage:		2772		Maximum capacity :	110,0 T
Propulsion :				**Concrete production :**	
Power :	4 x 900 kW azimuth - Schottel GmbH rudderpropellers			Batching plant supplier :	Europ Equipement
Installed power :	4 x 1200 kW	Caterpillar		Agregats storages	4 x 50 m
Bollard pull :	30 T			Concrete mixer capacity :	3,0 m3
Speed :	3,5 kts mini			Grout mixer capacity :	1,0 m3
				Ciment silos capacity :	185,0 m3
Mooring :				Conveyeor belt	
Winches pulling capacity :	40 T			Chilling plant	
Number of lines :	4			Concrete/Mortar pump	4 units
cable diameter :	52 mm				
				Main storages :	
Deck capacities :				Fuel storage MDO :	200 m3
Payload :	4730 T			Fresh Technical Water :	360 m3
Free deck surface :	1875 m2			Sanitary Water :	100 m3
Deck capacities :	10 T/m2 outside OHTC			Concrete Wash Water :	200 m3
	20 T/m2 under OHTC area				
	30 T/m2 at Fore			**Navigation & communication systems :**	
Others :				Dynamic Positioning DP1	Sirehna EasyDP
Accomodations :	12,0 persons			Positioning system	RTK
Max. number of persons on board :	50,0 persons				
Moon pool :	aft moon pool 25 x 25 m + remote wheelhouse control cabin				
Operating draft :	7,0 m				

Figure 14 – Main Ship Characteristics from [2] – Courtesy Compagnie Maritime du Littoral

Pile Installation Operations

In order to install the pile and ensure the construction of the road, a very demanding positioning accuracy is requested since the alignement between the road and the next pile is crucial.

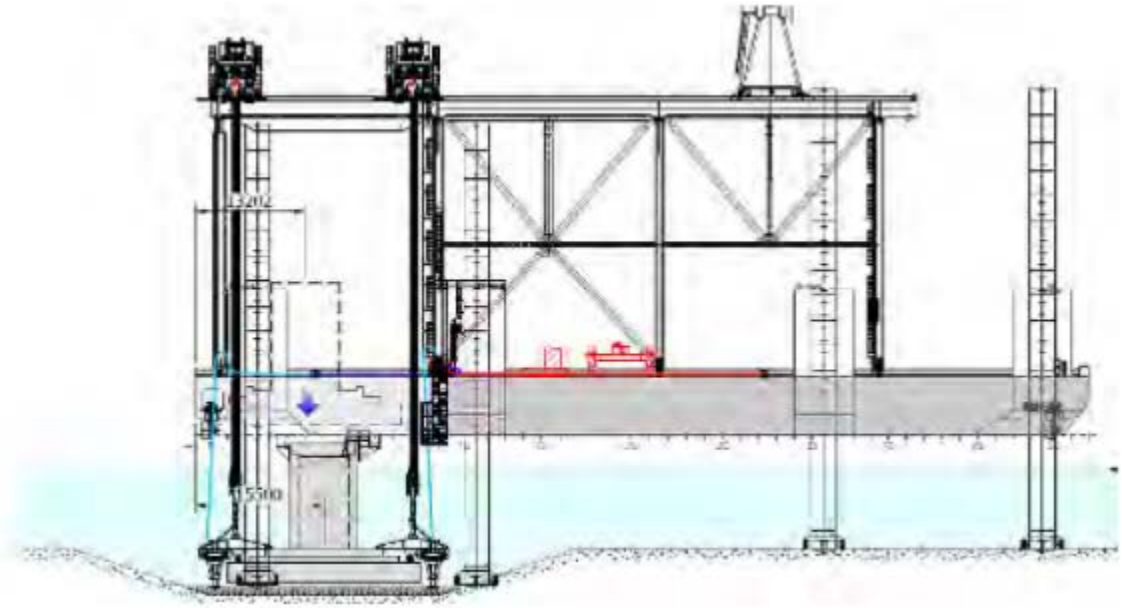


Figure 15 – Illustration of a requested DP location from [2]

Furthermore, a pile cannot be installed at once but in two times, reinforcing the needs of a very accurate,n robust and safe vessel.

Figure 16 – Pile assembly from [2]

Figure 17 – Pinocchio Dipper from [2]

The good soil conditions are ensured by a Dipper and is monitored by divers and automated measurements.

Furthermore, the required accuracy in the harbour is less than 15cm in order to load the piles as it is represented on the next figure.

Figure 18 – Pile Loading illustration – Courtesy Compagnie Maritime du Littoral

Tailored DP system

Requirements and State of the Art

As detailed in the previous section, numerous challenges have to be coped with.

- DP jacking operation
- High Accuracy and reliability
- Combination of demanding effects.

Therefore a bibliographic and experiences review study has been conducted in order to identify the main points. We have mainly found 2 papers

- IMCA Guidance for the positioning of DP Jack-up vessels on the seabed [4]
- DP Control Augmentation for Jack-up Vessels [5]

After analysis, it turns out that very few papers deal with DP Jack-up vessels and according to experienced operators, the project requests (<40cm accuracy) are not common. The operators are very satisfied with a positioning less than 5 meters which is more than 10 times the accepted limit. A strong effort of customization and improvements has then been led with Sirehna. These specific developments will be presented in the next sections.

The main reported challenge is associated to the modification of the aerodynamic and hydrodynamic responses of the barge as it is represented on the next figure. Also, a severe effect can occur if standard DP control schemes are used when the first leg has touched the bottom. If standard control scheme is still used, the integral effects and the overall control forces can quickly blow up, leading to unsafe propulsion requests.

In order to cope with this, IMCA has proposed very specific procedures and requirements as given in [4].

