Development of Reliability Centered Maintenance Plan RCM, Through Pulling Operations to Wells of a Marginal Oil Field

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Abstract*– The objective of this project is to develop a Reliability Centered Maintenance plan RCM, through Pulling operations to wells of a Marginal oil field those present a high frequency of failures at production string by sucker rod pump, swab and plunger lift. The first step was to rank the oil wells selected of the field of study through a Semi-quantitative Criticality Model "MCR" Criticality Risk Matrix and then apply the methodology RCM to wells those qualified in the very high criticality range. The methodology proposed will allow developing a maintenance plan for the wells of very high criticality.

Keywords—Reliability Centered Maintenance RCM, Pulling operations, Production String, Criticality Risk Matrix MCR, Sucker Rod Pump, Swab, Plunger Lift.

I. INTRODUCTION

In the marginal oil field, beside the production operations, well maintenance operations are carried out by the pulling team. The interventions occur in the non-productive wells, with production loss, jamming of deep equipment of different extraction systems that the company owns and to perform improvements and/ or optimizations.

The intervention reasons could be: change of the subsurface pump, replacement of the production string (full service), recover operations (fishing), clean-up operations (well cleaning), paraffinic treatments, among others.

The problematic lies in the well with high failures frequency index, that generates a high frequency of the pulling services, causing the wells inactivity that prevent accomplish with the production plans, that carries economic loses by production and costs due to non-scheduled maintenance

RCM or reliability centered maintenance is a technique used to know what must do to the physical asset continue working whatever the user wants it to do in the present operating context [1]. Thus, RCM does not eliminate future failures or fail modes, unlike it could deliver the time required to respond to failure modes in a controlled manner; providing time to generate a work order, to investigate the problem, time to move the repair personnel, time to arrange the necessary components or a full asset [2].The Project purpose is developing a maintenance plan of pulling operations applied in the wells of a marginal oil field that presents a high failures frequency at the production string by sucker rod pump, swab and plunger lift using the RCM methodology.

II. LOCATION

The Block 2 include the marginal oil field, located in the Santa Elena province that includes an area of 744 Km^2 onshore and 456 Km^2 offshore, adding a total of 1200 Km^2, as shown in figure 1 [3].

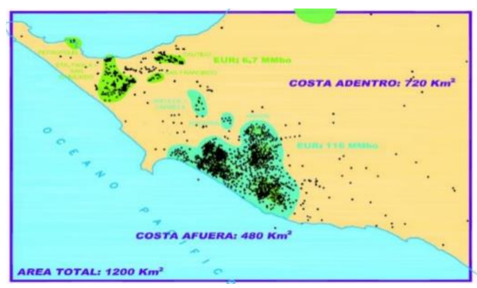

Fig. 1, Location of the Marginal Oil Field
Source: Pacifpetrol S.A., 2013 [4]

III. SEMI-QUANTITATIVE CRITICALITY MODEL "MCR" CRITICALITY RISK MATRIX

The proposed model is based on the risk factor estimation through the following expressions:

$$Risk = FF * C \quad (1).$$

Nomenclature:

FF = Failure frequency (number of failures in a given time)

C= Consequences of failures to safety, environment, quality, production, etc.

Where CONSEQUENCES is calculated with the equation 2, considering the percent addition of different impacts to consider must add 100 % or 1.

Digital Object Identifier: http://dx.doi.org/10.18687/LACCEI2021.1.1.184
ISBN: 978-958-52071-8-9 **ISSN**: 2414-6390
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$$
\begin{aligned}
C = \; & (\text{Impact on safety and the environment (SHE)} * \%) + \\
& (\text{Impact on quality (IQ)} * \%) + \\
& (\text{Impact on production (IP)} * \%) + \\
& (\text{Impact due to low maintainability (LM)} * \%) + \\
& (\text{Cost of maintenance (CM)} * \%) + \\
& \text{etc.}
\end{aligned} \quad (2).
$$

The results of the evaluation of above factors, are indicated in a criticality 5 x 5 matrix, as shown in figure 2, there the vertical axis is composed by five levels of failure frequency, while the horizontal axis is composed of five levels of failure consequences. The matrix is divided into four zones representing four levels of criticality:

Zones of criticality:

- L: Low Criticality
- M: Media Criticality
- H: High Criticality
- VH: Very High Criticality

Frequency					
5	H	VH	VH	VH	VH
4	H	H	H	H	VH
3	M	M	M	H	VH
2	L	L	L	M	M
1	L	L	L	M	M
	1	2	3	4	5
	Consequences				

Fig. 2, Criticality matrix proposed by the RCM model
Source: Parra and Crespo, 2012 [5]

IV. Application of Semi-Quantitative Criticality Model to Wells of a Marginal Oil Field

The number of wells that will be ranked with the semi-quantitative criticality model MCR is detailed below.

