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CONCEPT SELECTION METHODOLOGY FOR SUBSEA PROCESSING PROJECTS

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Abstract. *Various prospects are assessed when developing an offshore production system. This is done to select the best configuration to maximize oil recovery at lowest possible cost. Various Business Cases arise with different technologies, arrangements, systems, etc. and it is the Oil Company duty to select the most appropriate one. Investments in Oil&Gas are always huge, therefore is imperative to evaluate and select the best concept, which usually tends to prevent the adoption of new (and therefore risky) technologies. One area that is known for its novelties is the Subsea Processing domain, which in short, could be explained as the deployment of topside process operations (i.e. separation, pumping and boosting) to the seabed. Projects that considers Subsea Processing solutions should have a clear and documented process to demonstrated why a specific concept is selected, in order to minimize risks and facilitate Operator's investment approval.*

This paper proposes a new methodology for concept selection, that is able to provide a structured process to evaluate various technologies and concepts, to select the most appropriate solution for each application.

Research is based on a real Case Study that was performed for two major oil companies. A conceptual study was conducted to select the best subsea system, with the requirement to incorporate a specific patented technology for oil and water separation. To progress with the concept selection, a methodology that also incorporates the basis of the Pugh Matrix was proposed.

A structured process for assessment and selection was achieved. Good discussions were held to strengthen the path for the chosen concept, and disregard other technologies/systems, that initially seemed to be better.

The methodology was well received by all participating parties, which approved the process. They were used to like "brainstorming meetings" which lacks a structured way to evaluate all technologies and configurations. The process also allowed an in depth review and discussion of subsea processing technologies among all participants, which also promoted knowledge sharing and integration. Although improvements to the tool were identified, participants feedback was that they were willing to apply the methodology internally.

Keywords: *Concept Selection, Concept Methodology, Subsea Processing, Pugh Matrix*

1. INTRODUCTION

The Oil&Gas industry is known for its conservatism and slowness to adopt new technologies. Traditionally both cost and investment time, specially for offshore projects, are huge. When new opportunities arise, especially those that involves new areas/technologies, it is important to properly fundament the decision for non-standard solutions.

In the branch of novel areas on the offshore sector, lays the Subsea Processing domain, which is usually referred as subsea operations that includes separation (e.g. gas/liquid and/or oil/water) and boosting (pumps and/or compressors) in addition to all supporting elements (controls, process controls, power, power distribution, etc.). Another way to refer to Subsea Processing, could be a step towards moving some (or all) of the topside operations to the seabed. Although not new, there has been projects since mid-90's (INTECSEA, 2018), projects in the subsea processing domain are sparsely.

Going from topside to subsea brings benefits and challenges. A clear benefit is the lack of footprint restriction which is common in a platform. Equipment can be deployed alongside each other without any concern about area, which contribute to a flexible design to promote changes and/or addition of new equipment over the life of the field. Subsea systems shall allow remotely control, which also means removing people from dangerous areas, such as an offshore platform and helicopter travels. Subsea systems usually requires less materials (e.g. steel) than topside systems, as a minimum it doesn't requires a floating structure nor a space to host people with all the associated supporting activities (travels, supplies, etc.), which contributes to a reduced carbon footprint.

Other benefits of Subsea Processing is the potential to increase recovery and reduce OPEX. Hofstad and Nilsen (2017) compares a traditional field development with gas lift (no subsea boosting power) to an alternative solution with a boosting pump (Figure 1). They also assess the power implications (2 to 6 MW) on the pump. It can be seen that as the power increases, the total oil recovery also increases, and the reason is because as more power is provided, higher differential pressure can be achieved over the pump, which reduces the backpressure to the host facility, which can be 3000 m above seabed or some kilometers away, on the shore. The beneficial effect of the reduced backpressure is that it increases the well productivity, which is demonstrated by the increased total oil recovery.

The Annular Oil Production (Figure 1) shows that more oil is produced at the early years, leading to reservoir depletion sooner than without a subsea pump, as it increases well productivity. It means that subsea boosting allows to finalize one asset production earlier and relocate to another asset, which leads to lower OPEX.