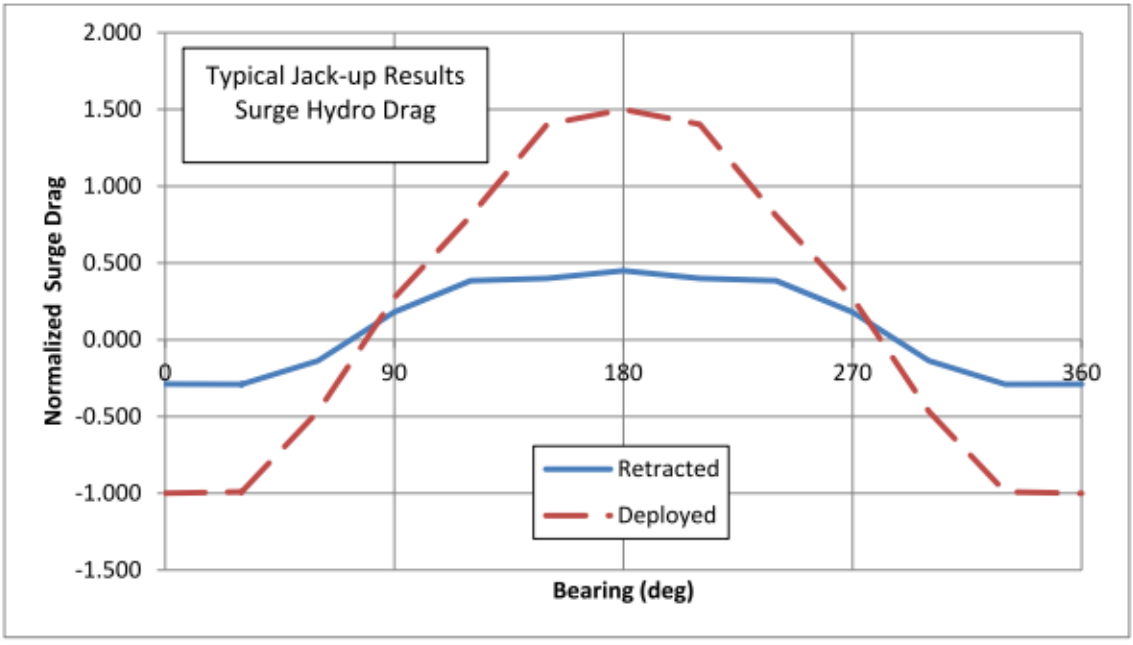


Figure 19 – Jackup legs hydrodynamic effects

i) Further lowering of the legs as defined by the vessel procedures should continue. The DPO should pay very close attention to the DP references and the position of the vessel and allow the DP system time to fully stabilise. Further adjustment of DP – When the legs are positioned the correct distance from the seabed as defined by the vessel procedures, the DP configuration should be selected as defined by the vessel procedures that may, for example, put the DP system into freeze current mode or low gain mode.

k) Soft pinning the legs and turning off DP – When the vessel's legs penetrate the seabed, the vessel is then effectively moored on the legs. As soon as it becomes obvious that the DP system is not required anymore for position keeping, the DPO can select manual joystick mode keeping all thruster propulsion at zero thrust. At this stage it is important the DP system keeps the DP model, in case the vessel has to transfer back to full DP mode during the initial stage of soft pinning of the legs.

i) Moment that the vessel becomes a free-floating vessel again (DP transition) – When the pre-defined clearance above the seabed is reached, giving the vessel enough clearance to move, the propulsion systems can be engaged, ensuring that there is a zero resultant force on the vessel. The DPO and vessel Master should be aware that large thrusts by the vessels propulsion systems can potentially result in damage to the legs or nearby structures.

k) Transit away from location – The use of auto DP mode is not recommended when transiting from location. There may not be sufficient time to build up the vessel's DP mathematical model with the legs still down. The vessel should continue to be moved away from the installation in joystick mode until in a pre-defined safe area. Full auto DP can then be selected. The DPO should always be aware of the depth of the legs and not exceed the maximum allowable forces on the legs (maximum speed). This information may be available on the DP system.

Figure 20 – IMCA guidance for DP Jack-upvessels

However, for this very specific project, we had to achieve more than the existing systems. Nevertheless the conclusions stated in [5] will be a very important input for the design and validation of the specific system.

Issue	Solution	Backup
Variable Aerodynamics and Hydrodynamics	Jack-up Compensation based on leg length input	Manual leg length input
Integral windup due to bottom forces at touchdown and prior to liftoff	Auto Integral Freeze at first contact	Manual contact input and Manual Integral Freeze
Drift-off during model development at liftoff	Current sensor input, operator assessment of currents, Current Compensation	Quick Current

Figure 18 –Issues and Solutions summary from [5]

Project Specifities – Control Engineering Approach

The presence of shallow water, the near-shore location along with really demanding performances are indeed very dedicated constraints we had to deal with.

Therefore the standard "Control Engineering" approach methodology has been deployed

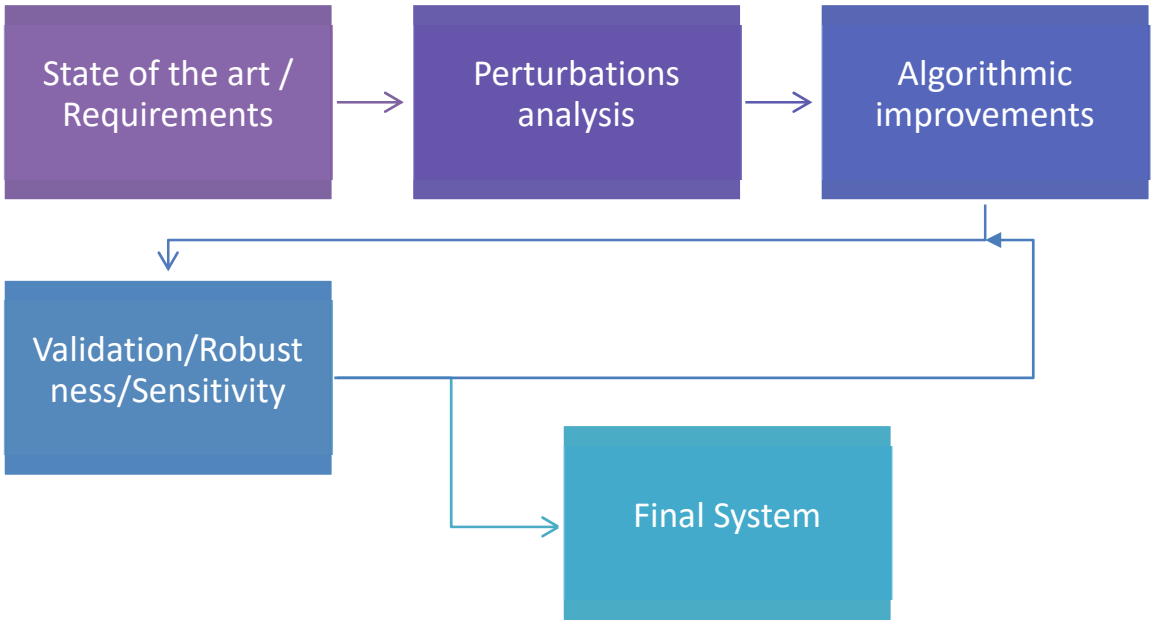


Figure 22 –Control Engineering methodology

Perturbations Analysis

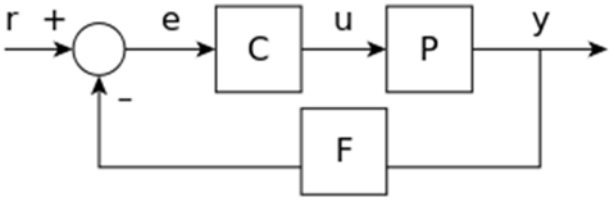


Figure 19 –Control engineering

The control theory is an engineering branch dealing with the behaviour of dynamical systems. The goal here is to determine what will be the most probable disturbances and their effects on the system in order to build control algorithms able to reject accordingly these perturbations and provide optimal performances. In this case the main contributors are