Table 1. Wells Submitted to Hierarchy Model

Wells type	amount
Wells with extraction system by sucker rod pump	318
Wells with extraction system by Swab	285
Wells with extraction system by Plunger Lift	2
Total	**605**

Source: Ramirez, 2020 [6]

A. Failure Frequency

The failure frequency was calculated through pulling interventions history from 2009 to February 2020 to the operative wells by sucker rod pump, Swab and Plunger Lift. Thus, the service to wells executed by the Pulling crew was counted, quantifying the number of failures that the production string had during the before mentioned time interval. Using equation 3, the failure rate (λ) was calculated, which is the relationship between the number of total failures in the analysis period.

$$\lambda = Tf / Tp \quad (3).$$

Nomenclature:

λ : Failure rate (failures / time)

Tf: Number of total failures in the analysis period

Tp: Analysis period

The weighted factors designed to rank failure frequency factor is detained below.

Table 2. Rank of Failure Frequency.

Rank	Events	Years	Failure rate	Failure rate intervals
1	1	5	O.2	0 - 0.2
2	1	4	0.25	0.21 - 0.25
3	1	3	0.33	0.26 - 0.33
4	1	2	0.5	0.34 - 0.5
5	1	1	1	> 0.51

Source: Ramirez, 2020 [6]

Where the Wells are ranking in a 1 to 5 scale according the number of total failures presented in an analysis period, where the scale 1 is the less critical and 5 is the most critical.

B. Consequences

The Impacts for failure consequences like as Environment and Safety, Production and maintainability were considered.

Impact on Environment and Safety: In this parameter selection, environment and safety factor will depend from the distance between the oil wells and civil construction, taking in consideration while the closer the civil construction is to the well the more critical it becomes. Using search and selection tools from Google Earth Pro application and with the help of UTM coordinates was possible determinate the location of the 605 oil wells of the study block.

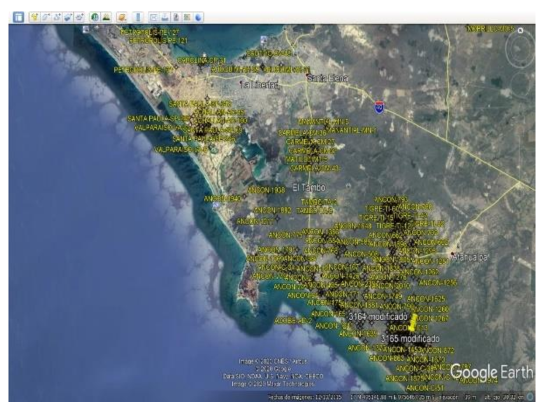

Fig. 3, Productive Wells of the Marginal oil field in Google Earth
Source: Pacifpetrol.

The weighted factors designed to rank the failure consequence factors in the environmental and safety parameter is detained below:

Table 3. Rank of the Failure Consequences, Environment and Safety Factor.

Impact on Environment and Safety * %	
Rank	**Ratio (meters)**
1	Isolated areas of the population
2	There are population> 100 and ≤ 200 meters around
3	There are population> 50 and ≤ 100 meters around
4	There are population> 30 and ≤ 50 meters around
5	There are population ≤ 30 meters around

Source: Ramirez, 2020 [6]

the Wells are ranking in a 1 to 5 scale, according the distance of an oil well from a civil construction, where the scale 1 is the less critical and 5 is the most critical.

Impact on Production: In the production factor, operative diary production wells by sucker rod pump, Swab, Plunger Lift data were taken. The weighted factors designed to rank the failure consequence factors in the production parameter is detained below:

Table 4. Rank of the Failure Consequences, Production Factor.

Impact on Production * %	
Rank	**BOPD**
1	0 – 1
2	1.1 – 2
3	2.1 – 3
4	3.1 – 4
5	> 4

Source: Ramirez, 2020 [6]

The wells are ranking in 1 to 5 scale according the daily oil production, where the scale 1 is the less critical and 5 in the most critical.

Impact on Maintainability: The maintainability factor was evaluated in relation to the depth of the production tubing in the well with respect to time; that is, the time it takes to perform the Pulling service based on the depth of the tubing in the well. The weighted factors designed to rank the failure consequence factors in the maintainability parameter is detained below:

Table 5. Rank of the Failure Consequences, Maintainability Factor.

