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A Model for the Management of Reliability in the Oil Industry

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Abstract

Equipment inspection uses quality, predictive maintenance and risk analysis tools within a framework of laws and standards to help keep asset integrity level to a desired level. In PETROBRAS, the inspection team must also comply with strict rules set by the Brazilian Ministry of Work and Employment to ensure workers safety and health, and this has become the main focus of the inspection team's efforts, sometimes to the exclusion of economic considerations. One of the main activities involves inspection of the production system, which comprises of several aerial pipelines, manifolds and ground pipes. Due to the lack of experience and standards on the subject, the current inspection interval for pipelines is very short, resulting in large amounts of interventions on a vast and logistically challenging environment. Over ten years now it has been followed without questioning, but recent expansion of the system has put a stress on manpower available to do the work. The present study was conducted to evaluate an optimal interval time based on historical data on degradation and failures, as well as to come up with a new inspection planning strategy which could help reduce ineffective work and yield free time to focus on the new systems being installed.

Findings: The paper indicates that statistical data analysis, system reliability analysis and Monte Carlo simulation, as well as the opinions of diverse field experts can be combined to present strategies which may sustainably reduce total pipeline inspection and maintenance costs by as much as 58% without increasing the risk of failure or accidents common in most cost cutting strategies.

Keywords: equipment inspection; production lines; reliability management; system reliability.

1 Introduction

Equipment inspection is a part of the maintenance organization charged to keep asset integrity at a desired level. To that end It requires several tools commonly used in quality assessment, predictive maintenance and risk analysis, used inside a framework of laws, resolutions and standards to ultimately safeguard worker's security. In the Amazonas Operational Unit (UO-AM) of Brazilian state-owned O&G company PETROBRAS, the inspection team is certified as a SPIE (Own Service of Equipment Inspection); a certification given by the Brazilian Ministry of Work and Employment (MTE) to companies who apply for it and which commit to an additional set of strict rules concerning inspection quality procedures, team expertise, training and contracting. Due to the extension of the production field and the variety of assets the inspection team is divided accordingly to allow for a better distribution of work.

One of these teams, composed by three technicians working on a 14x21 day rotation, is charged to care for aerial and ground pipelines by inspecting the assets, the tracks of land crossed by them, monitoring internal corrosion, cathodic protection system effectiveness, investigating failures and recommending repairs as well as seeing it done according to the quality parameters set. The current inspection strategy consumes a lot of time due to the high frequency of aerial pipelines inspections, together with difficult logistics and work liberation efficiency; specially when in remote areas or for extraordinary work after PIG internal inspections. This leads to scheduled work being delayed which directly compromise the compliance to the rules and threaten the SPIE certification.

Since the 1970's reliability engineering has been increasingly presented as a philosophy capable of allowing the optimization of asset life-cycle costs in all segments of industry. It does this by considering asset operational risk, consequences of failures and its impact on the organization profits (AHUJA e

KHAMBA, 2008). While many enterprises need to reduce their operational costs, the common strategy of cutting costs is carried on by reducing maintenance activities and investment in failure-avoiding improvements; this affects equipment durability and availability and, consequently lowering the profits in the medium term; which leads to further cost-cutting and so on (MITCHELL, 2007). In the long term, the practice affects team motivation, and may create a culture in which repairing failures quickly is more valued by managers than avoiding them (BOTELHO, 2012).

To investigate the best way to organize this activity a reliability study was conducted applying statistical data analysis to failure events, as well as to data such as the logistic difficulty to access remote places, the climate history in the region and transportation time. With these data, the optimum frequency of inspection was determined for all pipelines considering the risk of failure and its consequences, and a new way of conducting the inspections was proposed to minimize logistic delay and maximize efficiency.

2 Reliability, Availability and Maintenability Analysis

2.1 Framework and Considerations

Due to the complexity of the analysis some simplifying considerations were made at this first stage:

1. The scope of the analysis included only oil aerial pipelines, with some initial consideration given to other elements of the system to allow the creation of the complete oil production network for this and further studies;
2. The damages identified during inspection are corrected 75% of the time before developing into failures, this assumption is made based on the SPIE recommendation compliance indicator;
3. Manifolds - equipment which act as nodes allowing production routing - were not considered as fallible, their analysis is due in future studies to follow;
4. The only failure mechanism considered to affect ground pipelines was internal corrosion; ground pipelines inspection strategy is already being carried out in another study;
5. Oil wells are not considered in the scope of the inspection team, and thus, are not in the scope of this analysis;
6. Choke valves' failures were not included since their inspection frequency is already controlled statistically as a result of a previous study;
7. Corrective maintenance costs are estimated as being generally thrice the sum of inspection and condition-based preventive maintenance costs, based on specialist interview and maintenance order cost comparison.