- Shallow water effects induced by the platform and the legs (e.g [4] [2])
- Hydrodynamic loads induced by the current (e.g. [5] [6])
- Aerodynamic loads (Figure 11) – the superstructure are indeed very complex

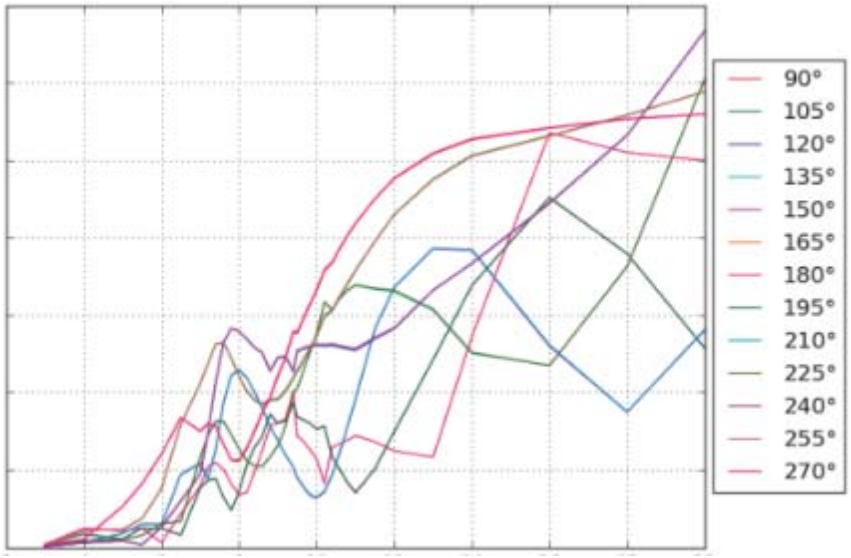


Figure 20 –Example of ship responses (RAO) in shallow water

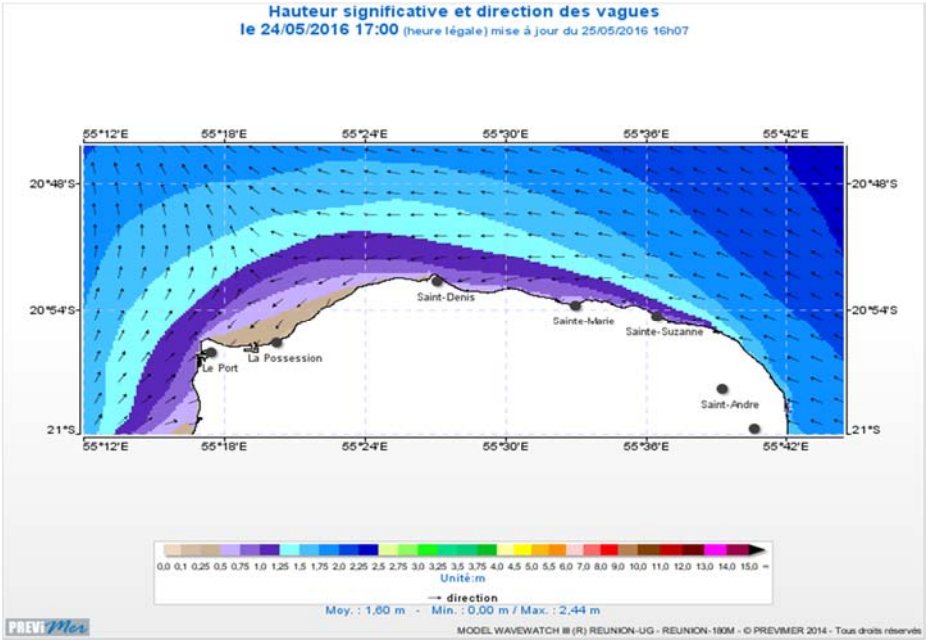


Figure 21 – Main waves direction and height analysis

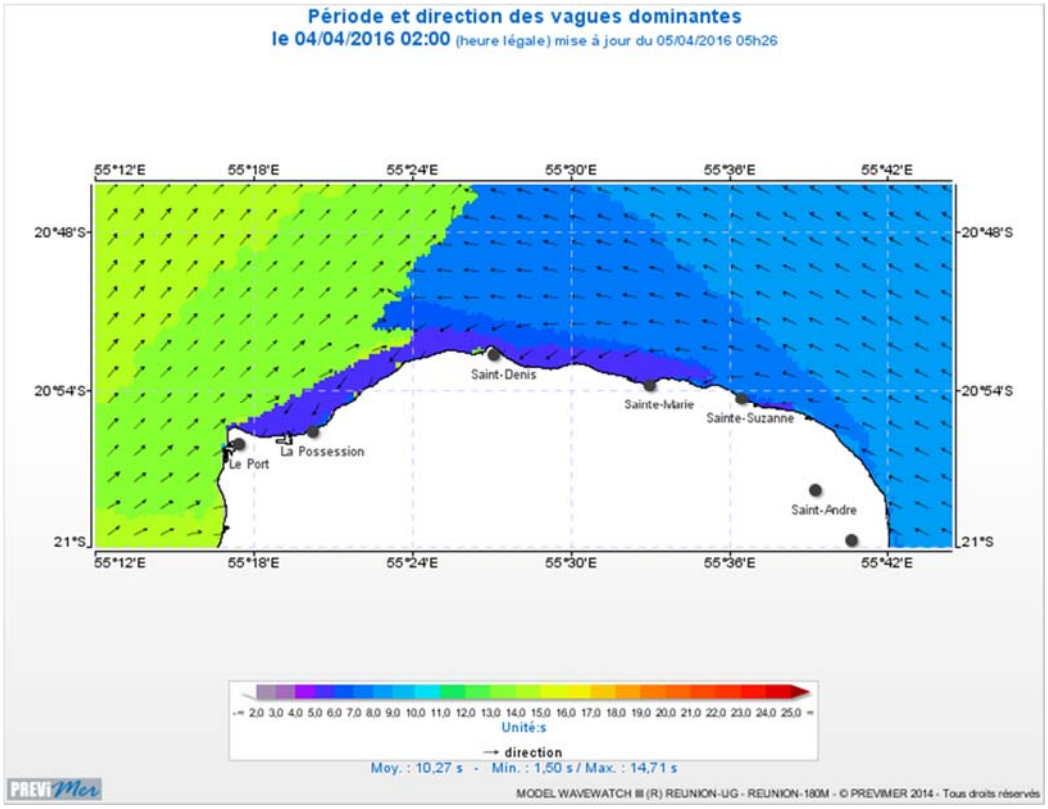


Figure 22 – Significant Period analysis

Specific wind and hydrodynamic studies have been performed and have been taken both in the design of improved control schemes but also in the software validation testing. Finally specific thrusters informations (thruster/thruster, thruster/hull, thruster/piles interactions) have been specified.