Impact on Maintainability * %		
Rank	**Tubing Depth (ft)**	**Service deep (hours)**
1	0 - 1000	0 UNTIL 8
2	1000.1 - 2000	8.1 UNTIL 16
3	2000.1 - 3000	16.1 UNTIL 24
4	3000.1 - 4000	24.1 UNTIL 36
5	4000.1 - 6000	> 36

Source: Ramirez, 2020 [6]

The wells are ranking in a 1 to 5 scale according the production tubing depth in the well with respect to the time it takes to perform the Pulling service, where in the scale 1 is the less critical and 5 is the most critical.

Percentage values of the factors considered in the consequences of failures: According to equation 2, percentage values are placed at the user's criteria, in this case, percentage values were established as listed below:

Table 6. Estimation of the Percentage Value of the Factors Considered in the Consequences of Failures.

Consequences	
Production	50%
Environment	30%
Maintainability	20%

Source: Ramirez, 2020 [6]

V. Reliability Centered Maintenance – RCM

RCM is a systematic way of analyzing and reaching the maintenance needs of an asset. It focuses on selecting the most appropriate maintenance technique in a cost-effective manner, preserving and / or improving integrity. The idea of doing any kind of maintenance has more to do with reducing the consequences of a failure than avoiding it altogether. RCM has been in use for decades, beginning with the aeronautical industry and now widely used in the chemical and petrochemical industries, Exploration and Production (E&P) companies have just begun to realize the benefits of this methodology [7].

The RCM methodology statement seven questions about the asset and that is key to be able to initiate analysis and develop Reliability Centered Maintenance [8].

1. What are the functions and respective performance standards of the asset (functions)?
2. In what aspect does it not respond to the fulfillment of its functions (functional failures)?
3. What causes each functional failure (failure modes)?
4. What happens when a failure occurs (failure effects)?
5. How does each failure affect (failure consequences)?
6. What can be done to predict or prevent each failure (intervals task and proactive tasks)?
7. What should be done if the appropriate action plan cannot be found (default actions)?

Equipment failures are classified into "evident" and "hidden" failures before proceeding with the analysis. In the case of "evident" failures, RCM prescribes certain "proactive" tasks such as:

- Scheduled restoration tasks
- Scheduled discard tasks
- Tasks in condition.

Tasks in condition are the special features of the RCM methodology.

RCM places special emphasis on methods of dealing with "hidden" failures, which are not part of any conventional maintenance program. Hidden failures are dealt under default actions. RCM recognizes the following main categories of default actions:

- Failure finding
- Redesign
- Unscheduled maintenance

These tasks are prescribed based on the technical characteristics of the failure and how effective the task prevents the consequences of the failure. These decisions are made during an analysis using an RCM decision diagram according to reference [9].

The development of this methodology summarizes two key working documents which are the information and decision worksheet. The information worksheet describes information on the assets and subsystems, such as functions, functional failure for each function, failure modes related to functional failures and failure effects; The decision worksheet details which maintenance routine will be carried out, how often, and who will carry it out.

VI. Development of the RCM Methodology to Wells in the Marginal Oil Field

In order to start the analysis and develop a Reliability-Centered Maintenance for the wells, the first four questions set forth in the RCM methodology must be answered, which will generate the information worksheet that is one of the two key working documents. The extraction systems of the wells that were located in the very high criticality range are sucker rod pump and swab.

Preparation of the information worksheet of sucker rod pumping wells; It was obtained through an analysis of the wellbore diagram of a well operated by sucker rod pumping system, where the functions, functional failure for each function, failure modes related to functional failures and the failure effects were determined. Through the analysis, the tubing subsystem, subsurface pump subsystem, rod string subsystem, and surface equipment subsystem were obtained.

The tubing subsystem is made up of the tubing, perforated tube, gravel pack screen, and landing nipple; the subsurface pump subsystem is made up of the subsurface pump, seating cup, traveling valve, and standing valve; the rod string subsystem is made up of the rod string and rod coupling; the surface equipment subsystem is made up of the polished rod. The information worksheet of sucker rod pumping wells is shown in table 7.

The elaboration of the information worksheet of Swab wells was obtained through an analysis of the wellbore diagram of a well operated by swab system, where the functions were determined, functional failure for each function, failure modes related to the functional failures and the failure effects. Through the analysis, the tubing subsystem and standing valve subsystem were obtained.

The tubing subsystem is made up of the tubing; the standing valve subsystem is made up of the standing valve, landing nipple, and crosshead. The information worksheet of Swab wells is shown in table 8.

It should be noted that the components that make up each subsystem are those components that really present failures during their operation and are the ones that are followed up.

