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Structural Risk-Based Underwater Inspection (RBUI) As A Cost Reduction Of Field's End Of Production Life

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Abstract. Mubadala Petroleum operates offshore platforms in a southern Makassar Straits that needs to be periodically inspected. The cost for the inspection is massive due to the high cost of mobilization and demobilization of vessels including crew and equipment. In response of a new approach to reduce cost, a Risk-Based Underwater Inspection (RBUI) methodology is developed. This RBUI purpose is to reduce the inspection interval of the offshore platform, from every 2 years to a longer period. There are existing RBUI methodologies, which are already developed and implemented in other companies. Purpose of this paper is to develop further detailed and more accurate RBUI methodology based on data analysis and the agile development method. Offshore platforms condition is dynamic and always changing from time to time. This methodology uses offshore platform design and condition data, including inspection data. All collected inspection data of offshore platform conditions will produce an accurate risk register of the platform. Thus, accurate risk register will give the best inspection interval time, considering its safety and economical benefit. From the RBUI analysis using this method, inspection interval can be deferred from 2 (two) years to range of 4-9 years, depending on the condition and risk of the platform. The operating cost of each platform also reduced up to US$ 670,737 per year.

INTRODUCTION

This RBUI purpose is to reduce the inspection interval of the offshore platform, from every 2 years to a longer period [1]. There are existing RBUI methodologies, which are already developed and implemented in other companies [2]. Mubadala Petroleum operates Ruby offshore field in Indonesia. Ruby field is located in south of Makassar Straits, between the border of three provinces; East Kalimantan, South Kalimantan, and West Sulawesi. The closest city is Kotabaru at Laut Island, South Kalimantan at 40 km to the west of Ruby Field. Due to unavailability of adequate oil and gas facility in Kotabaru, all operations support, personnel crew change and logistics support for Ruby Field are provided from Balikpapan, East Kalimantan that located about 300 km to the north west of Ruby Field[3].

The single subsea gas pipeline from Ruby Field to Senipah Onshore Receiving Facility (ORF) considered as the longest subsea pipeline from one field only at 312 km length. There are several subsea pipelines longer than Ruby Pipeline, such as West Natuna Transportation System (WNTS) and East Java Gas Pipeline (EJGP), but those pipelines are main transmission from several field along the pipeline [3].

The remoteness of the field and facility lead to higher operational and mobilization cost. Most of oil and gas operational support resources center in Indonesia are generally located at western part of the country, especially Jakarta and Batam. Specifically, resources center in the Makassar Straits area is located around Balikpapan, where both onshore and offshore oil and gas fields mostly located in radius less than 200 km from Balikpapan. Thus, Ruby Field operated by Mubadala Petroleum are categorized as remote location from oil and gas infrastructures, both regionally and locally.

BACKGROUND

Mubadala Petroleum operates 2 (two) offshore platforms (PQP and WHP) in Ruby Field that are connected with a bridge. The offshore platform stands at 60 meters depth with type of fixed platform with a skirt pile, at each of 4 legs (PQP) and 3 legs (WHP) respectively [3-6]. For its offshore platform operation, Mubadala Petroleum ensures the platform's structure condition is fit for services by conducting offshore platform's structure routine inspection [7-8].

Based on Indonesia's government regulation for offshore fixed platform time-based inspection [9], the inspection scope interval is described in Table 1 below:

TABLE 1. Government Offshore Platform's Inspection Regulation [9]

Level	Interval	Scope (General)
L1	Annual	Above water: • Above water structure inspection (from splash zone to top of platform) • Equipment layout as per as-built drawing Splash zone: • Cathodic Protection (CP) / drop cell inspection • Thickness measurement • Metal debris
L2	2 years	Minor Inspection Scope. From splash zone to seabed (underwater inspection/UWPI): • Visual inspection • Scour • Debris • Cathodic Potential (CP) measurement • Marine growth • Riser clamp bolt and nut • Thickness measurement
L2, L3, L4	4 years	Major Inspection Scope. Magnetic Particle Inspection, if any: • Overstress joint • Low fatigue joint • Damaged joint