2.2 Collection and Analysis of Data

A production line is hereby defined as a pipeline composed of varied elements like control valves, instruments and pipes, whose twofold function is to conduct fluid at maximum allowable flow rate for its diameter and pressure loss, without leaks of any sort. With this definition in mind all events that might affect these functions were listed and historical data was gathered from the CMMS and ERP software, as well as written inspection reports and work orders. The result was 77 oil production lines, 8 collect lines and 13 test lines. All failure and damage data was gathered into tables and input into RELIASOFT's Weibull software, to help fit the probability distributions for each type of pipeline.

There were altogether 387 failure events (real or potential) out of 597 total events registered for production lines (LPP); 132 failures out of 138 events for collecting lines (LCP), and 388 failures out of 402 events for test lines (LTP). Where "suspension" is defined here as an event (such as an inspection) were no failure happened or damages were detected. The failure mode was codified as per the ISO-14224 (2006)

standard; causes of failures, damages and failures not codified by that standard were codified by the author following the three letter rule. The most observed failure mode was ELP (External Leaking of Product); the main causes were CEX (external Corrosion), CIN (internal corrosion), TRN (cracks and ruptures), ERS (erosion in valves and components) and EST (loss of tightness in connections). These were all interval data (RELIASOFT, 2005) due to minor leaks, although a failure of one of the line's functions, being difficult to perceive right away, this means there is more uncertainty to the exact time of failure, which will later result in a tighter inspection frequency to avoid it happening. Besides failure events, data from condition monitoring were taken into consideration: so, the thickness readings registered during external inspections were analyzed using linear regression analysis to calculate potential future failure dates, these data were added to the failure date table for internal corrosion cause and ELP mode.

Also, the most observed non failure events were ARV (falling of trees over the pipeline), SER (movement of pipelines out of supports or over each other), ERF (land track erosion), SPT (falling of supports) and RET (degradation of corrosion protection tapes). These events, if not taken care of in due time can evolve into, or cause failures. To account for these events, which are not yet failures, and for which there is no rate of evolution measured, the second assumption was made (see 2.1). The consideration is that, after the damage is detected, the inspector recommends actions for its mitigation and stipulates a timeframe for the repair measure to be carried out. Since one of the requirements of SPIE is that 75% of all non critical to safety recommendations must be followed as scheduled by the inspector, 25% of them are, consequently, not carried out in time to avoid failure. This is in accordance with the historical record of the indicator which measures this requirement and such assumption was confirmed as plausible by the inspection team. All damage events were arranged in a Fault Tree Analysis (FTA) diagram for which the (25% of the time) criterion was input as a condition block which means that the basic event AND the 25% criterion all must happen so that the top event (ELP) can happen. Since all events lead to ELP as being the failure mode for aerial pipelines, the results of the FTA could be input into a Reliability Block Diagram (RBD) to analyze together both failure events from data as well as damage from condition monitoring and damaging events. Figure 1 shows the block diagram for production lines (LPP).

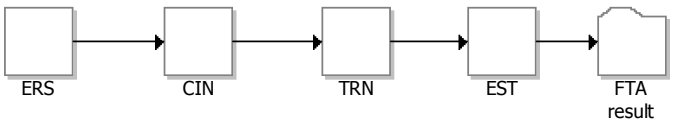

Figure 1: Reliability Block Diagrams (RBD) for production lines (LPP) showing the main ELP failure causes arranged in series. The last block represents the results of the FTA for LPP damages.