Table 7. Information Worksheet of Sucker Rod Pumping Wells

RCM Information Worksheet						
Asset: Sucker Rod Pump wells				**Made by:**		**Date:**
Asset location:				**Reviewed by:**		**Sheet N°:** 1 **OF:** 1
Component: Pulling – Sucker Rod Pump service						**Ref:**
Function		**Functional Failure**		**Failure Mode (Cause of Failure)**		**Failure Effects**
Tubing Subsystem						
1	Allows connection of reservoir fluids with surface installations.	A	Does not allow to connect the reservoir fluids with the surface installations.	1	Tubing body fissure.	Tubing breakage due to the friction effect between the rods and the tubing body, causing fluid leakage into the casing-tubing ring.
2	Allows the entry of solid free fluids into the tubing from the annular casing and tubing.	A	It does not allow the entry of fluids into the tubing from the annular casing and tubing.	1	Perforated tube plugging.	Clogging of the perforated tube, which does not allow the flow of fluids from the annular casing - tubing to the pump.
				2	Gravel pack screen plugging.	Clogging of the gravel filter, which does not allow the circulation of fluids from the annular casing - tubing to the pump.
3	Allows landing of the subsurface pump	A	Does not allow landing of the subsurface pump	1	Landing nipple wear.	Threads of the landing nipple in bad condition, causes decoupling of the bottom equipment.
Subsurface Pump Subsystem						
4	Displace the reservoir fluids from the bottom of the well to the surface through inside the tubing.	A	Does not allow the reservoir fluids to move from the bottom of the well to the surface through inside the tubing.	1	Failure (failure due to the presence of carbonates, paraffins, sand and gas) of the subsurface pump	Inefficient movement of the hydrocarbons from the tubing to the surface.

				2	Seating cups out of standard (S12)	Seating cups outside the specifications of API 11AX standards, if the diameter is exceeded ± 0.005 in of the recommended measurement, they do not generate a good seal between the tubing and the pump, because the cups do not a good anchor in the landing nipple.
				3	Traveling Valve Wear (V11)	The ball does not a good seal with the seat, leading to fluid runoff.
				4	Standing Valve Wear (V11)	The ball does not a good seal with the seat, leading to fluid runoff.
Rod String Subsystem						
5	Transmits up and down movement to the pump for fluid displacement.	A	It does not transmit up and down movement to the pump for fluid displacement.	1	Rod string body Wear.	Cracks and / or breakage of the rod string body due to its wear, causing the operation to stop.
			Failure in the connections between rods	2	Wear on the threads and the outer diameter of the coupling.	Decoupling of the rod and the coupling due to wear of the threads and /or external wear of the coupling.
Surface Equipment Subsystem						
6	Allows you to attach the rod pump.	A	It does not allow the rods to be attached to the pumping unit.	1	Wear of polished rod body.	Breaking of the body of the polished rod due to wear on the diameter of the polished rod, due to the effects of corrosion, friction.

Source: Ramirez, 2020 [6]

Table 8. Information Worksheet of Swab Wells

RCM Information Worksheet						
Asset: Swab wells				**Made by:**		**Date:**
Asset location:				**Reviewed by:**		**Sheet N°:** 1 **of:** 1
Component: Pulling - SWAB Service						**Ref:**
Function		**Functional Failure**		**Failure Mode (Cause of Failure)**		**Failure Effects**
Tubing Subsystem						
1	Allows connection of reservoir fluids with surface installations.	A	Does not allow to connect the reservoir fluids with the surface installations.	1	Tubing body fissure.	Tubing breakage, due to the friction of the lowering of the Swab assembly, or deterioration of the tubing, causing fluid leakage towards the annular casing-tubing.
Standing Valve Subsystem						
2	Allows fluid to flow in only one direction (upward) and prevents flow in the opposite direction.	A	Unable for fluid to flow in only one direction (upward).	1	Plugging of the standing valve	It does not allow the flow of fluids from the wellbore to the production tubing.
3	Allows landing of the subsurface pump	A	Does not allow landing of the subsurface pump	1	Landing nipple wear.	Threads of the landing nipple in bad condition, causes decoupling of the bottom equipment (standing valve).
				2	Crosshead break	It causes failures in the operation of the standing valve.

Source: Ramirez, 2020 [6]

The decision worksheet is the core part and one of the two key working documents of the RCM methodology. According to reference [10], the design of the decision worksheet will show the next information:

- RCM codes
- Consequences
- Type of maintenance
- Scheduled time
- Number of maintenances per year
- Time to perform maintenance % (traffic light)
- Time to perform maintenance in hours
- Last maintenance (how many hours ago)
- Horometer
- Next maintenance (hours)

The RCM code is obtained from the information worksheet shown in table 7 and 8, where information on the function (F), functional failure (FF) and failure modes (FM) of each item is reflected.

The evaluation of the consequences is carried out through an analysis using the RCM decision diagram according to reference [9], where it is reflected if they are consequences of hidden failure, for safety or the environment, operational or non-operational.