From installation year at 2013, Mubadala Petroleum conducted UWPI every 2 years, with updated cost at the year of 2020 complete scope inspection cost is around US$ 1.6 million [7-8]. The cost is quite high compare to other company or field mostly due to:

- One Time Contract basis. Mubadala Petroleum only has 2 (two) platforms, which are inspected simultaneously in one time every 2 years. It is different with other companies that have dozens of platforms, which has annual or multi-years UWPI contract scheme [7-8].
- Vessel contract. Mubadala Petroleum UWPI hire diving support vessel one time only for UWPI work, including inspection personnel and tools. It is different with other companies with dozens of platforms and fields that have multi vessels contract and utilize one diving support vessel (DSV) for UWPI work [7-8].

- Remote area location. Most of Indonesia's DSV provider stationed at Batam in western region of Indonesia. Mubadala Petroleum's field located at Makassar Straits in central-eastern region of Indonesia. For one UWPI work, it costs both of mobilization and demobilization. The mobilization takes 5 days journey from Batam to Ruby Field, which costs around US$ 200,000 each [7-8].
- Water depth. Ruby Field has 60 meters depth. For UWPI work, it requires diving intervention. Air diving, the easiest method is limited to 45 meters depth. To achieve more than 45 meters depth, it requires mixed-gas diving method, which have less bottom time and additional post dive requirement. This mixed-gas diving consumes higher personnel cost, equipment cost, and more operational time/duration [7-8].

As per limitation and challenges above, previously there are no opportunity to reduce cost for conduct UWPI as per government and safety regulation.

DEVELOPMENT OF RISK BASED UNDERWATER INSPECTION (RBUI) IN INDONESIA

American Petroleum Institute (API) releases API RP 2SIM (Structural Integrity Management of Fixed Offshore Structures), 1st edition at November 2014 [1]. This recommended practice provides guidance for the structural integrity management (SIM) of existing fixed offshore structures used for the drilling, development, production, and storage of hydrocarbons in offshore areas [1-2]. However, the general principles of SIM can be applied to any structure. The RBUI analysis process is carried out with the stages in the Fig. 1 below.

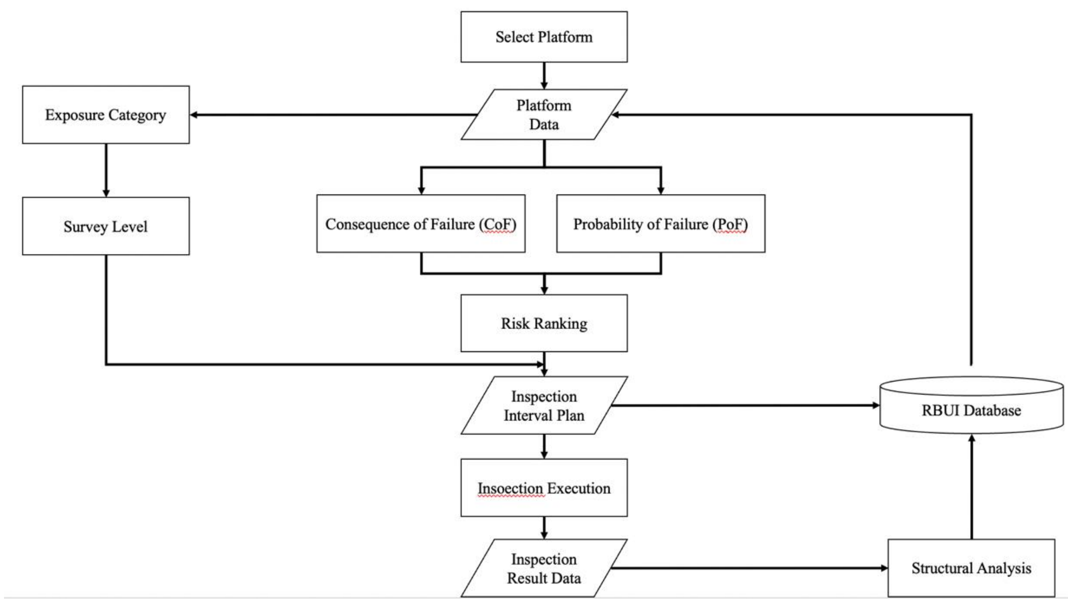

FIGURE 1. RBUI Process based on API RP 2 SIM [1]

Following API RP 2SIM release, several production sharing contract (PSC) companies in Indonesia started to implement RBUI for their facilities. Most of the PSC's are interested of opportunity of longer inspection interval time, as API RP 2SIM guidance in Table 2 below.