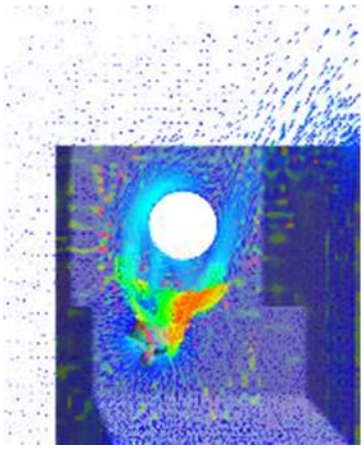


Figure 23 – Illustration of thruster interaction with a pile

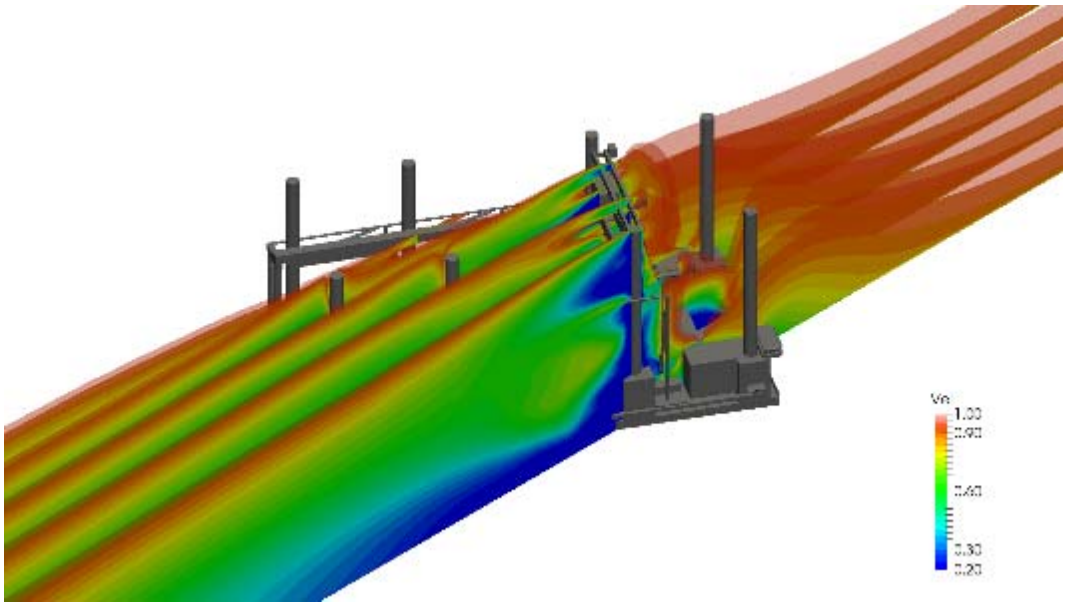


Figure 24 – Example of CFD calculation for the wind interaction

Sensors

Very accurate RTK measurements are provided giving an extreme confidence of the measurements (accuracy <2cm) while a precise Inertial Measurement Unit gives the attitude and heading of the vessel. The information are also redundant.

Dedicated Modes

SIREHNA has developped specific features (e.g. 'FREEZE CURRENT') and integrated the information of the legs and the dedicated project information in their DP system. This was permitted with the highly customizable DP HMI developped by SIREHNA and has been smoothly plugged in the system. Moreover a strong communication with the operators was done in order to ensure the clients desires and operational feasibility.

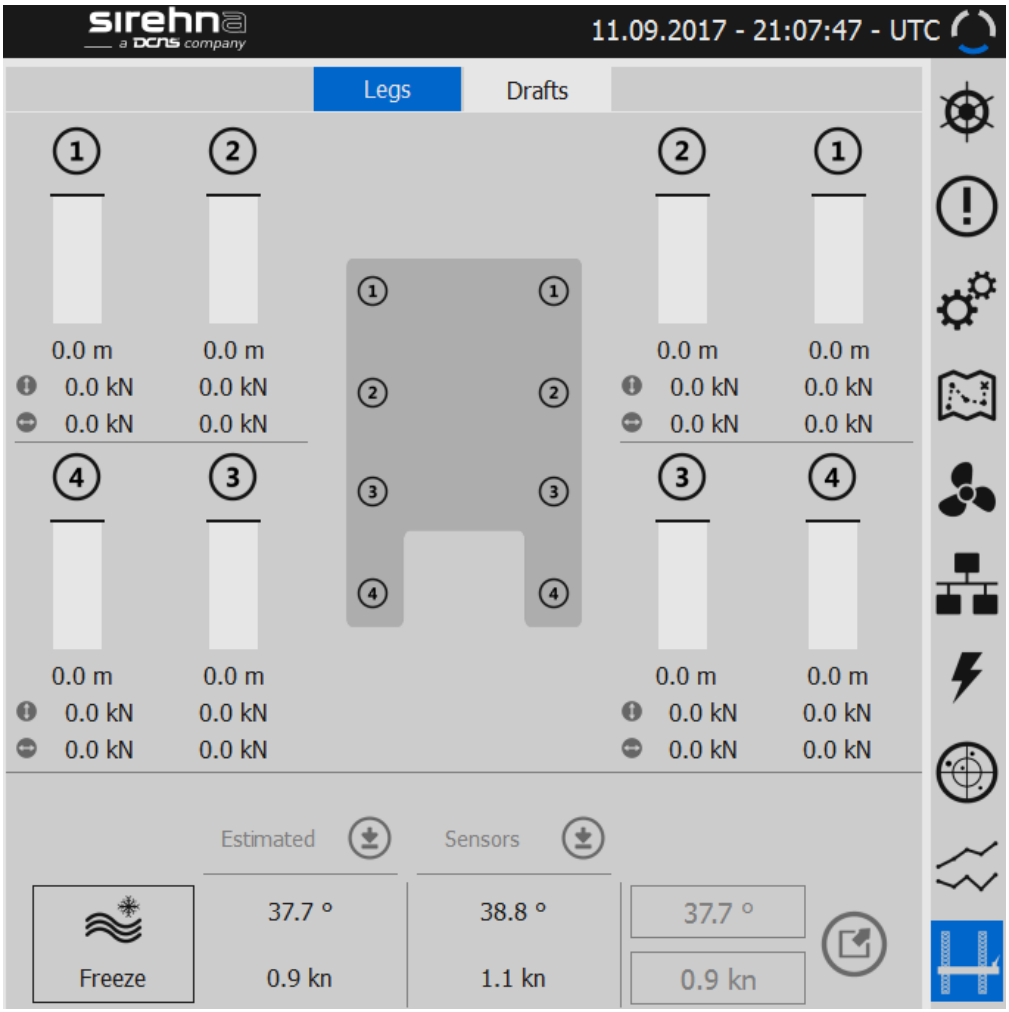


Figure 25 – Specific Mode developped by Sirehna for DP Jack-up Vessels

Figure 30 – Installed Sirehna DP system

Algorithmic Improvements

As shown in this paper, tailored developments have been achieved for the success of the project.