The type of maintenance is obtained through an analysis using the RCM decision diagram according to reference [9], where the different types of maintenance shown below will be known:

- Scheduled restoration tasks
- Scheduled discard tasks
- Task in condition
- Failure finding
- Redesign
- Unscheduled maintenance

Schedule time is a frequency to know how often (in hours) maintenance is going to be carried out on a certain asset, its equation is presented below [10]:

$$\text{Frequency} = (\text{date of last maint.} - \text{date of penultimate maint.})\,(\text{days}) * (\text{hours worked by the asset / day}),\ (\text{hours}) \quad (4).$$

The number of maintenances per year is calculated through the next equation shown below [10]:

$$\text{Number of maint. per year} = (\text{hours worked by the asset / year}) \;/\; (\text{scheduled time})\,\text{hours , year} \quad (5).$$

The time to perform the maintenance in percentage is calculated trough the next equation shown below [10]:

$$\text{Time to perfom maint.} = \left(\begin{array}{l} (\text{time to perfom maint.})\,\text{hours} \\ /(\text{scheduled time})\,\text{hours} \end{array} \right) * 100, \% \quad (6).$$

According to equation 6 calculation, the result (percentage) that is obtained, a color is assigned to obtain a traffic light and facilitate the reading of the data, the following table shown below details the traffic light to obtain:

Table 9. Traffic Light

Traffic Light	
Percentage (%)	**color**
67 - 100	Green
33 - 66	Yellow
0 - 32	Orange
≤ 0	Red

Source: Ramirez, 2020 [6]

The time to perform maintenance in hours is calculated by the following equation shown below [10]:

$$\text{Time to perfom maint.} = (\text{next maint.}) - (\text{horometer}),\ \text{hours} \quad (7).$$

The last maintenance is the horometer reading since the well or asset began to produce until the last maintenance was performed, this is because the start of operations and the different operational contexts that the well has had is not known exactly, during its productive life, it was decided to assign it a reference value of 100,000 hours, which does not affect the final result. The unit is in hours.

The horometer is calculated using the following equation shown below:

$$\text{Horometer} = \text{last maint.} + \text{number of hours that have passed since last maint. was made to the current date, hours} \quad (8).$$

The next maintenance is calculated using the following equation shown below:

$$\text{Next maint.} = (\text{last maint.}) + (\text{scheduled time}),\text{hours} \quad (9).$$

VI. Results

A. Application of Semi-Quantitative Criticality Model to Wells of a Marginal Oil Field

Through equations 1 and 2, all the wells with their respective extraction system were ranked as shown in table 10. According equation 2 the consequences of failure were established with impact on production, maintainability, environment and safety and their percentages are 50%, 20% and 30% respectively, as can be seen in table 6.

Using the criticality matrix, shown in figure 2, the wells are being located into different levels of criticality that the model has. The results of the ranking of the wells in the study field are shown below.

Table 10. Wells According their Ranking

Criticality \ Extraction system	Swab	Sucker rod pump	Plunger Lift	Total
L	160	114	0	274
M	87	94	0	181
H	35	86	2	123
VH	3	24	0	27
Total	285	318	2	605

Source: Ramirez, 2020 [6]

The 27 wells that qualified in the very high criticality range were shown with all the data and details of the ranking.

Table 11. Wells that Qualified in the Very High Criticality Range According to the Semiquantitative Criticality Model.