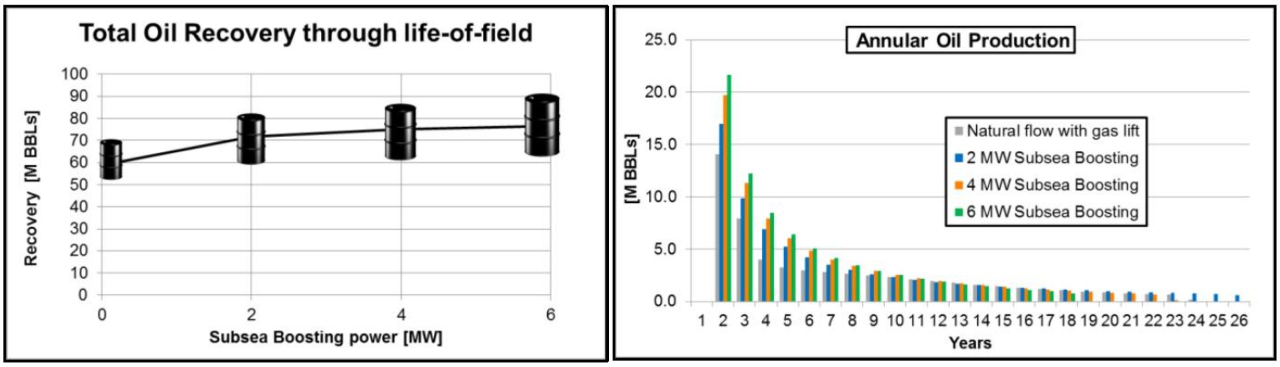

Figure 1. Total oil recovery (L) and annular oil production (R) (Hofstad and Nilsen, 2017)

One scenario often considered for Subsea Processing is to debottleneck platforms that are producing too much water. Water injection is one of the conventional solutions to increase oil recovery, but the injected water is recirculated back to the reservoir which over time increases the water/oil ratio. At some point the topside facility is capped on water, limiting the oil production. Since the platform has fixed space, little can be done. Those scenarios are good candidates to promote oil/water separation at the seabed. Water removal and reinjection subsea "frees" space topside for oil production.

Considering the balance of benefits and risks of Subsea Processing projects, it is usual when developing offshore fields to early evaluate concepts that incorporates Subsea Processing technologies. It is the perfect timing to investigate the likelihood to move ahead, and to start to propose mitigating actions when applicable. In order to properly evaluate those concepts a structured and formal methodology is proposed based on the Pugh Matrix. Such methodology has clear benefits when compared to brain-storming/heuristics type of approaches, helping the decision making process by incorporation a clear analytical process to evaluate different technologies, systems and recording all.

The methodology was applied to select the best subsea system considering a proprietary technology for oil/water separation and some other requirements. The technologies involved and proposed methodology will be described in the following chapters.

2. CASE STUDY

The proposed methodology described in Section 3 was developed for a specific Case Study. Two major Operators were interested in a conceptual solution for a subsea system being able to remove and inject water. Various requirements were given, such as flowrate, water cut, sand concentration, water depth, flushing requirements, availability, footprint, weight and many others. Another key requirement was that the chosen system shall contain the PipeSeparator technology, which is a solution to separate oil and water. The PipeSeparator is made of a long pipe(s) so that it provides relatively the same residence time as a gravity separator, which makes it more suitable for deep waters as the deeper it is, the higher the external pressure is, meaning that at some depth, a gravity separator vessel cannot be used, but a pipe can be. Some claims that the PipeSeparator performance is better than gravity separators, as reducing the flow area from a vessel to a pipe, reduces the droplet travel distance due to reduced diameter, which also increases the velocity, and due to density difference between oil and water, the shear force in the emulsion layer helps to break down the emulsion in the oil/water interface, which would lead to cleaner fluids.

Some Operators, vendors and universities have being developing and testing PipeSeparators based solutions, due to the benefits mentioned above. In 2012, Petrobras has installed a system based in the PipeSeparator technology called SSAO (Subsea Water / Oil Separator), in the Marlim field, in Brazil (Figure 2). The project aimed to remove and inject water subsea to increase oil production in the topside.

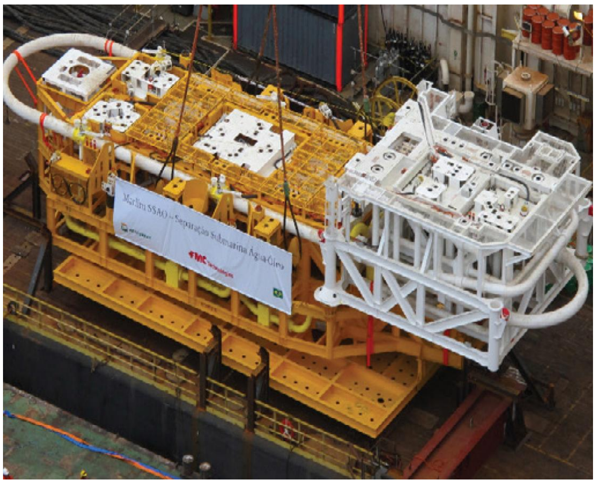

Figure 2 – Marlim SSAO (INTECSEA 2018)

Such a solution could be applied on Brownfields (such as Marlim) that already have a high water cut, but also on Greenfields to prepare for the water that will kick-in. In both cases, such system allows to increased oil recovery by maximizing topside facility to cater for oil production.