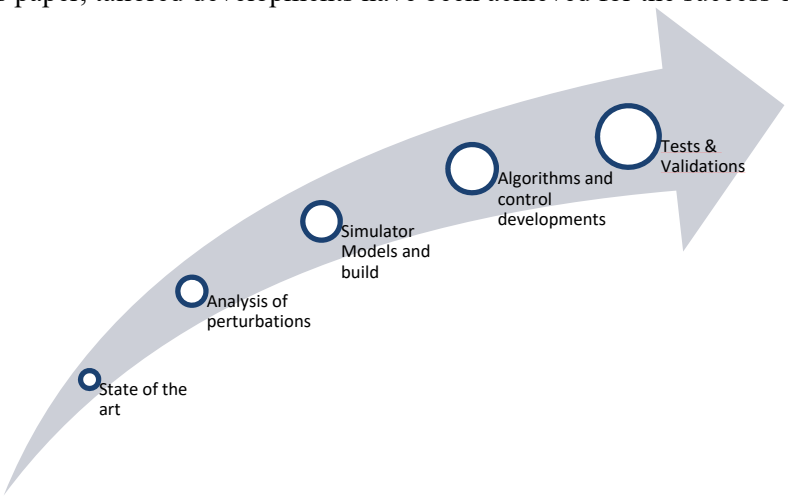


Figure 26 – Algorithms improvements methodology

Mathematical Modelling

The general equation driving an hydrodynamic platform is given by [6]

$$M\frac{d\vec{v}}{dt} + C_{RB}(\vec{v})\vec{v} = \vec{F}_T + \vec{F}_H + \vec{F}_A + \vec{F}_W \quad (1)$$

Where

- M is the generalized mass matrix of the vessel (including added inertia)
- C_{RB} is the rigid body and centripetal matrix
- $\vec{v} = [u \quad v \quad r]^T$ is the planar motion vector in the ship body frame
- $\vec{F}_T$ are the thruster forces
- $\vec{F}_H$ are the hydrodynamic forces
- $\vec{F}_A$ are the aerodynamic forces
- $\vec{F}_W$ are the waves forces

Hydrodynamics and Aerodynamic Modelling

Specific calculations had to be performed in order to identify the behaviour of the platform.CFD and potential theory calculations were lead since the platform is very complex and the positioning objectives are high.
These specific calculations were translated as specified in [6] in order to build an accurate mathematical model of the vessel taking in account all the different configurations (legs up/down, shallow water, near shore effects).
A simulator was built in order to validate the control schemes.

Specific Improvements

The standard DP scheme is represented below [7]

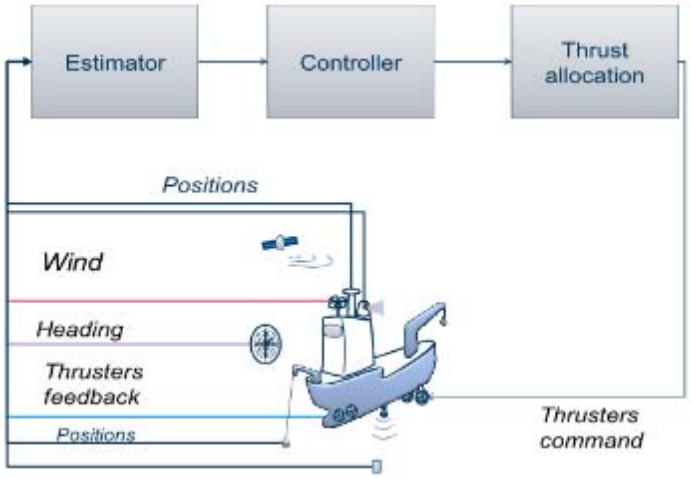


Figure 27 – Standard DP Control Strategy

For this project, we had to improve all the block diagrams to achieve the operational goals

Estimator

The estimator has to take in account the multiple existing configurations (legs up/down, draft, thrusters efficiency,….) and manage the contacts between the seabed and the legs. Sensors were installed on the leg and are able to inform the Estimator of the contact. The submerged length of each leg is also an input of the system and has been taken in account in order to deal with the modification of the ship hydrodynamics. An example of the improvements is given below.

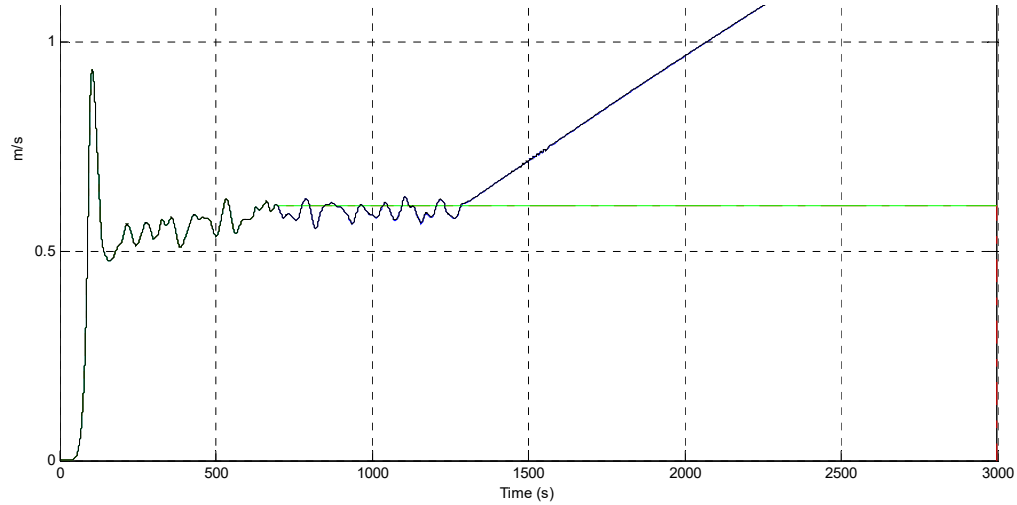


Figure 28 – Example of estimated current norm versus time – Black Standard DP - Green with Jack-up Estimator – Contact at 600s

Control Algorithms

The control algorithms were specifically reviewed in order to reject and cope with most probable sea conditions and deal with the seabed touchdown. Furthermore, several robustness studies were conducted in order to ensure the system performances.