Wells	X Coordinate	Y Coordinate	Extraction System	BOPD	# Pulling	Period (years)	# Interventions /Year	Failure Frequency	Impact on Production	Impact on Environment and Safety	Tubing Depth	Impact on Maintainability	Consequences	FF VS C
UPSEA0004	516323	9743844	BM	8	10	11	0,91	5	5	5	3314,9	4	5	MA
UPSEA0558	521591	9745320	SW	2,5	9	10	0,90	5	3	1	3920,3	4	3	MA
UPSEA0585	520314	9743826	BM	3,3	6	7	0,86	5	4	1	3383	4	3	MA
UPSEA0604	523091	9745344	BM	6	10	11	0,91	5	5	1	3470	4	4	MA
UPSEA0661	522253	9745418	BM	4	7	11	0,64	5	4	1	2807	3	3	MA
UPSEA1202	514744	9743769	BM	4	8	9	0,89	5	4	1	3740	4	3	MA
UPSEA1205	515702	9743036	BM	3	9	11	0,82	5	3	2	4155	5	3	MA
UPSEA1213	515256	9743260	BM	2,5	16	11	1,45	5	3	1	4132	5	3	MA
UPSEA1218	514319	9744625	BM	5	7	7	1,00	5	5	1	3365	4	4	MA
UPSEA1236	521450	9744673	BM	5	13	11	1,18	5	5	1	3668	4	4	MA
UPSEA1254	522268	9744072	BM	3	5	6	0,83	5	3	1	4332	5	3	MA
UPSEA1287	522602	9740534	BM	5	10	10	1,00	5	5	1	3515	4	4	MA
UPSEA1630	521075	9741259	BM	4	12	11	1,09	5	4	1	4257	5	3	MA
UPSEA1639	519169	9740411	BM	4,5	10	11	0,91	5	5	1	4609	5	4	MA
UPSEA1646	523529	9739653	BM	6	16	11	1,45	5	5	1	2376	3	3	MA
UPSEA1689	519384	9741505	SW	4	4	5	0,80	5	4	1	3207,2	4	3	MA
UPSEA1871	516848	9745363	BM	6	6	9	0,67	5	5	1	1388	2	3	MA
UPSEA1879	519408	9741482	BM	5	5	4	1,25	5	5	1	1304	2	3	MA
UPSEA1894	521826	9744444	BM	4	6	11	0,55	5	4	1	1538	2	3	MA
UPSEP0101	505398,5	9756522,1	BM	6	10	11	0,91	5	5	4	2021	3	4	MA
UPSEP0125	505346,1	9756398,8	BM	3	17	11	1,55	5	3	5	2857	3	4	MA
UPSESP0238	508572,6	9750715,2	BM	2	8	11	0,73	5	2	3	2139	3	3	MA
UPSESP0251	508409	9752220	BM	5	4	11	0,36	4	5	5	4495	5	5	MA
UPSESP1001	508470	9751329	BM	4	15	11	1,36	5	4	3	1973	2	3	MA
UPSESROC02	509052,3	9752912,6	BM	3	13	11	1,18	5	3	5	620	1	3	MA
UPSET0014	521853	9745968	BM	7	9	11	0,82	5	5	1	4380	5	4	MA
UPSET0027	522135	9746196	SW	3,33	10	10	1,00	5	4	1	3042	4	3	MA

Source: Ramirez, 2020 [6]

B. Development of the RCM Methodology to Wells in the Marginal Oil Field

The 27 wells that qualified in the very high criticality range which 24 are sucker rod pump wells and 3 are swab wells, these wells will be RCM applied. The maintenance to the selected wells will be carried out through Pulling operations.

Answering fifth until seventh question and doing the calculations using the fourth until ninth equation will be generated the decision worksheet, one of the most calculations is to know the scheduled time, which is the frequency to know how often it's going to perform maintenance on determining well. The schedule time of the 24 sucker rod pumping wells and 3 swab wells is shown in table 12 and 13 respectively.

Table 12. Scheduled Time of Sucker Rod Pump Wells

Wells	Extraction system	Last Maintenance Tubing Subsystem	Last Maintenance Subsurface pump and rod string subsystem	Penultimate maintenance Tubing subsystem	Penultimate maintenance Subsurface pump and rod string subsystem	Last Maintenance - Penultimate maintenance	Hours worked per day	Scheduled time (hours)
UPSEA0004	BM	06/04/18	06/04/18	19/6/2017	19/6/2017	291	3,2	931,2
UPSEA0585	BM	23/09/19	23/09/19	13/02/17	13/02/17	952	24	22848
UPSEA0604	BM	14/09/18	14/09/18	24/12/14	24/12/14	1360	24	32640

UPSEA0661	BM	08/08/19	08/08/19	25/08/14	25/08/14	1809	24	43416
UPSEA1202	BM	19/10/18	19/10/18	26/12/15	26/12/15	1028	24	24672
UPSEA1205	BM	05/06/18	05/06/18	18/06/14	18/06/14	1448	3	4344
UPSEA1213	BM	04/01/19	04/01/19	14/09/17	14/09/17	477	24	11448
UPSEA1218	BM	26/06/19	26/06/19	09/08/18	09/08/18	321	24	7704
UPSEA1236	BM	15/05/18	15/05/18	16/01/17	16/01/17	484	6	2904
UPSEA1254	BM	03/07/19	03/07/19	28/10/16	28/10/16	978	24	23472
UPSEA1287	BM	19/04/19	19/04/19	19/05/17	19/05/17	700	24	16800
UPSEA1630	BM	06/04/18	06/04/18	08/08/17	08/08/17	241	24	5784
UPSEA1639	BM	07/02/19	07/02/19	05/07/17	05/07/17	582	24	13968
UPSEA1646	BM	12/07/19	12/07/19	09/10/18	09/10/18	276	24	6624
UPSEA1871	BM	20/09/18	20/09/18	23/02/15	23/02/15	1305	24	31320
UPSEA1879	BM	04/12/19	04/12/19	10/04/18	10/04/18	603	12	7236
UPSEA1894	BM	06/08/19	06/08/19	06/03/18	06/03/18	518	4	2072
UPSEP0101	BM	25/12/19	25/12/19	10/10/18	10/10/18	441	24	10584
UPSEP0125	BM	21/05/19	21/05/19	16/08/17	16/08/17	643	24	15432
UPSESP0238	BM	14/06/18	14/06/18	21/11/17	21/11/17	205	24	4920
UPSESP0251	BM	17/08/18	17/08/18	10/09/13	10/09/13	1802	24	43248
UPSESP1001	BM	28/05/19	28/05/19	13/11/18	13/11/18	196	24	4704
UPSESRC02	BM	26/12/19	26/12/19	16/05/18	16/05/18	589	24	14136
UPSET0014	BM	24/12/19	24/12/19	13/11/18	13/11/18	406	16	6496

