Contributions to the improvement of the maintenance support information system

A case study at the Águas de Portugal Group

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Abstract

The Maintenance and Management of Physical Assets are, nowadays, an extremely important factor on a company's competitiveness, as the actions performed at that level have direct implications on the cost, deadline and quality of products or services. This way, it becomes important, not only to achieve the proposed goals, but also, to achieve them with minimum consumption or usage of resources.

In the field of maintenance management, this article intends to contribute to the development and improvement of maintenance in Águas de Portugal Group companies, henceforth referred to as AdP Group. Being the largest business group operating in Portugal in the environmental area, the AdP Group's main activity is the integrated management of the urban water cycle, working in all its phases. The several infrastructures of the Group supply around 80% of Portugal mainland population and are distributed widely around the country. For the importance played on the sector, and for the importance of its equipment, the companies of the AdP Group must practise an efficient maintenance, to ensure the quality of the provided services.

In this context, knowing, evaluating and classify the situations in which the equipment fail become central to modern organizations, since it is through this knowledge and study that solutions can be developed to revert the faults that occur, resulting in a greater availability and reliability of equipment.

Therefore, this article focusses the methodology for the development of a failure mode classification, having in consideration the contribution of suppliers, technicians and engineers of the AdP Group. In addition, it develops a solution for the monitoring and maintenance systems compatibility, crucial to the maintenance activities, concerning failure detection and diagnosis.

Keywords: Assets; Maintenance; Failure Modes; Pump.

1. Introduction

Nowadays, maintenance is one of the essential areas in the business context and elevates its importance with the contributions it can provide to a good production performance, to safety, to quality, to the company image and economic profitability and to the preservation of investments [1]. Its actions have direct implications in costs, deadlines and quality of the produced products or provided services, Therefore, it becomes important, not only to achieve the proposed goals, but also, to achieve them with minimum consumption or use of resources.

In Portugal, investments of around 8 billion euros have been made since 1993 in water supply systems, wastewater sanitation and urban waste management, of wich 7.5 billion were carried out by the AdP Group. The strong investments made have made significant progress towards adequate provision of these services, meeting the stringent community and national environmental and public health standards [2].

Since these infraestrucutres constitute a very significant part of the public utility, of high economic and social value, they must be preserved and maintained [2]. However, despite the crucial importance they represent to society, these systems are in poor condition, undermining the service provided to the population, as it renders them more vulnerable to unexpected failures [3].

This way, in the field of maintenance management, this article intends to contribute to the development and improvement of maintenance in Águas de Portugal Group companies, henceforth referred to as AdP Group.

Being the largest business group operating in Portugal in the environmental area, the AdP Group's main activity is the integrated management of the urban water cycle, working in all its phases. The several infrastructures of the Group supply around 80% of Portugal mainland population and are distributed widely around the country [4].

With the introduction of PENSAAR 2020 – New strategy for the water supply and wastewater treatment of Portugal mainland – there are stablished the operational targets for the sector aiming efficiency and profitability of systems and resources, advocating the strategy should focus on assets management, its operation and the quality of the provided services [5].

Therefore, the goals of this article focus on the definition of methodologies and creation of solutions, to provide information and tools to the maintenance area for an efficient and timely management in the AdP Group companies. Accomplishing, the goals are:

- To assess and classify the current maintenance system, regarding reporting and available information;
- To develop classifications of failure modes of an equipment typology of extensive usage and high operational and financial importance, as a way to increase the level of information transmitted and stored;
- To develop a classification to failure detection by sensors, to connect the maintenance and operational areas of the AdP Group.

2. Methodology followed

To represent the followed methodology to to develop this article the figure 1 is presented.

At an early stage it was studied, in addition to the AdP Group companies and their core business, the reality of the Group assets maintenance, focusing its organisation, the tools used to evaluate and report the occurred failures and how is the performance analysed in the maintenance area.

For this, several facilities were visited and the area operation modes of the AdP Group were observed and, moreover their maintenance activities were monitored, where it was possible to understand the difficulties felt by the operators while carrying out their work.

Subsequently, the corrective maintenance reports of some companies of the AdP Group were analysed. Through this study, it was possible to verify the lack of coherence of the existing information, as it doesn't aloud to conclude about the maintenance performance, but only about the expenses incurred on the maintenance actions performed.

In resolution of this first phase, one extensive usage typology was selected, important for the Group in terms of failures, but also in terms of investment. Based on this equipment (pumps) typology, two more classifications would be developed. The first, related to the failure modes of the typology in use, where it would be possible to classify a maintenance intervention recurring to a Problem, a Cause and a Solution. The second, based on the previous, would concern the use of the sensors on the pump for failure detection.