3. **PROPOSED CONCEPT SELECTION METHODOLOGY**

A concept selection methodology was developed to find the best solution for the system design challenges, proposed by Company, based on previous experience and Pugh’s matrices.

The methodology presented in Figure 3 shows how, from design basis, a list of potential technologies are identified and screened, moving ahead on the process to select the base case solution and further progressing on tasks to deliver a solution aligned with requirements and Company needs.

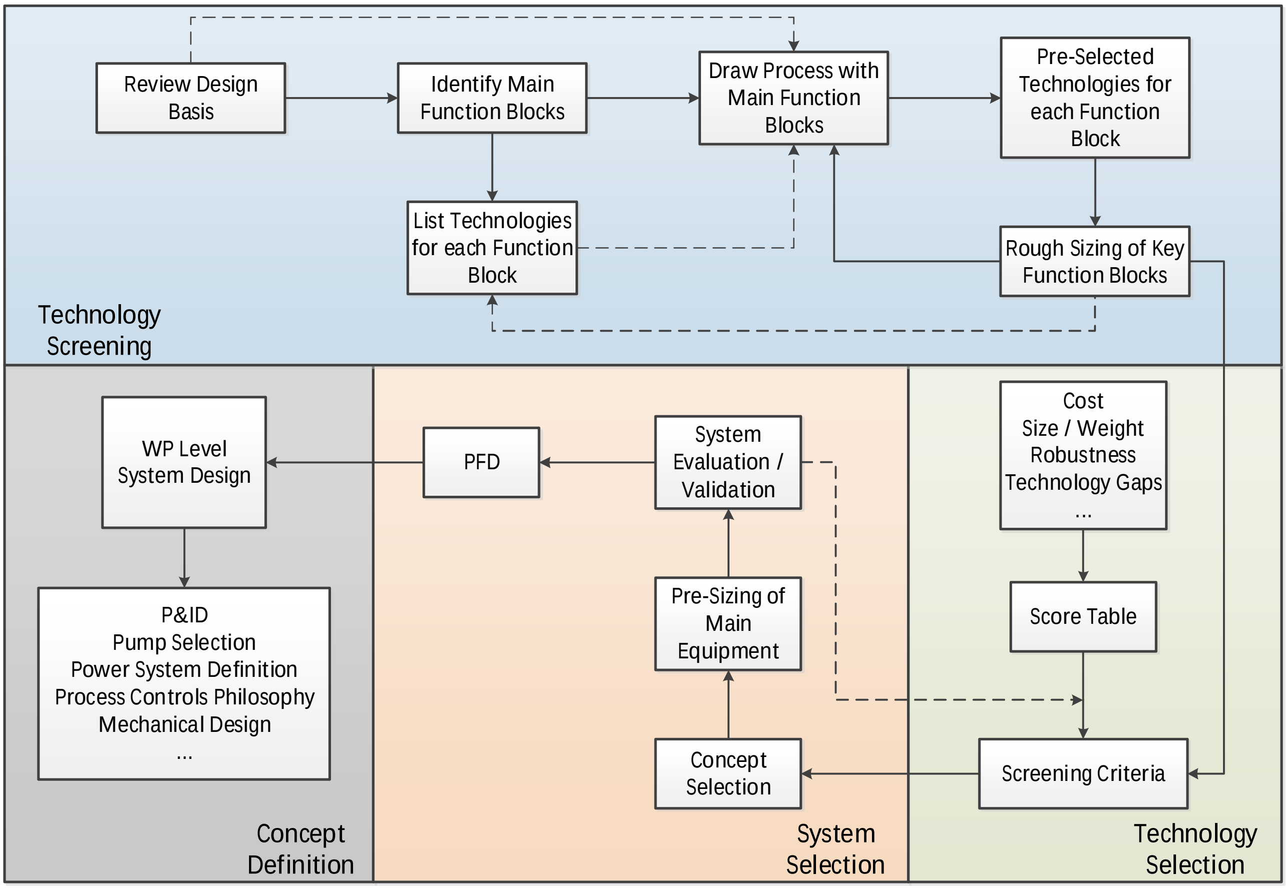

Figure 3 – Concept Selection Methodology

Four main stages are defined in the methodology and they are summarized in Table 1.