The best pdf must be chosen from a pre selected few which can theoretically model the physics of failure expected for each failure mode with the available data, through the use of tests like Anderson-Darling and Kolmogorov (MONTGOMERY e RUNGER, 2003). For the present study, the two parameter Weibull distribution was chosen where there were sufficient failures, while the exponential distribution was used when there were fewer data, or when the tests did show it to be the better for adjusting the data to. The method used for adjusting the data was the maximum likelihood function (RELIASOFT, 2005):

2.3 Determining Ideal Inspection Frequency

The first objective was to determine an ideal inspection interval. One way to accomplish this when there are no loss of life consequences is to account for the costs of more frequent corrective actions when inspection frequency is low, and inspection plus condition based maintenance costs when frequency is high; and find the optimum point of cost x frequency. In this study it was used a formula found in RELIASOFT (2007):

$$C(t) = \frac{C_P \bullet R(t) + C_c \bullet (1 - R(t))}{\int_0^t R(s)ds} \qquad \text{Eq.1}$$

where:

C_p is the inspection plus condition based maintenance cost;

C_c is the corrective maintenance cost;

R(t) is the reliability function for the equipment or part;

Corrective actions usually cost more than preventive ones. While the second is planned ahead, have parts acquired in time and ready personnel, the first is usually not expected, must be assessed to discover the extension of the damage (which is usually greater for the failure can damage other previously undamaged parts), risks not having the parts in stock and personnel ready, which leads to emergency purchasing and contracting, and, usually, is not as thoroughly planned due to time constraints caused by the ongoing loss of profit. As informed, the corrective costs for the present case are evaluated as being three times higher than inspection plus maintenance, or Cc = 3x Cp. So, by applying it to each kind of pipeline the optimum inspection time can be determined for most reliability functions. Table 1 shows the results of the calculations for the parameters of the weibull distribution and for the ideal interval time between inspections.

Table 1: Distribution parameters and optimal inspection time for all types of lines.

Line type:	LPP	LCP	LTP
Parameter/ Distribution:	2 Parameter Weibull		
β	1,08	1	4,74
η	2622	82632	5028
Interval, Year	57,53	N/A	9,32

It can be seen that for Production lines (LPP), the low cost interval would be around 57 years, while for collecting lines (LCP) the formula results in infinite time (hence, non applicable). This is due to the parameters obtained for the weibull distribution; for LPP, the shape parameter β was near 1, while for LCP it was equal to 1. For this value, it can be shown mathematically that the weibull distribution becomes the exponential distribution, and, for exponential distributions, the hazard rate function h(t) = λ. So, there is no point to converge since it is a constant (BOTELHO, 2012).

Although the mathematical results show that the optimum inspection interval would be over 8 years long it is important to consider some facts before accepting the results. First, the data used for the calculation had a small percentage of failure times over 4 years, since the actual interval is about 3 years long. This means that there is greater uncertainty on the behavior of the item at times over this interval. Physically this means that other failure modes which are not dominant or have not yet had time to manifest may develop, like, for example, fatigue associated with strain due to longer periods of time operating without proper support. Nevertheless, the experience in the Operational Unit is that some anomalies can be perceived by operators and communicated to inspection personnel, so that an extraordinary (unplanned) inspection can be made and avoid the problem altogether, but, once again, this is subject to operator error as well as other unrelated problems such as the operator being capable of noticing the anomaly due to line visibility being affected by vegetation growth.

At this point experience must be used to moderate the decision process and, after consultation with specialists in the field, as well as planners, the basic interval of 8 years was accepted as a maximum possible interval; after that, a sensitivity analysis was conducted. All lines belonging to a manifold subsystem were grouped together and the groups where there was a high incidence of random failures like fallen trees had their inspection times reduced by a correction factor. This resulted in a new strategy

with only 9% of the subsystems with an 8 year interval, 5% were kept at a 3 year interval, and most (45%) with an interval of 6 years.

2.4 Reliability, Availability and Maintainability Analysis (RAM) Using Monte Carlo Simulation

To evaluate the impact of several policies in the production system, it is important to consider the consequences of each particular failure upon the system. One common tool to analyze system behavior is the Reliability Block Diagram. In such a diagram each pipeline, manifold and ground pipe can be considered a block which is connected in a manner that relates the failure of the block to the failure of the system. By applying the failure distributions to all blocks and running a Monte Carlo simulation (MOSS, 2005) it is possible to obtain the availability function of the system. Modern simulation softwares allow the input of other variables such as repair time, cost of repair and logistic delay, which allow calculation of the maintainability function – or, the probability that the piece of equipment will be repaired at a certain amount of time with given resources.