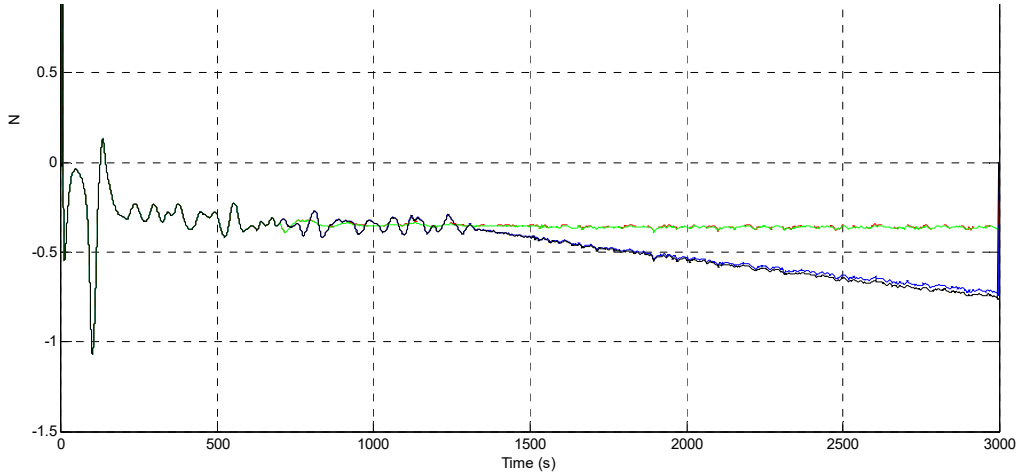


Figure 29 – Example of requested Surge Forces norm versus time – Black &Blue Standard DP – Green & Red with Jack-up Estimator – Contact at 1250s

Thrust Allocation Logic

Specific strategies have been deployed according the results of the CFD studies. Furthermore, a significant effort was done together with the electrical manufacturer in order to boost the thrusters reactivity.

System Validation

The full system and control schemes have been intensely validated in SIL (Software in the Loop) and HIL (Hardware in the Loop) testings. These methods are fairly recognized today as state of the art of System Engineering [8] [9] [10]. Their benefits have been reported in many different papers and especially in the last MTS DP conference editions. They provide a direct return on investments by reducing the time of Sea Trials and improve the systems reliability.

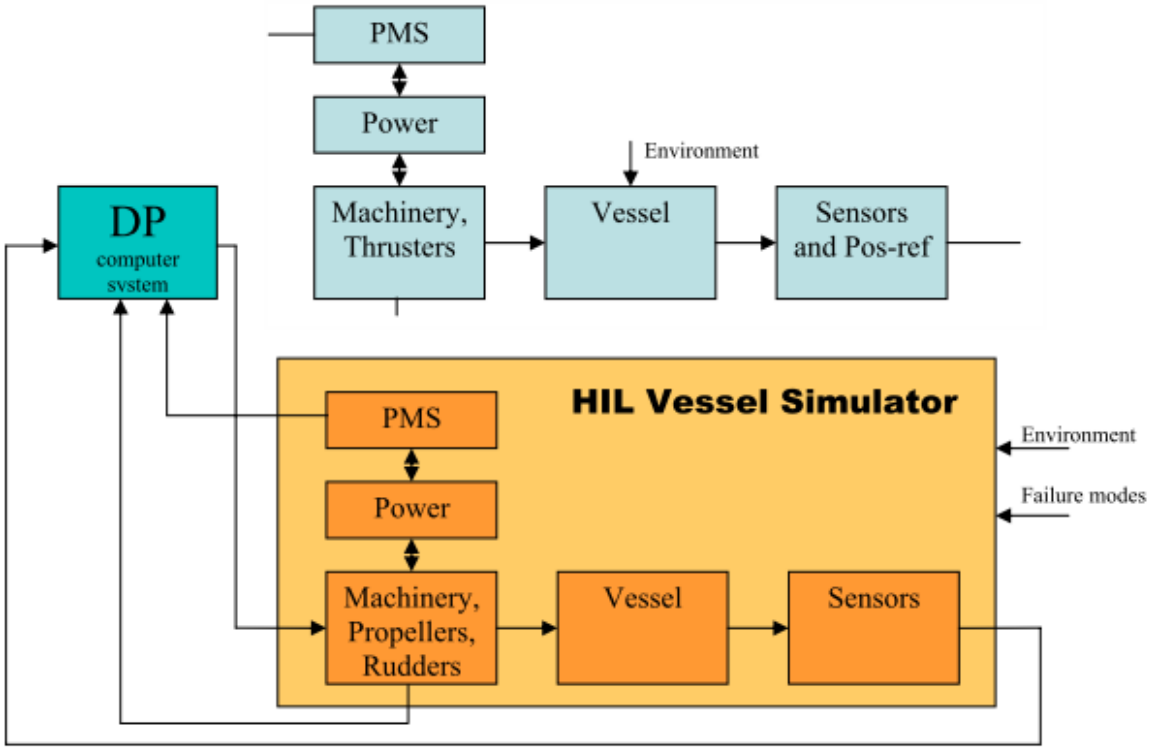


Figure 30 – Standard HIL Vessel Simulator From [8]

HIL and SIL testing were setup in the early phase of the project in order to cope with unplanned scenarios which can occur with an higher probability in innovation projects.

Reliability and Safety Analyses

After bibliographic review, operators feedback analyses and HIL/SIL testing, it turns out that the most critical operations is the unjacking of the vessel. The DP current is indeed not build as the ship is above the water with the system switched off. Furthermore, the tolerances are very low (less than 1.5 meters) and it is required to leave the location very quickly.

All other critical operations have been also analyzed and prioritized in the testing methodology.