Therefore, the maintenance systems, till then independent, could transmit information between each other, speeding up and increasing the level of information of both areas.

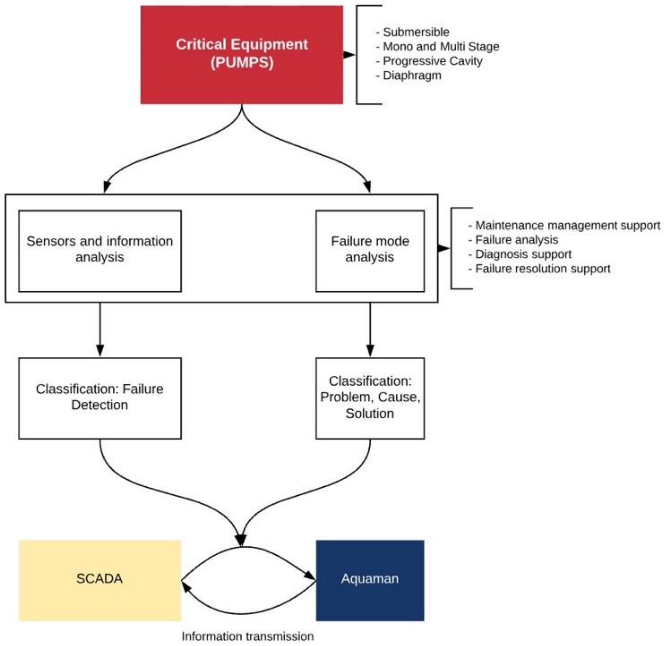

Figure 1 - Methodology followed to develop this article

3. Working methods of the AdP Group

The AdP Group establish, the so-called Policy of Group assets management, through the creation of a set of rules concerning the several operational and managing processes.

The Policy of Group assets management is enforced by two areas of the companies: Operation and Maintenance.

The Operation is composed by technical remote teams that monitor the facilities functioning with help from the monitoring systems. This area works as a first stage of maintenance, since when it detects a problem, it performs a preliminary diagnosis and initiate procedures with the intention of solving the problem [3].

The maintenance has the main goal of keeping the effective working of the equipment installed, ensuring the efficiency and fulfilment of the provided services. Composed by internal or external teams, it's responsible for solving any problems occurring in the equipment and for preventing them to happen, it's supported by the maintenance management system [6].

To assist these two areas, different computing platforms are used, each holding different functions in the business world. In the Operation area, there's the monitoring system (SCADA - *Supervisory Control and Data Acquisition*) which is used for operational control and monitoring of the installed equipment. In the maintenance area, there's the maintenance system (Aquaman) used for managing de maintenance interventions [6].

The Maintenance organisation of the AdP Group has the contribution of both these areas. In case of failure or malfunction of a certain equipment or system, the Operation detects the malfunction, by means of routines, or through alarms in the monitoring system. With the malfunction detection, it's its responsibility to communicate the failure through the opening of an Operation Request, which involves a brief description of the problem, indication of the equipment localization and the choice of a problem from the classification of the existing failure mode.

The Operation Request is analysed by the maintenance area and, if it's accepted, a Working Order is generated which will culminate on problem resolution.

With the analysis of Maintenance data from some AdP Group companies, it was possible to realise the failure information transmitted by the Operation is reduced, which most of the times results on the Maintenance area not being able to properly diagnose failures, wasting time and human resources for that.

Until then, the analysis to the failure mode was made in an unclear way, where causes were mixed with problems, making impossible the extraction of important information.

4. Development of the failure mode classification

This way, one of the developed solutions is the creation of a failure mode classification, comprising five pump typologies: submersible pump, single stage pump, multistage pump, progressive cavity pump and diaphragm pump.

The classification development demanded an in-depth knowledge of all pump typologies in study, in terms of components, or in terms of possible failures equipment associated and operation modes. This way information sessions were arranged with two relevant companies in the pump sector.

With the support of suppliers and engineers linked to the AdP Group maintenance was possible to develop a classification including a list of 16 problems, 58 causes and 66 solutions.

At an early stage, there is a filter for the pump typology, meaning when one of the 5 studied typologies is chosen, the problems appearing will only be related to the chosen typology. Consequently, when 1 of the 16 problems is selected, will only be presented as an option the causes related, meaning that will only be presented causes which could effectively be the origin of the problem. Lastly, to each cause, are associated defined solutions, in another words, there are specific solutions for each existing cause.