Due to the great number of lines, manifolds and ground pipes, and their interconnections, the diagram was subdivided using RELIASOFT's Blocksim software. Since each manifold acts as a node, grouping together several incoming parallel production pipelines and some out coming collecting or test lines, for each of them a sub diagram was created and, finally, all sub diagrams were interconnected by the ground pipes, which is shown in figure 2.

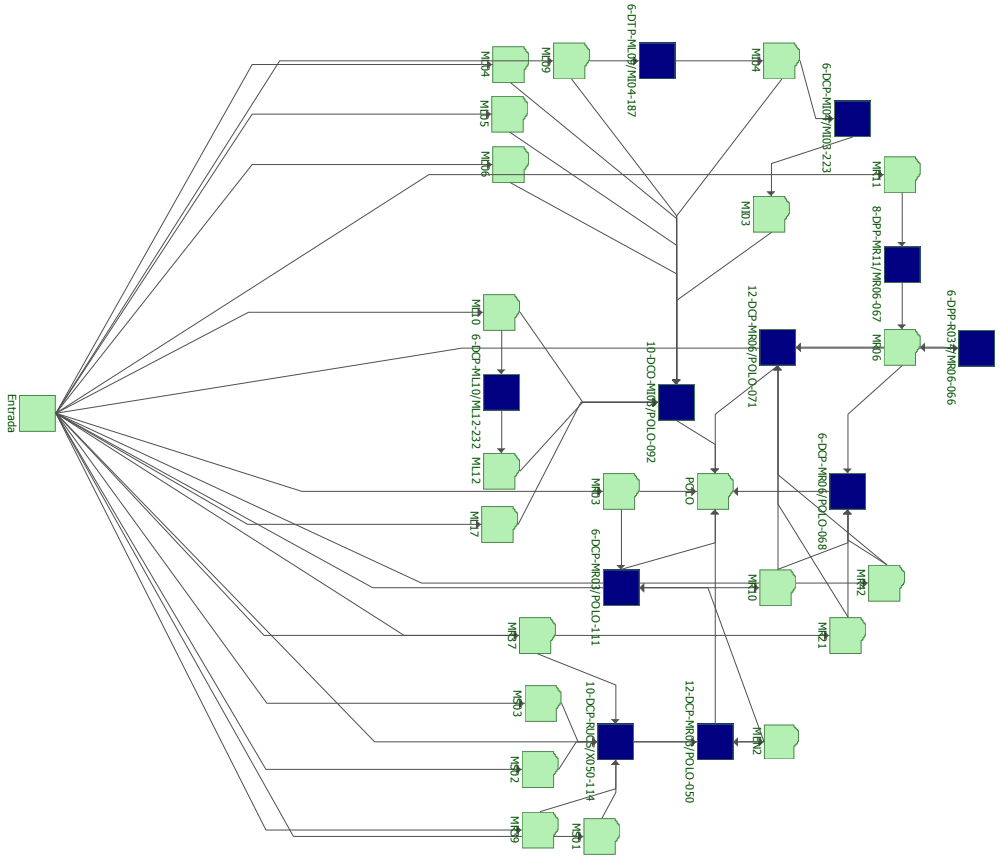

Figure 2: Complete diagram, showing all manifold sub diagrams (green folder-like blocks) connected by ground pipes (blue square blocks) and collecting lines.

Monte Carlo simulation was done by first generating a random failure time for each block based on its underlying distribution and relating the individual block results to the system result by applying the system reliability equation, which, due to its complexity, is computed using a software like the one above

mentioned. If there results a failure, a random repair time is generated based on the corrective maintenance distribution for the block (KOBBACY e MURTHY, 2008), if there are no failures before the inspection interval has elapsed an inspection is performed and the inspection detection threshold is compared to the next simulated failure time. If the next simulated time for the block falls inside the threshold inspection detects the future failure (damage already incurred) and condition based maintenance is scheduled. For all maintenance actions it is also considered the restoration model. For this simulation, it was considered that repaired systems are as good as new, which means all maintenance repairs all accumulated damage on the item. This is plausible for a first analysis, since usually repairs are conducted by changing the damaged part for a new one to lower downtime.