Criticity	Operation
1	Unjacking with MSVP (Mega Voussoir sur Pile) on site in shallow water and maximal accepted sea states in real near shore conditions
1.5	Unjacking with MSVP (Mega Voussoir sur Pile) on site in shallow water and maximal accepted sea states
2	Jacking with Base installed on site in shallow water and maximal accepted sea states near shore
2.5	Jacking with Base installed on site in shallow water and maximal accepted sea states
..	…

Table 1 - Operational criticity analysis

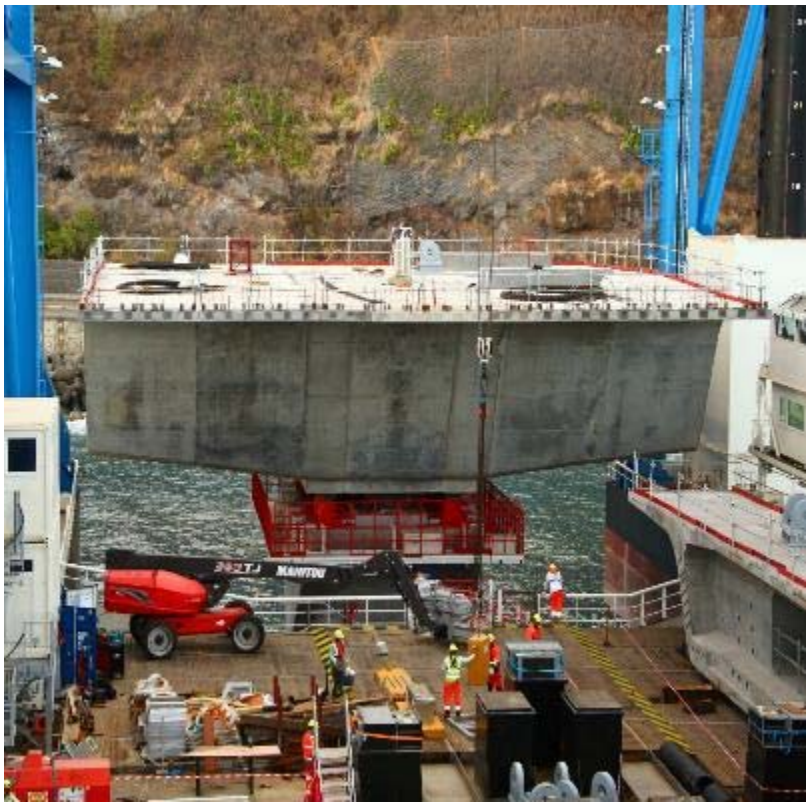


Figure 31 – Unjacking configuration with the full installed pile

Operations Feedback

Sea Trials and Commissioning

There is no surprise but there is always a gap between theory and practice. Regarding the complexity and the operational requirements, real simulation of jacking/unjacking operations were conducted successfully during the sea trials. They have demonstrated the necessity to improve the thrusters responses in order to boost the positioning performances and spotlight more than all the importance of communication between the DP operator and the Jackman. DGPS with RTK corrections have been outlined as crucial element.

From these tests, specific operating guidelines were written and all the main actors (OEMs, Crew, Engineers) have been involved during the first jacking operation onsite.

DP Performances and Operating Guidelines

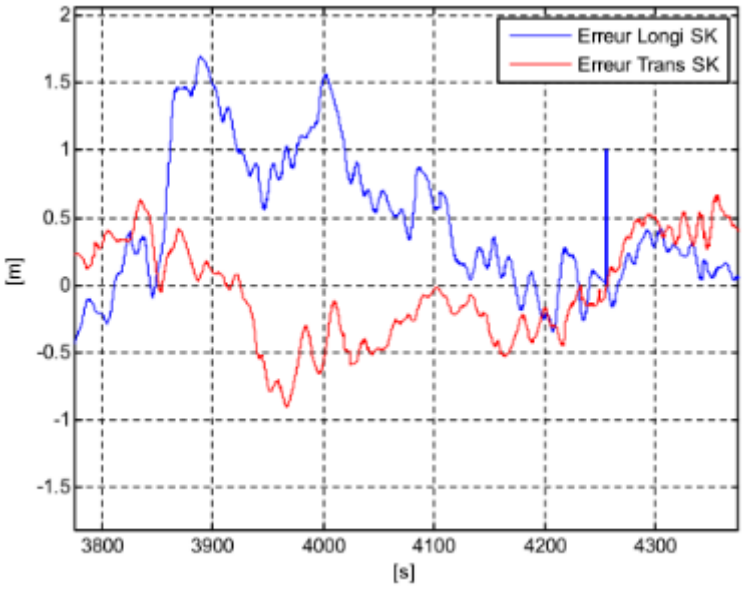


Figure 327 – Recorded position error during jack-up operations

The SIREHNA DP System performs very well. The crew has been well trained off-site and on-site and is able to understand the challenges and understand very well the DP System reaction. Having all engineers and the experts onboard during the first critical operation was very helpful. This brings a lot of confidence to the operators.

Moreoever, it is important to note that the DP reference point is not the final targetted point which is tracked by an external system (POSIT – delivered by CADDEN, a french Company). A first jacking attempt, a final jacking error of 50cm was reached which was out of the design limits. A second attempt has been done, after providing a quick feedback and spotlighting the main weakness : communication between jackman and DPO. As shown on above figure, the ship is actually “hovering” above the target point. The communication between the jackman and the DPO is essential to ensure that the legs will be lowered at the good time as represented on the next scheme.

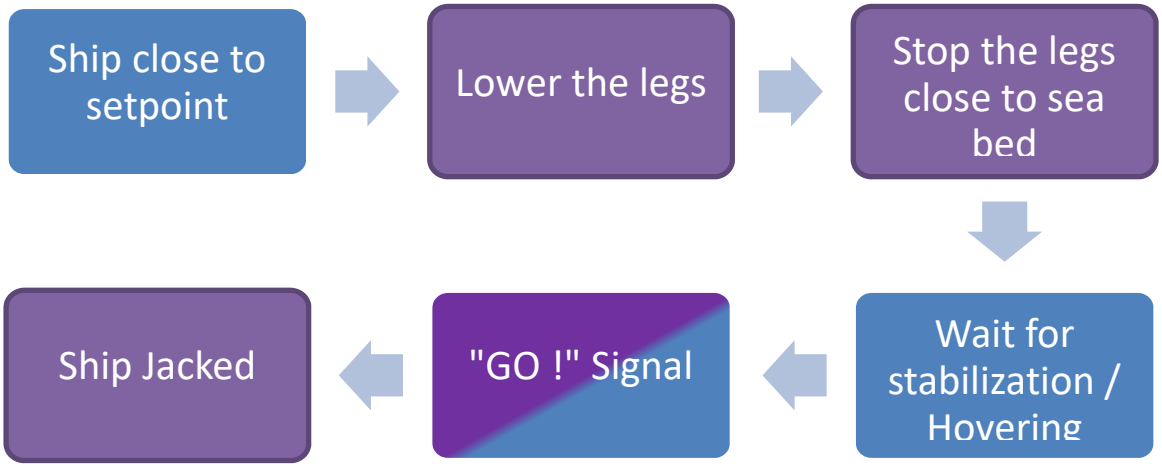


Figure 33 – Jacking Sequence – purple : Jackman Responsility – Blue : DPO Responsibility

As a result the final jacking accuracy experined is 1 centimeter which is the most accurate DP jacking operation ever done and has been pictured below.