Furthermore, this proposition develops a new paradigm, concerning the previous, as far as it centres the failure mode analysis, in a functional analysis of the equipment. Meaning they're part of the behaviour hypothesis classification which the equipment can have when in failure.

For best exemplify the operation mode of this classification, the figure 2 is presented. In this figure, it's possible to deduce the tree diagram coming from the operation mode described above, where to a specific problem only correspond its specific causes and to those causes only correspond its specific solutions.

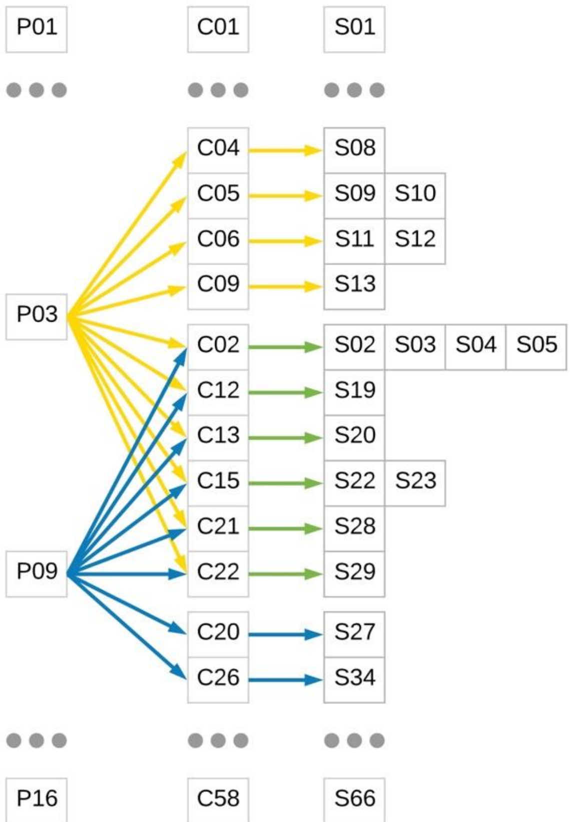

Figure 2 - Functioning scheme of the new classification Problem, Cause, Solution

The presented scheme shows for the typology "submersible pump" the combination of results to the problems "P03 – The pump starts, but stops immediately" and also, "P09 – Energy consumption too high".

It appears that for the problem 03 there are 10 possible causes to choose from (yellow vectors), and for the problem 09 there are 8 possible causes to choose from (blue vectors). On the central part of the scheme, it's also possible to verify the existence of 6 common causes of the two problems. Regarding solutions, it's possible to ensure that for the same cause it's always available the same set of solutions. Using this new operating mode, it's possible to verify that the possible combinations of choice are reduced, helping operation and maintenance technicians to perform diagnosis and collect information, helping to solve the problem. Choosing the problem P09, it's possible to determine there is the maximum of 12 combination possibilities (1 cause with 4 solutions = 4 combinations + 1 cause with 2 solutions = 2 combinations + 6 causes with 1 solution = 6) that in the end represent 4 + 2 + 6 = 12.

For a better comprehension of the developed classification will be presented some examples describing real possible situations.

Example 1:

For a submersible pump it's possible, due to its composition and operation mode, to understand that one of the possible causes for a full stop is the presence of humidity in the engine compartment. With this event, the existing sensors force the equipment to stop, alerting to an event. For this problem resolution, there are three possibilities which can be taken, the O-rings, the seal and/or, the humidity sensor can be replaced. This action may include the replacement of only one of the options, two of them, or even the three of them (table 1).

Table 1 - Example of Problem, Cause and Solution for submersible pump

Problem Code	Problem	Cause Code	Cause	Solution Code	Solution
P02	The pump stops	C10	Presence of humidity in the engine	S14	O-rings replaced
P02	The pump stops	C10	Presence of humidity in the engine	S15	Seal replaced
P02	The pump stops	C10	Presence of humidity in the engine	S16	Humidity sensor replaced

Example 2:

For a single stage pump, working dry, the increasing of temperature in this or in the engine can arise from a bad alignment with the engine or existence of resonance in the pipeline. For this problem to be repaired, two solutions can be held: the pump and engine realignment; or the corrections/alteration of joints between pipelines (table 2).