New failure and repair times are calculated until the length of time for the system operation is spent. This process is repeated a number of times determined by the user and, at the end of all iterations, the average and standard deviation of the system variables are calculated based on all the results (RELIASOFT, 2007). The inspection and maintenance policies and strategies can be input as well, inspection can be simulated as an action which does not cause the system to stop production and which has a probability of finding damage before it turns into a failure (that will stop system production). The simulation handles this by applying a failure finding threshold, which is a probability of finding the (randomly defined block failure time) at a given time before it actually happens. If it does, condition based maintenance is then scheduled to happen immediately or at a future time dependant on maintenance team delay time. If it happens before the failure time, it counts as a condition based maintenance, with all due costs, if it takes longer to happen, a corrective maintenance is then automatically scheduled. The simulation results from the Blocksim software for a 20 year operation period are shown in table 2 for both a 3 year (old strategy) and the new strategy for inspection intervals.

It can be seen on the comparison column on table 2 that availability is not significantly changed even if a twice longer inspection policy is adopted. This confirms that the actual policy is excessive and squanders resources best used for other more effective actions. It can also be seen that corrective maintenance (CM) and condition based maintenance (CbM) actions are not changed by the new strategy. This may arise from the β parameter close to 1, as mentioned earlier, from some of the line types, which means these failures are random and cannot be prevented. Nevertheless, the results also show a possible maximum cost reduction of 7%, mostly due to reduction in the number of inspections (IN).

Table 2: System simulation results. Relative values were obtained by dividing partial values by the total cost for the strategy. Absolute values for costs are not shown to preserve sensitive information.

		Old Strategy	New Strategy	Comparison
Availability	Mean Availability (All Events):	0,99	0,99	100%
	Std Deviation (Mean Availability):	0,00	0,00	95%
	Mean Availability (w/o CbM & Inspection):	0,99	0,99	100%
	Expected Number of Failures:	27,92	28,27	100%
	Std Deviation (Number of Failures):	4,78	4,84	99%
Events	Number of CMs, Day:	27,92	27,92	100%
	Number of CbMs:	4,55	4,55	96%
Costs	Relative Total CM Costs:	7%	7%	
	Relative Total CbM Costs:	8%	8%	
	Relative Total Inspection Costs:	85%	85%	
	Relative Total Costs:	100%	100%	93%

3 Inspection Planning

Production system is spreads over 3 production fields 60 km apart in the Amazon rainforest. Although most principal roads are paved, many accesses are still done through muddy roads, specially difficult to

manage where crossed by one of the many small rivers that dot the region or during the rainy season. Vegetation growth is also another obstacle which hampers vision and blocks access as well as hides dangerous wildlife, some damaging events like soil erosion and fallen trees may also interfere. Weather and climate conditions such as high temperature and humidity, heavy rains and insolation means that special care must be taken to avoid ill effects on workers. The careful planning must somehow take all of this into consideration so as to make the best use of all resources available in an attempt to eliminate waste and also to focus on customer (in this case internal customer) needs (KISTER and HAWKINS, 2006).

3.1 Climate History in the Production Region

Climate data from the production Field area was acquired in a previous study conducted by UFAM (Amazonas Federal University) which gathered weather data through a weather station installed in the region. From 1997 to 2004 the Uruclima project collected data on precipitation, temperature and humidity; from this data it is possible to analyze how these variables may interfere with scheduled work. The probability distribution for the amount of rain in a month, and for the number of days of rain per month was obtained from the monthly day to day averages. Table 3 shows the results.

Table 3: Pluviometric level average, rain distribution and probability of rainy days per month.

Month	Pluviometric level	Monthly rainy day distribution			Rainy days per month	
		Distribution	1st Parameter	2nd Parameter	@90% probability	Frequency
JAN	285,6	LOGNORMAL	3,21	0,1374	21	0,68
FEB	295,6	LOGNORMAL	3,13	0,1091	20	0,71
MAR	345,1	LOGNORMAL	3,2	0,1172	21	0,68
APR	314,1	NORMAL	23,42	2,1782	21	0,70
MAY	236,0	WEIBULL	5,62	24,79	17	0,55
JUN	133,1	NORMAL	17,5	5,58	10	0,33
JUL	113,3	NORMAL	14,25	5,43	7	0,23
AUG	80,5	NORMAL	12,62	3,58	8	0,26
SEP	110,6	LOGNORMAL	2,67	0,1826	11	0,37
OCT	193,7	WEIBULL	5,66	18,04	12	0,39
NOV	187,8	WEIBULL	3,43	21,6	11	0,37
DEC	239,7	WEIBULL	5,47	23,44	15	0,48

According to XAVIER and LAMBERTS (2011) evaporation is the main body temperature regulation mechanism and it is influenced by some climate variables. A temperature-humidity index (ITU) is presented by the authors to help quantify the thermal comfort felt by workers.

$$ITU = T - 0.55 \times (1 - UR) \times (T - 14) \qquad \text{Eq. 2}$$

where:

T is the temperature in Celsius scale;

UR is the relative air humidity.