Table 1 – Methodology stages

Stage	Main tasks
Technology Screening	• Review and understanding of Design Basis and Operator requirements • Identification of Function Blocks and Technologies • Pre-selection of technologies • Rough sizing of technologies
Technology Selection	• Technology selection based on agreed criteria, weights and score • Selection done with all participants • Chosen technologies moves to next stage
System Selection	• System selection based on agreed criteria, weights and score • Selection done with all participants
Concept Definition	• Detailed definition of the chosen system to progress with engineering activities

3.1 Technology Screening

On this type of project, Client creates a document usually called Design Basis or Technical Specification, which includes the objective of the study, deliverables, technical requirements and system boundaries. The first step in the methodology is to “Review the Design Basis”, in order to have clear understanding of what is required and make a clarification list, to solve any uncertainty and/or ambiguity.

With Design Basis understood, the main process operations are identified in order to propose a system that can achieve the objective described in the Design Basis. This step is to list the main “Function Blocks”, which are unit operations that requires equipment/technology, such as: separation of any kind (gas/liquid, liquid/liquid, gas/gas, etc.), compression, pumping, buffer tank, cooler, slug handling, dew point control, dehydration, etc. For this particular project, the following Function Blocks were identified.

Table 2 – Project specific Function Blocks

Function Block	Description
Slug handling	Ability to accommodate slugs, minimizing the effect on downstream equipment
Bulk gas/liquid separation	Separation of the majority of the gas and liquid (oil + water)
Bulk oil/water separation	Separation of the majority of the oil and water
Produced water treatment (PWT)	Fine separation of the oil in water, to achieve good water quality
Sand handling	Ability to remove sand particles from a stream
Multiphase Pump	Pump capable of operating with multiphase (oil, water and gas) flow
Water Injection Pump	Single phase pump capable to achieve required pressure for water injection into reservoir

Once the Function Blocks are identified there are configured into an engineering flowchart (Figure 4) that represents all the process steps. This is similar to making a simplified Process Flow Diagram (PFD). The previous definition of all Function Blocks is very helpful as various flowcharts can be drawn based on a selected set of Function Blocks. For instance, the “sand removal” function can be placed at various locations: at the inlet of the system, it protects downstream equipment from sand, while at multiple locations can probably maximize sand removal. Some functionalities can also be combined, the “slug handling” and “gas/liquid separation” can be done together in a single equipment, depending on the technology adopted, or alternatively performed with two pieces of equipment.

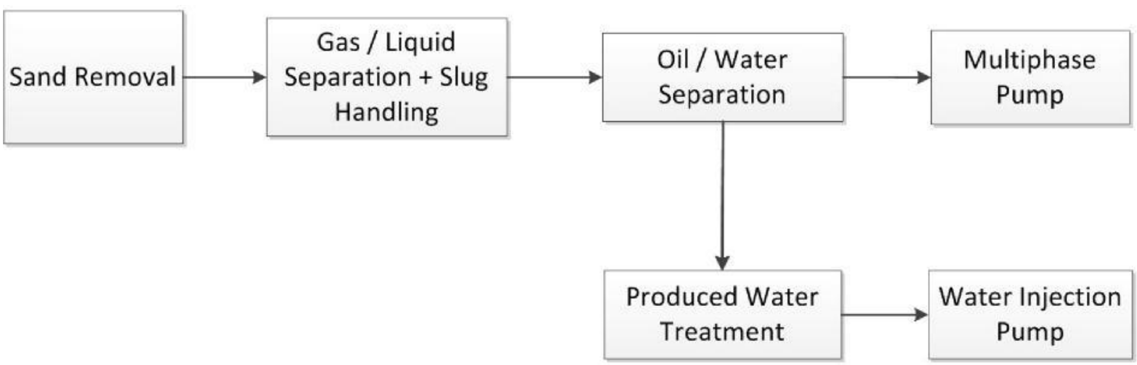

Figure 4 – Case study specific Processing Function Blocks

The sequence and coupling of these functions may vary from one system configuration to another. The slug handling and G/L separation may for example be integrated into one component, or be split into two separate components. Also, the sand handling may need to be done in one or several locations, depending on component types and configuration.

A screening process is run to identify components for each of the functions. Table 3 summarizes the functionalities, identified technologies and preliminary screening for the case study.