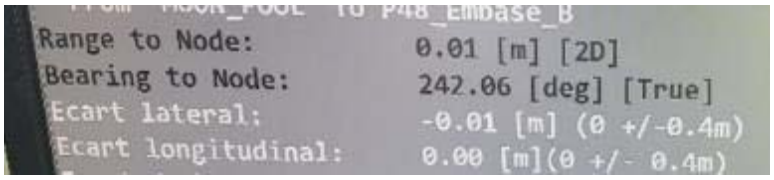


Figure 39 – Final jacking position performances for the first operation

Operating guidelines have then been tailored to the actual system performances and also with operational analyses. For example, one can monitor the buoys installed near the operations area to assess and better anticipate what will happen.

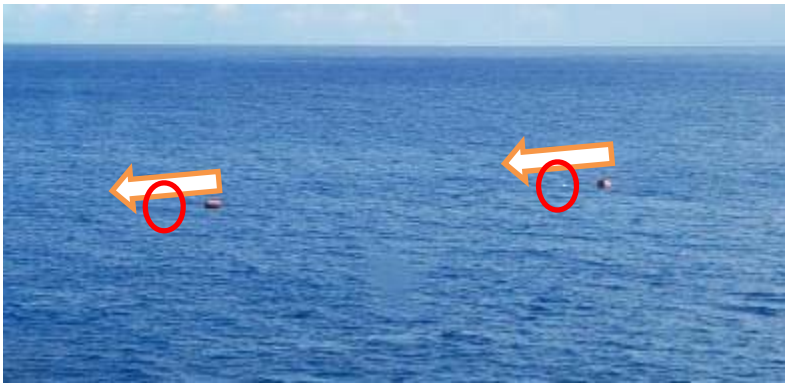


Figure 40 – Example of "human monitoring"

Figure 41 – Local learnings

A unexpected effect was the thermic winds from the island in the morning. This was difficult to forecast but experienced sailors know them well

One year after the commissioning and the first jacking operation, more than 12 piles have been installed which is inline with the planning. No DP incident have been related and the crew have gained great confidence in the installation method, reducing more and more the time required to perform a pile installation.

Conclusion

This project and achieving unmatched performances is "only" a fine combination of technology and people. We can achieve the best and push the limits with strong implication, team work, good communication, training and expertise. All people involved in these project have given their best to achieve these unpublished results.

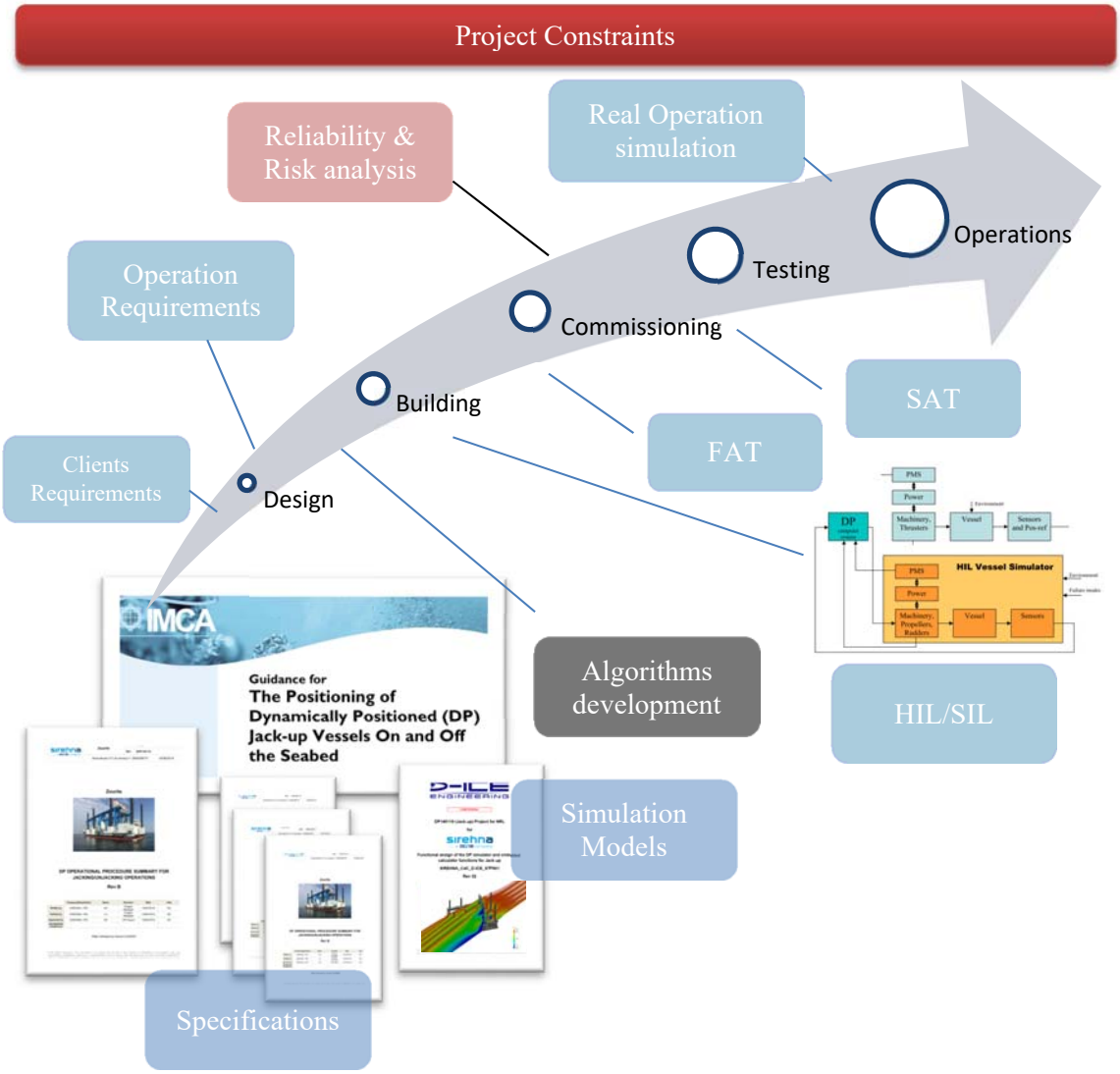


Figure 34 – Overall development process and working methodology

Solid and recognized methods and best practices in Control Engineering and System Engineering (Simulations, Calculations, HIL/SIL) have been deployed. It was crucial to rely on experiences feedback and IMCA guidances. In the future, we can still improve the methods and the system thanks to better confidence in the numerical models and in algorithmic improvements but nothing will replace experienced people (engineers, crew) and efficient teamwork. It was the true key parameter for the success of the operations.

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