TABLE 2. Risk Based Underwater Inspection (RBUI) intervals (API RP 2SIM: 2014, Table 2) [1]

Platform's Risk Category	Inspection Interval Ranges
Higher	3 years to 5 years
Medium	6 years to 10 years
Lower	11 years to 15 years

From Table 2 above, the minimum inspection interval time is 3 years for platform with higher risk. Even for the most high-risk platform, the inspection interval can be longer for 1 year, from every 2 years to 3 years. It will be longer period of inspection (up to 15 years) for unmanned or very low risk platforms [1].

Beside longer inspection interval, API RP 2SIM also offering inspection scope that less strengthen than previous requirement in API RP2A WSD (Working Stress Design) [10]. The level of inspection also widened from 3 levels to 4 levels, where wall thickness measurement and joint NDT (Close Visual Inspection and Magnetic Particle) will be applied if there are any findings in Level 3 inspection [1, 10].

Detail of inspection scope as per API RP 2SIM are presented in Table 3 below.

TABLE 3. Default Inspection Program (API RP 2SIM: 2014, Table 2) [1]

Interval (Years)	Exposure Category[a] L-3 5-10	Exposure Category[a] L-2 5-10	Exposure Category[a] L-1 3-5
Level II			
General visual survey	X[b]	X[b]	X[b]
Damage survey	X	X	X
Debris survey	X	X	X
Marine growth survey	X	X	X
Scour survey	X[c]	X[c]	X[c]
Anode survey	X	X	X
Cathodic potential	X	X	X
Riser/J-Tubes/Caisson	X	X	X
Interval (Years)	Exposure Category[a] L-3 d	Exposure Category[a] L-2 11-15	Exposure Category[a] L-1 6-10
Level III			
Visual corrosion survey	X[e]	X[e]	X[e]
Flooded member detection or member close visual inspection	X	X	X
Weld/joint close visual inspection, after cleaning to bright metal	If required	If required	X
Level IV[f]			
Weld/joint NDT	g	g	g
Wall thickness	g	g	g

[a] Exposure category is defined in 5.3.4
[b] Detection of significant structural damage should from the basis for initiation of Level III survey in 6.5.1.
[c] If seafloor is conducive (loose sand) or seafloor instability is known/suspected, a scour survey should be performed.
[d] Only required if the results from Level II survey indicate suspected damage.
[e] Not required if the annual above-water inspection CP survey indicates uninterrupted protection below water.
[f] Only required if the results from the Level III survey indicate suspected damage
[g] Surveys should be performed as indicated in 5.5.4.3.

RBUI METHODOLOGY

From various standards of offshore structures (such as API, DNV, Norsok, ISO, etc), API RP 2SIM is chosen as main reference for implementing RBUI and Structural Integrity Management (SIM). As a main reference for Structural RBUI for offshore platforms, API RP 2SIM is adequate to provide general methodology for implementing, calculate, and brief the general methodologies. API RP 2SIM general methodology briefs risk matrix, exposure category, general likelihood (probability of failure / PoF) and general PoF determination [1].

Related to API RP 2SIM, this paper presented RBUI methodology (Figure 1) that clearly following the main reference and breakdown the detail methodology following API RP 2SIM and applied semi quantitative method, compared to previous implemented RBUI in other companies that mostly qualitative method using scoring based on criteria[1-2].

It can be concluded that RBUI is a calculation based on platform data, inspection result data, and structural analysis result data. RBUI also a continuous, dynamic process and always changing depend on the inspection result data based on structural condition, which leads to changing Probability of Failure (PoF) value as per structural analysis result[1-2].

The next sections explain approach methodology and determining each RBUI tasks/steps.

Consequence of Failures (CoF)

CoF which consists of safety, business, and environment will be determined further by using a combination of subjective expert judgment and qualitative analysis of those losses associated with platform failure [1]. Summary of CoF factors threshold are presented in Table 4 below.