Table 3 – Function Blocks with associated technologies/equipment

Function Block	Technology / Equipment
Bulk gas/liquid separation + slug handling	- Gas harp - Flow Conditioning Unit (FCU) + Compact Cyclone Degasser (CCD) - Flow Conditioning Unit (FCU) + Gas harp - Gravity separator - Gas Liquid Cylindrical Cyclonic Separator (GLCC) - Multi-pipe slug catcher
Bulk gas/liquid separation	- Gas harp - Compact Cyclone Degasser (CCD) - Vertical vessel - Gas Liquid Cylindrical Cyclonic Separator (GLCC)
Bulk oil/water separation	- Pipe separator + outlet section - Multiple pipe separator + outlet section(s) - Conventional and reduced outlet section - Horizontal 2-phase separator - Horizontal 3-phase separator - Cyclonic bulk separator (BOW) - Cyclonic bulk separator + Gravity separator
Produced water treatment	- Pre-deoiler cyclones + hydrocyclones - Hydrocyclones in series - Compact Flotation Unit (CFU)
Sand handling	- Sand Screen - PW desanding cyclone (upstream or downstream PWT) - Solids flushing (pipe separator) using increase bulk water velocity - Solids flushing (pipe separator) using nozzles - Solids flushing (horizontal vessel, outlet section) - Wellhead desander

Once the technologies are identified for each Function Block, a preliminary sizing shall be done with available information and assumptions at that stage. This is important to help the screening process, by given somehow a more measurable way to compare things. All sizing is done for 100% capacity, no margin has been added. Using parallel units will reduce size of individual components, but it increase system complexity.

With the flow diagram containing the Function Blocks, technologies for each Function Block shall be listed. For a "gas/liquid separation" some technologies could be: 3 phase gravity horizontal separator, 2 phase gravity horizontal separator, gravity vertical separator (scrubber), bulk cyclone, Gas/Liquid Cylindrical Cyclonic Separator (GLCC). The list should compile the technologies known by participants, and also consider new ideas that are not at a commercial stage yet. This is to prevent new technologies to be disregarded, and it will be shown later in the methodology that there will be some penalty for novelty due to risk. Table 3 is specific for the Case Study, representing the assessment done with the project participants.

With the list of technologies at hand, some rough sizing is performed in order to allow a better comparison between technologies. At this stage a rough sizing is good enough to speed-up the process. As the focus is the subsea environment, size is a key information, as it affects weight, cost and the selection of installation vessels, which are limited by footprint and crane capacity. In some cases, one can be limited to very few vessels in the globe, meaning that it could be needed to bring a specific vessel from another region in the world, which is extremely costly. As rule of thumb, the bigger and heavier the equipment, costlier it is to install it. The rough sizing is not need for all Function Blocks as for some of them can be irrelevant. If we consider "water injection" as a function block, the technology behind it is a liquid pump, or a hybrid pump that tolerates some more gas, but in both cases and regardless of the vendor, in average they have the same envelope and weight.

It is expected to have some closed loop iteration between the steps of "Drawing Process with Mains Function Blocks", "Pre-Selected Technologies for each Function Block" and "Rough Sizing of Key Function Blocks", before a PFD can put forward to the next stage (technology selection). As explained above, some technologies may prove to be not suitable for the conditions specified in the Design Basis, after the rough sizing is done, leading to potential changes in the PFD and selected technologies.

3.2 Technology Selection

With a very preliminary and simplified PFD ready the technology selection stage is started. The objective is to select the best technologies (e.g. top 3) for each Function Block. At this point a screening matrix is built with: all selected technologies for each Function Block and a list of criteria. A criterion is something that each technology will be measured against, such as cost, complexity, size / weight, technology readiness level (TRL) and reliability. The selection of criteria and proper definition of them is key in the methodology, and it shall be done together with the Operator. A clear understanding of each criterion is important before scoring starts. Cost or size are usually easy to understand and compare, while robustness or risk may have different interpretations among the participants. If a not so clear criterion is chosen, it shall be followed by a description to avoid any confusion. Table 5 compiles the criteria and its definitions as agreed in the Case Study.

Weight is a measurement of how important is a criterion (Table 4). It is rated from 5 (highest importance) to 1 (lowest importance). The weight of each criteria is another key step of the methodology as it will vary from project to project and also according to different participants group. Therefore, is essential to agree the weight for each criterion with operator based on their needs for an opportunity. When giving weights participants tends to choose always high weights such as 5 or 4, which does not create differentiations between the criterions. In some cases, criteria are moving in opposite directions and cannot have the same weight, such as two important criteria for subsea systems as: performance and maintenance frequency. It is always desirable a high performance equipment with low maintenance, especially when subsea, but usually higher performance requires more frequent maintenance, so when giving weights to these two criteria, they cannot have the same weight, because they are usually inversely proportional. Operator shall evaluate for its specific scenario what is more important: performance or maintenance, and rate them accordingly.