Source: Ramirez, et. al. 2020

Table 13. Scheduled Time of Sucker Rod ump Wells

Wells	Extraction system	Last Maintenance Tubing and standing valve subsystem	Penultimate maintenance Tubing and standing valve subsystem	Last Maintenance - Penultimate maintenance	Hours worked per day	Scheduled time (hours)
UPSEA0558	SW	06/01/20	06/02/18	699	1	699
UPSEA1689	SW	11/06/19	23/12/16	900	1	900
UPSET0027	SW	12/07/19	20/12/17	569	1	569

Source: Ramirez, 2020 [6]

In the decision worksheet of the 27 selected wells, the horometer runs until the date of January 31, 2021, the number of daily hours that have passed since the last maintenance until January 31 of this year, depends on the operational context of each well.

The polished rod with the RCM code 6A1 was assigned a task to condition with a failure mode inspection twice a year, the number of hours of scheduled maintenance will depend on the operational context of each well, where the last maintenance is simulated Predictive to failure mode 6A1 was performed on October 16, 2020, to all 27 selected wells.

Table 14 shows a summary of the decision worksheet of the 27 wells that qualified in the very high criticality range, and table 15 shows the decision worksheet of UPSEA0585 well with all the parameters considered in the design of the decision worksheet.

Table 14. Summary of the Decision Worksheet of the 27 Wells

Wells	Extraction system	Scheduled time (hours)	Time to perform maint. (%)	Time to perform maint. (hours)
UPSEA0004	SRP	931,2	-254	-2368
UPSEA0585	SRP	22848	48	10944
UPSEA0604	SRP	32640	36	11760
UPSEA0661	SRP	43416	70	30408
UPSEA1202	SRP	24672	19	4632
UPSEA1205	SRP	4344	33	1431
UPSEA1213	SRP	11448	-59	-6744

UPSEA1218	SRP	7704	-82	-6336
UPSEA1236	SRP	2904	-205	-5952
UPSEA1254	SRP	23472	41	9600
UPSEA1287	SRP	16800	-93	-15672
UPSEA1630	SRP	5784	-328	-18960
UPSEA1639	SRP	13968	-24	-3408
UPSEA1646	SRP	6624	-106	-7032
UPSEA1871	SRP	31320	43	10584
UPSEA1879	SRP	7236	30	2148
UPSEA1894	SRP	2072	-5	-104
UPSEP101	SRP	10584	9	912
UPSEP125	SRP	15432	3	528
UPSESP0238	SRP	4920	-369	-18168
UPSESP0251	SRP	43248	50	21696
UPSESP1001	SRP	4704	-213	-10032
UPSESR0C02	SRP	14136	32	4488
UPSET0014	SRP	6496	0	32
UPSEA0558	SW	699	44	308
UPSEA1689	SW	900	33	300
UPSET0027	SW	569	0	0

Source: Ramirez, 2020 [6]