TABLE 4. Summary of CoF Factors threshold [12]

CoF Factors	**Score**				
	1	**2**	**3**	**4**	**5**
			Safety		
Occupancy	Unmanned	-	Normally Unmanned	-	Manned
			Business		
Oil Production (BOPD)	≤ 100	100 < x ≤ 500	500 < x ≤ 1000	1000 < x ≤ 2000	> 2000
Gas Production (mmscfd)	≤ 10	10 < x ≤ 50	50 < x ≤ 100	100 < x ≤ 500	> 500
Replacement Cost ($ MM)	< 100	-	100 - 300	-	> 300
			Environment		
Oil Production (BOPD)	≤ 100	100 < x ≤ 500	500 < x ≤ 1000	1000 < x ≤ 2000	> 2000
Gas Production (mmscfd)	≤ 10	10 < x ≤ 50	50 < x ≤ 100	100 < x ≤ 500	> 500

Probability of Failures (PoF)

The PoF is determined by failure parameters associated with damage mechanism and threat to the platform. Failure parameters are factors that occur from characteristic and condition aspects [1].

Each probability of failure factor contributes to the calculation in the form of scores which varies from 1 to 5 with score 5 being the highest score of PoF. Weightings of each PoF factor are added in the form of percentage (%) to differentiate one factor to another. The weightings are determined based on the significance of each PoF factor to the risk level with the total weighting for all PoF factor is 100% [1,11].

Based on API RP 2SIM, PoF factors mainly consist of [1]:

- Characteristic Factor
- Condition Factor
- Loading Factor

Characteristics factors are platform design that implies to the probably of occurring, while condition factors are inspection results that provide additional risk associated with the probability of failure [1]. And loading factors are probability related to load and structural analysis aspects. Summary of PoF factors threshold are presented in Table 5 below.

TABLE 5. Summary of PoF Factors threshold [12]

PoF Factors	**Score Weighting (%)**	**Score**				
		5	**4**	**3**	**2**	**1**
Characteristic Factor [3]						
Platform's Age	5	80-100% design life	60-80% design life	40-60% design life	20-40% design life	0-20% design life
Leg and Brace	5	3 Legs, / Brace	3 Legs, K Brace	4 Legs, / Brace	3 Legs, X Brace or 4 Legs, K Brace	4 Legs, X Brace
Platform's Functions	5	Process	Wellhead	Storage	Living Quarters	Flare
Condition Factor [7-8]						
Marine Growth	5			Maximum value		
		80-100% design	60-80% design	40-60% design	20-40% design	<20% design
				Average value		
		>40% design	30-40% design	20-30% design	10-20% design	<10% design
Scour	5			Maximum value		
		80-100% design	60-80% design	40-60% design	20-40% design	<20% design
				Average value		
		>40% design	30-40% design	20-30% design	10-20% design	<10% design
Corrosion	10			Maximum value		
		80-100% design	60-80% design	40-60% design	20-40% design	<20% design
				Average value		

		>40% design	30-40% design	20-30% design	10-20% design	<10% design
Cathodic Protection	15			Maximum value		
		> -800 mV or < -1100 mV	-	-800 mV to -850 mV	-	-850 mV to -1100 mV
				Average value		
		> -800 mV or < -1100 mV	-800 mV to -850 mV	-850 mV to -900 mV	-900 mV to -1000 mV	-1000 mV to -1100 mV
Debris	5	> 1 Metallic contact	-	1 Metallic contact	-	No metallic contact
Mechanical Damage	10	>1 Heavy damages	1 Heavy damage	>1 Light damages	1 Light damage	No damage
Loading Factors [4-6]						
Unity Check	15			Maximum value		
		0.8 – 1	0.6 – 0.8	0.4 – 0.6	0.2 – 0.4	0 – 0.2
				Average value		
		0.4 – 0.5	0.3 – 0.4	0.2 – 0.3	0.1 – 0.2	0 – 0.1
Fatigue Life	15			Minimum value		
		1 -2 x service life	2 -3 x service life	3 -4 x service life	4 -5 x service life	>5 x service life
				Average value		
		1 -2 x service life	2 -3 x service life	3 -4 x service life	4 -5 x service life	>5 x service life

Risk Ranking

Risk Categorization Matrix is a matrix to show comprehensive value from Exposure Category, CoF and PoF to be converted to inspection interval [1]. The simplified method is 3 x 3 risk matrix, which contains minimum risk level from 1, 2, and 3, or high, medium, and low as shown in Table 6 below.