Table 4 – Criterion Weight

Weight	Importance Level
1	Lowest
2	Low
3	Normal
4	High
5	Highest

Table 5 – Case Study selected criteria and definitions

Criterion	Definition
Cost	Total cost (complete module or similar). The cost will be evaluated relatively based on high-level master equipment list and the most cost effective solution will be preferred.
Performance	Ability to meet performance requirements. The process performance of the system will be evaluated, along with the system's ability to keep acceptable production during rapid transient variations and long term variations. The ability to produce on spec re-injection water is required by the system. The OiW quality may vary between the concepts and will be considered. Generally increased water removal (better oil quality) shall be prioritized, but on-spec re-injection water is main priority.
Flexibility	Ability of the system to handle flow variations and transients, turndown and turnup capability.
Size & weight	Based on the availability of vessels that operate offshore with a reasonable lifting capacity, the maximum weight for retrievable modules shall not exceed 75 tons. All main components for each system will be sized and the weight will be estimated. Generally lower weight and smaller size will be preferred.
Installation	Installability based on geometry (leveling, connection points, installation vessel time consumption, etc.)
Complexity	Overall complexity of component as well as system impact. Small number of components in the system will reduce system complexity (additional components, controls required, level control, etc.)
Maintenance frequency	Not likely to have frequent interventions for maintenance.
Operational availability	Lower probability for clogging, services (e.g. chemical injection), cleaning procedures and sand accumulation.
TRL	TRL level (API 17N): (4) Field Qualified: 6 and 7 (3) Prototype Environment/System Tested: 4 and 5 (2) Prototype Tested: 3 (1) Proof of Concept: 1 and 2 (0) Unproven concept: 0
Risk	This screening criterion is an attempt to capture any concerns that are not expressed in the others. This can include factors such as vendors' ability to design the system and/or qualify the technology within project need deadline, whether the system is highly dependent on unqualified technology etc. A high score (e.g. 4) means low risk.

With the criteria defined with its associated weights, it is time to populate the score table. A score from 0 to 4 is given to each technology for each criterion. Table 6 refers to each score and its respective meaning. When giving scores, is not mandatory to give different values to each technology, as some of them or all may score as high as 4 for a certain criterion. Scoring means to compare the different technologies from a Function Block.

Table 6 – Technology score

Score	Meaning
0	Unfeasible
1	Worse
2	Medium Low
3	Medium High
4	Best

After scoring all the technologies for each criterion, the total score is calculated by the Eq. (1). It can also be noticed that when a technology score is zero, the total score will also be zero, and that technology is ruled out. The technologies with total score above average are chosen to proceed to the System Selection phase.

$$Total\ Score = \sum (Criterion\ Score) * (Weight) \quad (1)$$

Table 7 – Case Study technology score table sample

Criterion	Gas / Liquid Separation + Slug Handling					
	Gas Harp	FCU + CCD	FCU + Gas Harp	Gravity Separator	GLCC	Multi-Pipe Slug Catcher
Cost	2	1	1	2	3	2
Performance	3	3	3	4	3	3
Flexibility	3	2	3	4	2	3
Size & Weight	1	3	3	2	3	2
Installation	2	4	3	2	4	1
Complexity	4	1	2	4	2	2
Maintenance Frequency	4	2	3	3	3	3
Operational Availability	4	2	3	3	2	3
TRL	3	1	1	4	3	2
Risk	4	3	3	3	2	2
Total Score	104	79	91	111	97	86

As an example from the Case Study, Table 7 shows the score table for the “Gas / Liquid Separation + Slug Handling” Function Block. Based on Eq. (1), three technologies were scored above average: Gas Harp, Gravity Separator and GLCC. Those three will be assessed in the System Selection stage. The same process was done for the remaining Function Blocks. Due to confidentiality aspects, the column with information about weight for each criterion was omitted from Table 7.

3.3 System Selection

The System Selection holds the same steps as the Technology Selection, that are necessary to make a system score table, but it is structured to combine all the possible configurations between the selected technologies. By doing so the number of possible systems may be huge, and some simplifications are welcome, if agreed among participants. For instance, if a Function Block such as sand removal can be freely placed at various positions in the system, without affecting or with minor interference in the entire system, the sand removal functionality could be omitted from the System Selection. Also, if one technology is clearly the winner among the top 3 (total score is way higher than the two others), that technology could be considered the sole winner for that Function Block.