Table 15. Decision Worksheet of UPSEA0585 Well

RCM Desicion Worksheet Sucker Rod Pumping Wells																							
Asset:		Sucker Rod Pump wells								N°			Made by:			Initial date:							
Component:		UPSEA0585								Ref:			Reviewed by:			Last change date:							
Information reference			Consequence evalution				H1 / S1 / O1 / N1	H2 / S2 / O2 / N2	H3 / S3 / O3 / N3	Default action			Type of maintenace	Proposed task	Number of maintenances per year	Scheduled time [hours]	Horometer (update daily) [hours]	time to perform maintenance [%]	Time to perform maintenance [hours]	Last maintenance	Next maintenance [hours]		
F	FF	FM	H	S	E	O				H4	H5	S4											
Tubing subsystem																							
1	A	1	YES	NO	NO	YES	NO	YES					Scheduled restoration tasks	Check the condition of the body of the tubing, presence of fissures, deformation or breakage, scale encrustations, wear of the threads. Change pipes in poor condition, have the necessary stock in the warehouse for a certain task.	0,4	22848	111904	48%	10944	100000	122848		
2	A	1	YES	NO	NO	YES	NO	YES					Scheduled restoration tasks	Clean the perforated tube, check the condition of the perforated tube, presence of fissures, deformation or breakage, scale encrustations, wear of the threads. Change perforated tube, if necessary.	0,4	22848	111904	48%	10944	100000	122848		
2	A	2	YES	NO	NO	YES	NO	YES					Scheduled restoration tasks	Check + clean the gravel pack screen, remove all the gravel and wash or change the gravel. Change the gravel pack screen, if necessary.	0,4	22848	111904	48%	10944	100000	122848		
3	A	1	YES	NO	NO	YES	NO	NO	YES				Scheduled discard tasks	Change landing nipple.	0,4	22848	111904	48%	10944	100000	122848		
Subsurface pump subsystem																							
4	A	1	YES	NO	NO	YES	NO	NO	YES				Scheduled discard tasks	Send subsurface pump to workshop, enter a repaired or new pump.	0,4	22848	111904	48%	10944	100000	122848		
4	A	2	YES	NO	NO	YES	NO	NO	YES				Scheduled discard tasks	Change seating cups.	0,4	22848	111904	48%	10944	100000	122848		
4	A	3	YES	NO	NO	YES	NO	NO	YES				Scheduled discard tasks	Change traveling valve, if it does not make a good seal with the valve seat.	0,4	22848	111904	48%	10944	100000	122848		
4	A	4	YES	NO	NO	YES	NO	NO	YES				Scheduled discard tasks	Change standing valve, if it does not make a good seal with the valve seat.	0,4	22848	111904	48%	10944	100000	122848		
Rod string subsystem																							
5	A	1	YES	NO	NO	YES	NO	YES					Scheduled restoration tasks	Check for the presence of solids (scale or paraffin incrustations) on the rod body. Change rod if its body shows wear greater than 1/8 "in 5 feet in a complete turn. Change rod, if the rod pin has worn threads and missing parts of material.	0,4	22848	111904	48%	10944	100000	122848		
5	A	2	YES	NO	NO	YES	NO	YES					Scheduled restoration tasks	Check + clean rod coupling. Change coupling if its body has torn material, bumps and deformation. Change the coupling if the threads show wear.	0,4	22848	111904	48%	10944	100000	122848		
Surface equipment subsystem																							
6	A	1	YES	NO	NO	YES	YES						Tasks in condition	Inspect the condition of the polished rod, generate a work order if necessary.	2	4320	102568	41%	1752	100000	104320		

Source: Ramirez, 2020 [6]

VII. Conclusions

A total of 605 producing wells were ranked with an extraction system by Sucker Rod Pump, Swab and Plunger Lift belonging to a marginal field, resulting in that 274 wells qualified in the low criticality range, 181 wells qualified in the medium range criticality, 123 wells qualified in the high criticality range, 27 wells qualified in the Very High criticality range. The wells that were qualified in the Very High criticality range were applied RCM.

For the calculation of the scheduled maintenance of the wells that work with the extraction system by sucker rod pump it was decided to use the same date of the last and penultimate maintenance obtained from the pulling history in the tubing, subsurface pump, and rod string subsystem because when the Pulling crew performs a complete service, each component of the completion is maintained.

If the Pulling crew only performs the pump change service due to technical decisions, to perform this maintenance only the subsurface pump and rod string subsystem would intervene, therefore with the passing of time new calculations of scheduled maintenance will be obtained in the different subsystems of the wells that work with the extraction system by suck rod pump.

Through the analysis of the decision diagram, the polished rod with its respective RCM 6A1 code was assigned predictive maintenance with a condition task, due to the climatic conditions that arise in the field of study, the task will be carried out twice a year to check the condition of the polished rod. The scheduled maintenance of the RCM 6a1 code will depend on the operational context of each well.

The RCM methodology does not intend to change the organization of the work or add maintenance tasks that are not possible to perform, it can simply be evidenced the components and failure modes that had the most impact to take proactive actions to ensure that the asset continues to function.

VIII. Recommendations

To Carry out maintenance the Wells that qualified in the high criticality range with previous analysis that justifies that they need maintenance and monitoring the productive wells those are close to the town because maintenance work is high risk.

Monitoring scheduled time of the decision worksheets because wells behavior is dynamic and scheduled time may change.

Develop a maintenance plan to pulling rig to avoid unscheduled downtime at the time or before the well servicing for a better optimization in time and costs.

IX. Acknowledgment

To Universidad Estatal Peninsula de Santa Elena for opening its doors to us in its academic to do this research.

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