TABLE 6. Risk Categorization Matrix [1,11]

CoF	High	Risk Level 2	Risk Level 1	Risk Level 1
	Medium	Risk Level 3	Risk Level 2	Risk Level 1
	Low	Risk Level 3	Risk Level 3	Risk Level 2
		Low	Medium	High
		PoF		

Exposure Category

Following API RP 2SIM chapter 5.3.4.1, table below determine life safety of the platform to produce exposure category and survey interval. Exposure Category Matrix is presented in Table 7 below.

TABLE 7. Exposure Category Matrix [1]

Life Safety Category	CoF C1	CoF C2	CoF C3
S1	L-1	L-1	L-2
S2	L-1	L-2	L-3
S3	L-2	L-3	L-3

Life safety in the platform should consider the maximum anticipated environmental event that would be expected to occur while personnel are on the platform. Categories for life-safety are [1]:

- S-1 = manned-non-evacuated
- S-2 = manned-evacuated
- S-3 = unmanned

The consequence of failure should include consideration of the anticipated impact to the environment, and the possible economic impact through losses to the owner (platform and equipment repair or replacement, lost production, etc.) and anticipated losses to other operators (lost production through trunk lines). Categories for CoF are [1]:

- C-1 = high CoF
- C-2 = medium CoF
- C-3 = low CoF

Inspection Interval and Survey Level

Risk-based inspection intervals are assigned to each platform based on the matrix of interval as shown in Table 2 above, depend on each platform's risk value. The scope of inspection is determined as shown in Table 3 above, depend on each platform's exposure category value. Due to interval in Table 2 stated in ranges, it should spread depend on each risk value, as shown in tables below. To be noted that table from API is for 3x3 matrix. For company risk matrix that use 5x5 matrix, it should spread proportionally. Inspection Interval for platform with various exposure category and survey level are presented in Table 8, Table 9, Table 10, Table 11, Table 12 and Table 13 below.

TABLE 8. Inspection Interval for Platform with Exposure Category L-1 - Survey Level 2

Survey Level 2				
CoF	High	4	3	3
	Medium	5	4	3
	Low	5	5	4
		Low	Medium	High
		PoF		

TABLE 9. Inspection Interval for Platform with Exposure Category L-1 - Survey Level 3

Survey Level 3				
CoF	High	8	7	6
	Medium	9	8	7
	Low	10	9	8
		Low	Medium	High
		PoF		

TABLE 10. Inspection Interval for Platform with Exposure Category L-2 - Survey Level 2

		Survey Level 2		
CoF	High	8	6	5
	Medium	9	7	6
	Low	10	9	8
		Low	Medium	High
		PoF		

TABLE 11. Inspection Interval for Platform with Exposure Category L-2 - Survey Level 3

		Survey Level 3		
CoF	High	13	12	11
	Medium	14	13	12
	Low	15	14	13
		Low	Medium	High
		PoF		

TABLE 12. Inspection Interval for Platform with Exposure Category L-3 - Survey Level 2

		Survey Level 2		
CoF	High	8	6	5
	Medium	9	7	6
	Low	10	9	8
		Low	Medium	High
		PoF		

TABLE 13. Inspection Interval for Platform with Exposure Category L-3 - Survey Level 3

		Survey Level 3 (*if required*)		
CoF	High	*	*	*
	Medium	*	*	*
	Low	*	*	*
		Low	Medium	High
		PoF		

CALCULATION AND RESULT

RBUI Calculation conducted for 2 (two) platforms, PQP and WHP. The platform data and calculation step are presented in Table 14 below.