Repeating criteria selection and definition and also weighing for a system level can lead to different results than when assessing the technologies. Maintenance of one technology or subsea module may have one weight, while the maintenance of the entire system may have another weight, especially when one system holds technologies that are requires more frequent interventions. Is essential to keep in mind how the entire system behaves and how different systems compare to each other, which is more challenging to visualize than when comparing only technologies for the same Function Block.

Table 8 represents how a system score table would looks like. For simplification reasons, only three criteria are chosen with its associated definition and weight. In the example there are only three Function Blocks: Function Block 1 has two wining technologies (A and B); Function Block 2 also has two wining technologies (C and D) and Function Block 3 has only one wining technology (E). So the system score table contains a total of 3 possible systems based on the selected technologies, from the previous stage. Eq. (1) is used again to calculate the total score for each system and the winning system is the one with the highest total score.

Table 8 – System score table

Weight	Criterion	Criterion Definition	System 1	System 2	System 3
			Function Block 1A	Function Block 1B	Function Block 1A
			Function Block 2C	Function Block 2C	Function Block 2D
			Function Block 3E	Function Block 3E	Function Block 3E
Weight 1	Criterion 1	Criterion 1 Definition	Score (1 – 5)	Score (1 – 5)	Score (1 – 5)
Weight 2	Criterion 2	Criterion 2 Definition	Score (1 – 5)	Score (1 – 5)	Score (1 – 5)
Weight 3	Criterion 3	Criterion 3 Definition	Score (1 – 5)	Score (1 – 5)	Score (1 – 5)
Total Score			Total Score System 1	Total Score System 2	Total Score System 3

It is recommended to pre-fill Table 8 before meeting with all participants. During the pre-filling inconsistencies may be found or needs to re-size some equipment. It also helps to calibrate the criteria and its definitions when moving from technology to system selection. This step may incur in an iteration with the technology score table from the previous stage.

The Case Study ended with 5 different systems to be assessed in the system score table. System 4 was selected with the following technologies: GLCC, Multiple PipeSeparators and CFU. For sand removal, since it could be placed at various locations without significant impact to the system, and to avoid a bigger number of systems to be assessed, it was agreed to select the sand removal technology in the Concept Definition stage.

Final step from the System Selection is to draw the PFD of the selected system. A simplified version of the Case Study PFD is represented in Figure 5.

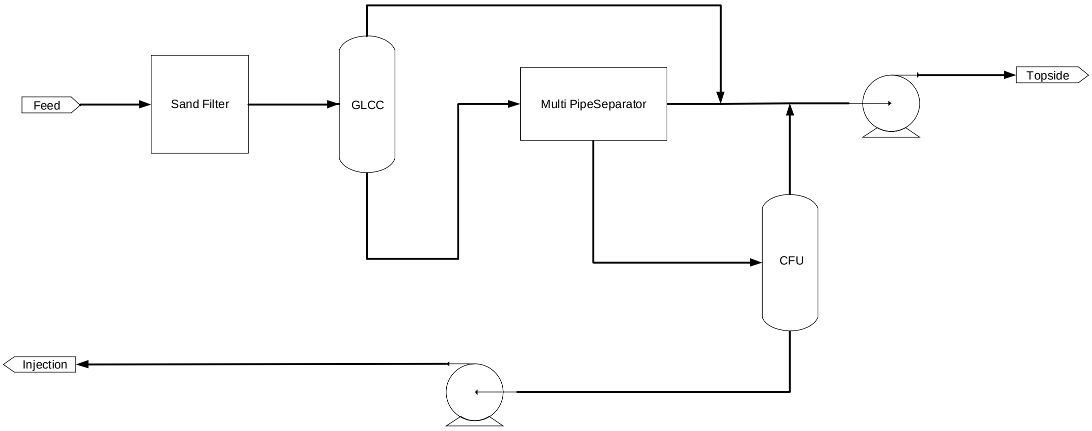

Figure 5 – Case Study simplified PFD

3.4 Concept Definition

With the PFD in place, the concept selection is finished and the next stage is to start to define the chosen concept. Usually the project is divided by Work Packages (WP), which are a sort of product lines. The WP starts to detail the product in a conceptual level still. As work progress the various WPs interacts as information is needed between them, for instance the pump as a product is handled by one WP, while the power system product, which is required to feed power to run that pump is handled by another WP. So the power system WP progress is limited by the pump selection, without knowing the power demand required by the pump unit the power system WP cannot be completed. Additionally the power demand from the pump unit is related to the process needs, and therefore all WPs are interconnected.