Table 2 - Example of Problem, Causa and Solution for a single stage pump

Problem Code	Problem	Cause Code	Cause	Solution Code	Solution
P10	Temperature too high in the pump or engine	C45	Pump poorly aligned or resonance in the pipeline	S52	Realigneent of the pump and engine
P10	Temperature too high in the pump or engine	C45	Pump poorly aligned or resonance in the pipeline	S53	Correction /alteration of joints between pipelines

The development of this Problem, Cause, Solution classification, offered an uniformization which until then wasn't developed at the level of pumps subclasses. This, because it enabled the comprehension that for different typologies pumps the same Problems, Causes and Solutions may occur, which wasn't perceptible before. The level of development presented by the manufacturers isn't even in every typology, existing, naturally, some typologies more developed than others.

This way, the proposed classification allows some help on the problem diagnosis, providing indications on equipment operation, but it also works as the base for using the information coming from the sensors, detecting malfunctions and, eventually, its causes according more and better information. Besides, it also enables the evaluation of problem and its causes under an asset management perspective, as far as it provides information on causes, more or less important, referring to occurrence and severity of failure.

5. Study of the information obatained by the monitoring system

Like explained above, the Operation area is equipped with a facilities and equipment monitoring system which transmits, in real time, equipment performance indicators. This way, this system allows, in some equipment, to detect abnormal working situations. The equipment in which it's possible to detect these situations is equipped with sensors enabling the transmission of such information, existing a functional monitoring system (software + sensors).

The maintenance area doesn't have direct access to this information, wherefore the diagnosis, only with the information given by operation technicians, becomes a time-consuming process with great challenges for the maintenance technicians. Besides, the possibility of analysis of the equipment history is reduced, as these don't exist in the maintenance area.

Therefore, some of the abnormal situations detected by this monitoring system, should be immediately and automatically reported to the maintenance area, through the opening and filling of work requests, avoiding fillings done by operation technicians.

In this sense, it was carried out a study of the existing types of sensors in the market to measure indicators and performance values of equipment. Apart from that, was also held an analysis to every existing combination in the classification problem, cause, solution, with the purpose of understanding how it would be possible the relate the sensor collected data with a detection of a failure mode.

To collect the necessary information were arranged information sessions with pump manufactures, with the purpose of understanding how the sensors are installed on the equipment in study and what type of information is possible to collect.

The study held is presented on the table 3 and it summarises the existing types of sensors used in the pump sector. Its purpose isn't to get further knowledge on the sensor itself, but to focus on measures and transmitted information. This is due to the different typology and working mode, found between different brands.

In the first column, it's possible to verify the common name used to describe the sensor, followed by examples of market names (technical names). In the following columns are described each sensor function and, also, what is expected to occur in abnormal working situations of the equipment with sensors.

Table 3 - Market study of existing sensors for pump equipments

	Sensor	Typologies	Description	Measured values
Pump	Pump or engine temperature sensor	- Thermal contacts - PTC Thermistor - Pt100	Monitoring sensor for the pump or engine temperature.	Makes the pump stop, sends out a signal when the working maximum temperature is exceeded
	Bearings temperature sensor	- Pt100 - Pt1000	Monitoring sensor for the pumps bearings temperature	Provide an alert when the bearings working maximum temperature is exceeded
	Water on oil sensor	- Capacitive sensor - Level sensor	Monitoring sensors for the water level on the	Provide an alert when the fluid level on the compartment rises

			lubrification compartment	
	Humidity sensor	- Level sensor	Monitoring sensors for the fluid level on the engine compartment	Provide an alert when the fluid level on the compartment rises
	Vibration sensor	- accelerometer	Monitoring sensors for the vibrations level during equipment operation	Provide an alert when the vibration level is excessive
Installation	Flow meter	- Flow meter	Monitoring sensors for the fluid quantity running the pipeline	Provide values for the flow quantity running the pipeline
	Pressure meter	- Pressure switch	Monitoring sensors for the pressure on the pipeline	Provide values for the pressure on the pipelines

With the acquired knowledge through the study of type of sensor was created a complement to classification, previously presented as problem, cause, solution.

The goal of gather and treat information coming from the monitoring system goes through detection and diagnosis of occurred malfunctions, for that matter, for each combination problem, cause, solution developed in the previous classification, was studied the best way to combine information resulting from the sensor reaction to failure modes.

Therefore, was created a detection classification associated to the one previously designed. This one considers 22 forms of abnormal events detection.

The operating principle is similar to the one developed in the problem, cause, solution classification, since it's structured in a tree diagram where the same detection can be attributed to different failure mode combinations (problem, cause, solution) (figure 3).