TABLE 14. RBUI Calculation Data and Result [3-8]

Steps	Criteria	Platform	
		PQP	**WHP**
Platform Data	Structural Type	Jacket	Jacket
	Number of Leg	4	3
	Water depth	60 m	59 m
	Functions	Process and Quarter	Wellhead
	Occupancy	Manned	Unmanned

	Product	Non-sour gas	Non-sour gas
	Storage	Yes	No
	Evacuate	Yes	Yes
	Location Seismic Activity	Low	Low
	Number of Well	-	4
	Production Flow	100 MMscfd	100 MMscfd
	SSSV Presence	-	Yes
	Equipment number	>2 equipments	>2 equipments
Structural Analysis Data	Latest Analysis year	2017	2017
	RSR value	1.8	2.4
	Fatigue design value	15 years	15 years
	Fatigue life value	68	73
	UC value	0.86	1.04
Inspection Data	Exceeding design data	No	No
RBUI Calculation	CoF	E	C
	PoF	2	3
	Risk	Medium	Medium
	Exposure Category	L-1	L-2
	L2 Survey Interval	4 years	7 years
	L3 Survey Interval	8 years	12 years
	Last L2 Survey	2020	2020
	Last L3 Survey	2020	2020
	Next L2 Survey	2024	2028
	Next L3 Survey	2027	2032

The implementation for RBUI interval is not strictly following the calculation result. Another consideration may be applied if the interval is longer than design life, critical due date year, or government consideration during presentation workshop in the approval process of RBUI implementation [9].

COST REDUCTION

For longer inspection interval, there are reduced cost to operate offshore platform, especially for inspection cost. Table 15 below shows inspection reduction simulation for risk based compared to time-based. Due to PQP and WHP platform are connected by bridge, those platforms should inspect simultaneously.

TABLE 15. RBUI Inspection Schedule [7-8]

Inspection Level	**1**	**2**	**3**	**Remarks**
2020	x	x	x	Last inspection’s year
2021	x			
2022	x			
2023	x			
2024	x	x		
2025	x			
2026	End of production			
2027	ASR (decommissioning)			Design life/PSC end year

An inspection interval change resulted in cost reduction, with comparison of time-based and risk-based, as shown in Table 16 and Table 17 below.

TABLE 16. Time-based inspection cost [7-8]

Inspection Level	**1**	**2**	**3**
2021	5,000		
2022	5,000	1,445,615	
2023	5,250		
2024	5,513		1,689,600
2025	5,788		
2026	6,078	1,734,738	
2027	ASR (decommissioning)		
Cost (US$)	**27,628**	**3,180,353**	**1,689,600**
Total Cost (US$)		**4,897,581**	

TABLE 17. Risk-based inspection cost

Inspection Level	**1**	**2**	**3**
2021	5,000		
2022	5,000		
2023	5,250	1,517,896	
2024	5,513		
2025	5,788		
2026	6,078		
2027	ASR (decommissioning)		
Cost (US$)	**27,628**	**1,517,896**	
Total Cost (US$)		**1,543,896**	

From time-based and risk-based inspection cost table, it is concluded that cost reduction within next 7 years (design life/PSC end year) is US$ 3,353,685 or US$ 670,737 per year.

CONCLUSIONS

As a summary, the results of RBUI assessment can be concluded as follows:

- RBUI methodology and detail calculation is following API RP 2SIM as a reference.
- RBUI calculation result are from 2 (two) active platforms that assessed, 1 (one) platform has high risk and 1 (one) platform has medium risk.
- Inspection plan is divided to (3) three survey levels and each platform has 2 (two) different inspection schedules for each level except for survey level 1 which needs to be carried out every year. Inspection range is different for each individual platform.

- The inspection plan above is the recommended interval based on RBUI. Mubadala Petroleum could do a grouping of inspection campaign to consider the practicality and economically of the underwater inspection execution, however the interval should not be later than the above interval.
- The potential cost reduction within next 7 years US$ 670,737 per year.

From this paper it is expected that the above approach can be a reference to conduct semi-quantitative RBUI calculation based on API RP 2SIM, mainly for a remote platform or a field with a lot of platforms. The methodology and calculation sequence also be able to apply to many cases. The RBUI with this methodology also give offshore platform's operator to reduce significant cost and risk of underwater inspection execution, while keep maintaining confidence level and safety of the platform's structure.

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