Values over 25 or under 15 would be considered uncomfortable by the majority of the population. With the historical data values: average, maximum and minimum, a triangular distribution was fitted for the variables and the ITU was obtained using Monte Carlo Simulation. Average monthly temperature, relative humidity and the ITU index are shown on figure 3.

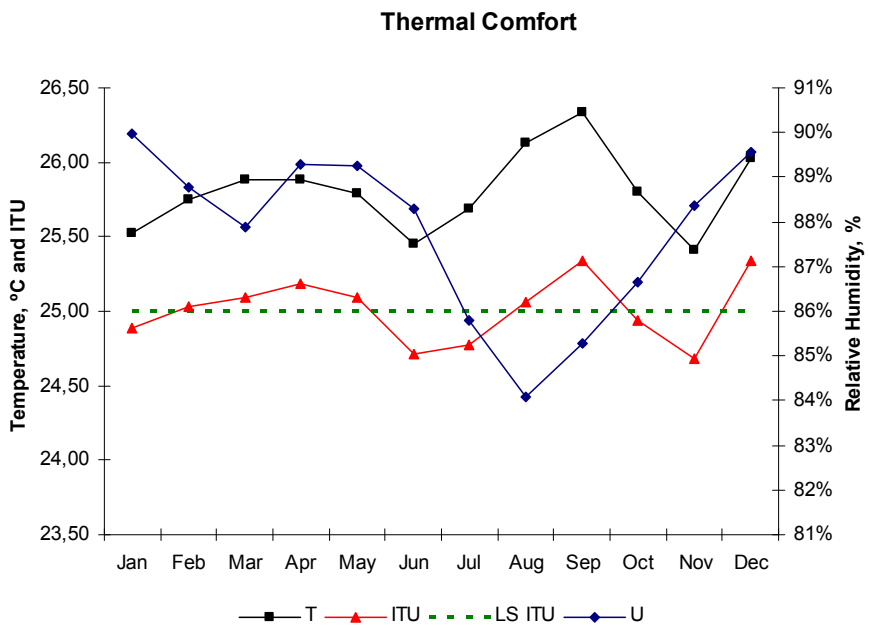

Figure 3: Humidity (U), temperature (T) and temperature-humidity index (ITU) monthly average results.

Crossing the information on Figure 3 and table 3 it can be seen that there is a period with less rain volume (pluviometric level) between May and October, which corresponds to the rainforest "dry" season. Temperature averages remain almost always above 25,5ºC throughout the year, while humidity drops in the beginning of the dry season . The average ITU drops below its upper level (LS) only in June and July, and then again in October and November.

3.2 Access Difficulty

Road access is also a problem to be considered. To assess this information, a list of locations was created and distributed among operators to evaluate the access conditions on their own experience. It was asked of them to tell which kind of vehicle would be necessary to access each location with both good and rainy weather, and the answers could be either a normal car, a 4x2 traction pick-up, a 4x4 traction pick-up, or an helicopter. Then, access weights of 1, 0,75, 0,5 or 0,25 were given accordingly. Although this is in no way an affirmation that there is a real interval property between the choice of vehicles, suffice it to say that, if a location can be accessed by a common car, it can also be accessed by all other vehicles, thus, leaving four in four access options, while locations which can only be accessed by helicopter have only one in four access options.

This values were used to calculate a relative probability of access to each location considering rainy and dry days, as follows:

$$P(a) = \frac{1}{12}\sum_{i=1}^{12} W(a_c) \bullet R_i(c) + W(a_s) \bullet (1 - R_i(c)) \qquad \text{Eq.3}$$

where:

n is the number of lines per manifold subsystem;

P(a) is the access probability to a location along the year;

W(ac) is the access weight in a rainy weather;

W(as) is the access weight in dry weather;

$R_i(c)$ is the ratio of rainy days per month.