At the end of the Concept Definition, all WPs should have provided a selection of their products so that P&ID and 3D layouts can be made. Being in a conceptual phase, some detailed information shall be provided for the system solution, but not as detailed as a typical delivery from a Front End Engineering Design (FEED). An example of a 3D layout as one of the main deliverables from the Concept Definition is displayed in Figure 6, it indicates how the system would be in real life, including the technologies that were selected in the previous stages.

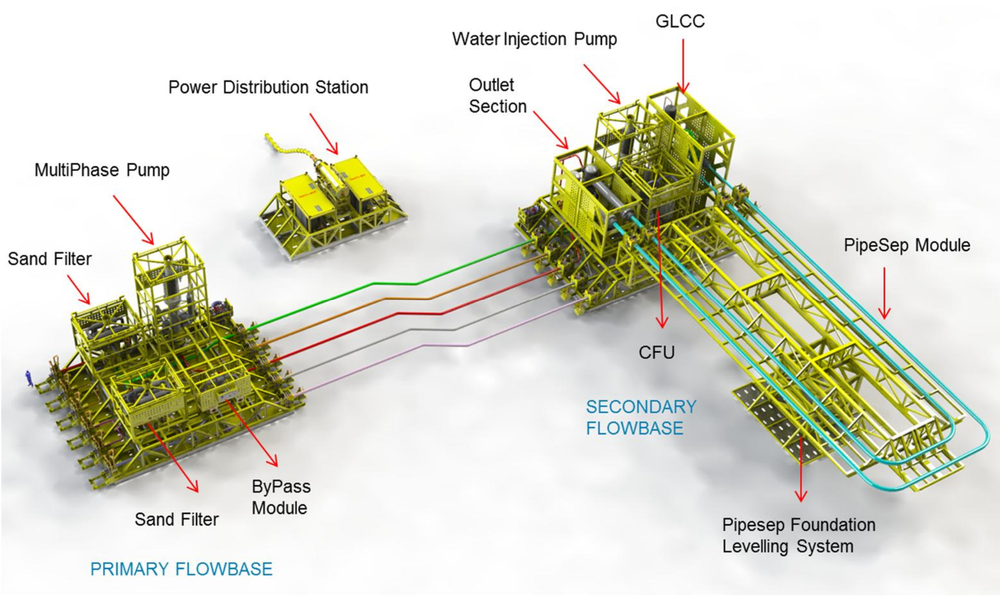

Figure 6 – Case Study System 3D layout (Hauge et al 2016)

The results from the Concept Definition should provide good technical information and cost estimate to allow Operators to evaluate the way forward. Usually the next step would be a FEED, and if the prospect remains competitive the project will became an EPC (Engineering, Procurement and Construction), meaning that the system will be manufactured and later installed in the seabed.

4. CONCLUSION

A structured and robust methodology to evaluate and document the assessment of different technologies and systems alternatives at a conceptual stage was achieved.

The concept selection took longer than initially planned, but all participants agreed that the process was robust and required, so that the chosen concept is strong enough to move ahead and avoid rework at a later stage, because when discussing technologies and systems at an early phase, with a multidisciplinary group of specialists, issues could be captured and solved before the Concept Definition. Usually, inconsistencies found as close as to the end of a project, leads to a higher impact. Operators realized that a solid concept selection benefits the entire project cycle, by freezing a strong concept the next step will be only engineering and fewer deep changes are expected.

The proposed methodology helped to leveled participants knowledge and experience with different technologies, equipment and systems, which greatly contributed to the entire process. It was observed that some participants that initially had a strong preference for a certain technology/equipment, without too much thinking, when submitted to the steps of the methodology, actually changed their mind, and realized that their first “gut feeling” was actually not the best choice.

A common feedback from participants was that they were used to like “brainstorming meetings” for concept selection, which is not the best approach to provide a solid and robust way to evaluate technologies and systems. They were satisfied with the methodology and were willing to apply it internally.

Opportunities for improvement were also identified, specially on how to use the score table. Criteria definitions is very important, it should be tried to select easy to understand and define criteria, to avoid confusion among participants and speed-up the meeting. Preferably, a pre-agreement with Operators about criteria, criteria definition and criteria weight, may save some time, to allow participants to focus on scoring and selection, instead of debating principles.

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