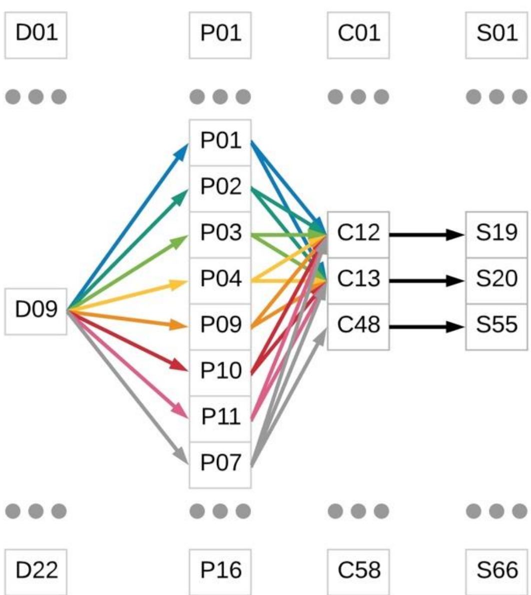

Figure 3 - Functioning scheme of the new failure detection classification

For the “Submersible Pump” equipment typology it’s possible to verify that the detection “D09 – flow diminution, increased power consumption, increase pressure and temperature” can help the detection of 8 problems with only 3 associated causes. For the different combinations, the same set of indicators is used, however, the stablish values may change to inform an equipment failure.

Through detection methods it’s possible, having in account the information given by the monitoring system, to attribute temporary problem classification and, in some cases, causes to the order requests generated automatically. This way, it’s possible, when an alarm appears in the monitoring system, the automatic creation of a working request with a problem suggestion or, in some cases, problem and cause.

With this form of detection, the generated requests will automatically communicate the equipment working status alarm, facilitating the remotely diagnosis made by maintenance teams.

It becomes important to define which values should be measured, transmitted and, subsequently stored by the maintenance system, to be possible to generate automatically work requests and use the investment done in sensors, not only for failures detection, but also equipment analyses for behaviour and reliability.

Table 4 presents indicators which must be part of pump typology equipment history and should be supplied with data coming from the monitoring system.

Table 4 - Indicators collected for pump equipments

Pump equipment Indicators	
Operational hours	Pump operating frequency
Voltage between phases	Working pressure
Power	Pipe pressure
Active power	Upstream pressure
Apparent power	Downstream pressure
Reactive power	Temperature
Thermal protection regulation	Rotation speed RPM
Vibration/Noise	Operational status

The record of these indicators can be done, in the equipment prepared for it, consulting directly the monitoring system. However, the AdP Group has equipment which doesn’t have this type of sensors, making impossible the existence of an equipment working history based on sensors. This information must be collected, regularly, by maintenance technicians, before and after an equipment maintenance intervention, having this type of equipment occasional records. This way, it starts to exist a working history form every pump equipment of the AdP Group, however different in terms of data quantity.

6. Conclusions

This article had the main goal of analyse the current maintenance system of the AdP Group, focusing on the information collected and how it was reported and, moreover the development of methodologies and, consequently, solutions capable of supporting the classification and characterisation of equipment failures. Through this, it becomes possible to provide the area with enough information, both for quicker, more efficient, diagnosis from a distance, and to support and bear the strategies and actions of maintenance management.

At a first stage, as a result of the AdP Group maintenance status analysis, it’s understandable the need to develop a failure mode classification. It was chosen an equipment typology of extensive use and with an operational and financial importance. This classification mainly focuses the equipment working status, where a failure mode concerns a functionally loss of the equipment in study.

After being developed the failure mode classification, and with the goal of using the information generated by the monitoring systems, was also developed a detection classification enabling, based on the failure modes, the analysis through a combination of specific factors measured by the monitoring system and the attribution of a problem classification, and subsequently, the cause to an abnormal situation.

Additionally, the insertion of the relevant data transmission from a pump to the maintenance system, makes the equipment functional analysis possible to perform.

Therefore, the AdP Group equipment start to have, besides the intervention history where the dates and content of the intervention made are detailed, the history of operational equipment indicators, related to maintenance, meaning, it's available for the maintenance area to be able to study and analyze the behavior of working equipment.

Concluding, it's possible to said that the development of the tools and methodologies above referred enabled the creation of patterns of action and uniformization of collected information, assisting the maintenance management. Concerning the AdP Group, is expected the presented measures and developed tools to help the progress of the maintenance area of the various Group companies, also enabling the Group itself, to evaluate the performance of its companies concerning maintenance.

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