Equation 3 was applied to each line, and then, all results from lines of the same manifold subsystems were averaged to provide a priorization index.

3.3 A Priorization Rule for the Scheduling of Work

Starting with the manifold subsystems with lower average access probability work was manually distributed by month taking into consideration, when applicable, the cases where a particular location of a pipeline had a much different access probability than the average of its subsystem. Figures 4 and 5 shows the inspection distribution per month of all lines subdivided by manifold subsystems. It can be seen that in the old strategy the inspector would go to the same geographical location (manifold subsystem) several times in different occasions to inspect each line separately. With the new strategy, the inspector spends some days in one occasion, and inspects all lines from the same subsystem.

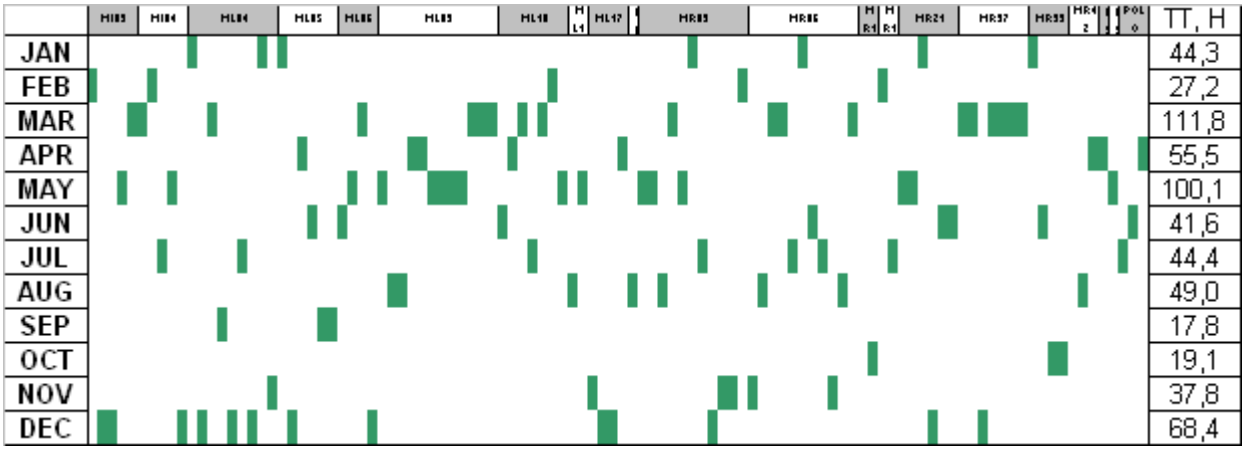

Figure 4: Previous distribution of inspections per month (lines inspected independently).

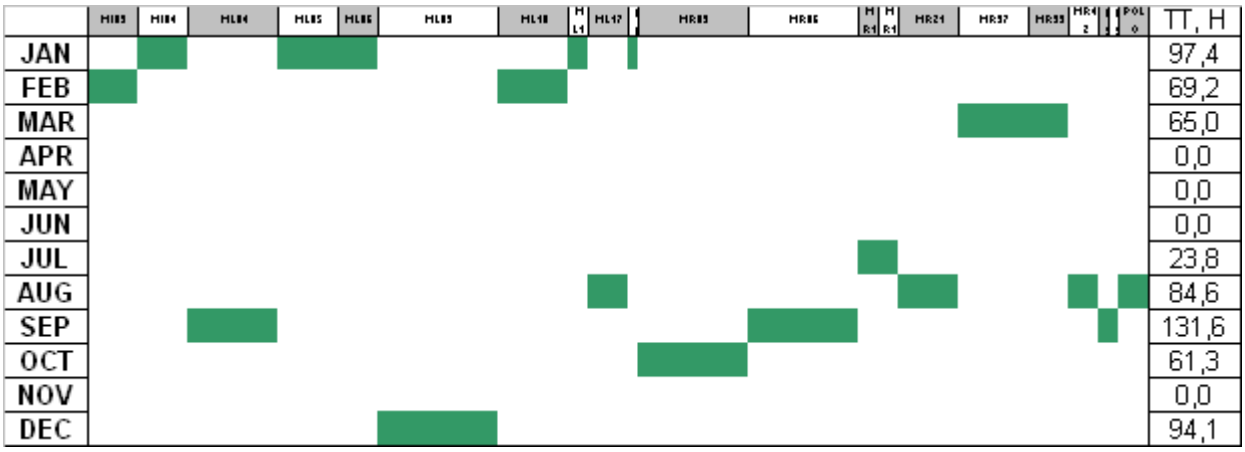

Figure 5: New distribution of inspections (lines grouped into manifold subsystems).

Since every line has an inspection duration based on its length and some constant factors such as preparation time, the comparison between the previous and the current strategy was done by multiplying the total time per month by the inverse of the probability to rain, shown in table 6. The optimization shows a possible reduction of 18,11% in lowering rework time due to allocation of inspections of difficult access areas to dry months; when considering the synergy of inspecting lines that cross the same track simultaneously there is a possible reduction of 43,86% in the inspection time.

4 Conclusion

The application of statistical and stochastic techniques to engineering and planning problem solving is not new in academic literature, but they are not as frequently applied to day to day problems which arise in industry and which must be dealt with by field engineers who frequently opt to use experience and expert opinion to make technical decisions. Although this may be often on the safe side and have no impact on equipment integrity, nevertheless, nowadays, fast changing global competitive scenario means that companies must stay fit for competition, which means to follow a dogma of low costs and steady profits. Asset maintenance is getting more complex as a combination of shorter equipment life cycles and incremental innovation leads to quicker obsolescence, but still problems are dealt separately by professionals, without taking in consideration interfaces, feedbacks and emergent system properties. While there are not yet mathematical methods for correctly dealing with system complexity, the integration of knowledge, as proposed by Morin (*apud* MARIOTTI, 2007) allows specialists to see the problem from a holistic point of view. So, while the mathematical methods used in this case require some simplifying assumptions, the combined opinion of experts when confronted with the same problem may help better understand the system and allow the crafting of a strategy which is at the same time based on hard data and the elusive but important empirical knowledge.

The strategy hereby applied indicates a possible total cost reduction of 58% from the old inspection strategy, even with a slight increase in maintenance work. This reduction is achieved by combined reduction of the sheer number of inspections as well as the increase in inspection efficiency due to increased synergy (contiguous lines being inspected simultaneously) and reduction of lost work by minimizing inspections in rainy seasons. This is significantly more than would have been obtained by the application of only one of the methodologies.

References

AHUJA, I.P.S.; KHAMBA, J.S. Total productive maintenance: literature review and directions. In: The International Journal of Quality and Reliability Management. Vol. 25, No. 7, 2008. pp. 709-756. Emerald Group Publishing Limited;

BOTELHO, A. G. Gestão da Confiabilidade: Análise em uma Empresa de Petróleo. M.Sc. Dissertation, PPTEC/CEFET/RJ, Rio de Janeiro, RJ, Brazil, 2012;

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION – ISO-14224: Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment. ISO, 2006;

KISTER, T. C.; HAWKINS, B. Maintenance Planning and Scheduling: Streamline your organization for a lean environment, Burlington - US: Elsevier Butterworth-Heinemann, 2006;

KOBBACY, K. A. H. e MURTHY, D. N. P. Complex System Maintenance Handbook. London – UK: Springer, 2008;

MARIOTTI, H. Pensamento complexo: suas aplicações à liderança, à aprendizagem e ao desenvolvimento sustentável. São Paulo: Atlas, 2007;

MITCHELL, J. S. Physical asset management handbook. Houston- US: Clarion, 2007;

MONTGOMERY, D. C.; RUNGER, G. C. Applied statistics and probability for engineers. 3ª ed. New York – USA: Wiley, 2003;

MOSS, T. R. The reliability data handbook. London: Professional Engineering publishing, 2005;

RELIASOFT. Life Data Analysis Reference. Tucson: Reliasoft Publishing, 2005;

RELIASOFT. System analysis reference. Tucson-USA: Ed. Reliasoft publishing, 2007;

XAVIER, A. P. P.; LAMBERTS, R. Proposta de zona de conforto térmico obtida a partir de estudos de campo em Florianópolis. Fortaleza: V Encontro Nacional de conforto no ambiente construído, 1999. Available at http://fisica.ufpr.br/grimm/aposmeteo/cap3/cap3-4.html. Accessed in February, 10, 2012.