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KPI development and obsolescence management in industrial maintenance

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Abstract

Since the industrialization of the mid-19th century, the role of maintenance has become increasingly important as time moved on. Proactive maintenance has gained a crucial role, even though a lot of organizations still view it as an expense and not an investment. This paper highlights the role of KPIs and obsolescence management in maintenance operations. The first step was to create a new KPI to assess the work done in maintenance, relating it to the work done in production. Although the ISO 15341:2007 maps out certain KPIs, the creation of a new one was necessary. The result was a two phases KPI, in which its values are matched to a decision matrix that gives a qualitative evaluation of the performed work. The second step was to create a decision-making tool to evaluate the obsolescence of electronic components and choose the mitigation approach. The IEC 62402:2007 shows some terminology and some conditions to check for obsolescence, but does not point out whether a proactive or a reactive approach should be used. Like the KPI developed, it is also composed of a two-phase process. The first phase helps to see which components are at a higher risk to become obsolescent, while the second phase evaluates the repercussions to mitigate its obsolescence. The values obtained are also connected to a decision matrix to decide whether the approach for its mitigation should be proactive or reactive. The novel KPI and obsolescence approach were successfully tested in practice in a dairy processing factory, showing perfectly fulfil the goals initially set.

Keywords: Proactive maintenance, Obsolescence, Key performance indicators, KPI, Maintenance, Maintenance management.

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1. Introduction

Regardless of the type of industry, maintenance has come from an initially simple and frivolous task to one that has become increasingly more important as time goes by. This has gone from simply repairing equipment when it brakes, to an ever more complex and scientifically driven process [1]. Also, the role of maintenance has become so important that, in order to survive in the modern market, most companies have to strive to have a well-implemented process and management, of this task [2]. Indicators can have an important role in helping prioritizing sectors and tasks to implement in any sort of production system, as well as help with the maintenance tasks [3–5]. The military was the first sector to be truly affected by obsolescence issues and, due to that, it was also the first one to develop tools to mitigate that situation [6,7]. The purpose of this work was to create a Key Performance Indicator (KPI) that allows a company to evaluate the work done on maintenance activities, as well as a model to evaluate the obsolescence of electronic components present in the machines included in a production line. Case studies were developed to help to validate the novel KPI and obsolescence approach model.

2. Literature review

According to the ISO 13306:2010 [8], maintenance is defined as all the operations required to retain or restore an equipment ability to perform its task. Maintenance can be divided into two main philosophies for its monitoring. These can be defined as either proactive or reactive. Proactive maintenance can be defined as all operations related to maintenance that is undertaken before any breakdown or stoppage occurs. while reactive maintenance is described as the act of performing said operations when the breakdown or stoppage is detected [9,10]. Fig. 1 [9] shows how these two main philosophies branch out.

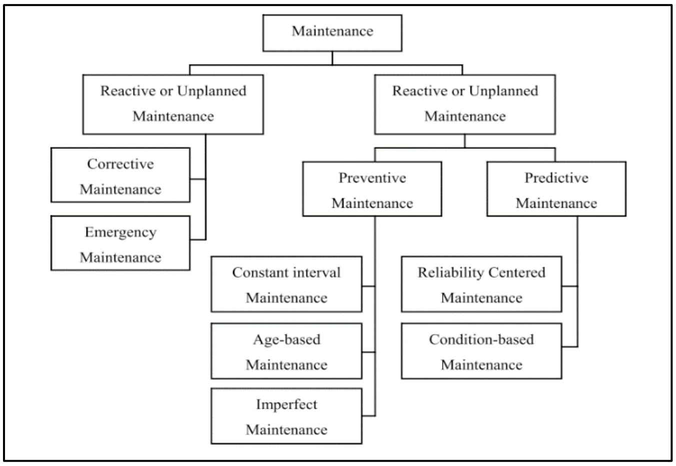

Fig. 1. Different types of maintenance

As the need for improved and more robust processes in maintenance has increased, the need for more reliable and readable data for those processes has increased [11,12]. With this more reliable collection of data, KPIs have become increasingly more important in maintenance management. The main Indicators used for maintenance are Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and lastly the Overall Equipment Effectiveness (OEE) [3,13]. The ISO 22400-1:2014 [14] is the standard that lists the KPIs that can be used for maintenance activities, separating them from technical, economical and organizational.

Obsolescence is also a problem that can affect companies in the long run [15]. The existence of obsolescence can be confirmed for a certain component, if the component in question does not perform according to its design or if the original supplier does not provide it anymore [16]. The military industry is one in which this is a very recurring problem, given the shift from using specially designed electronics, which would, in turn, take longer to turn obsolescent, to using mostly "Commercial of the shelf components", or COTS [7,17]. Rojo *et al.* [6] have implemented a study to do an evaluation of obsolescence based in two steps which calculate probability and risk, based on a few easily determined variables. Grichi *et al.* [18], on the other hand, have developed a “Random Forest” algorithm which uses Baysean statistics to forecast the probability to turn obsolescent.

3. Methodology

The methodology for this paper can be divided into four stages. The first stage resulted in a review of literature related to maintenance, obsolescence management and KPIs used in industry. The second stage consisted of collecting data for the variables required, for both the KPI and obsolescence model, as well as creating both of these tools. The third stage consisted of creating a case study to assess the validity of the KPI and model created. Ultimately, on the fourth and final stage, the results of both case studies were analyzed and conclusions were determined, regarding the validity and utility of said KPI and model.

4. KPI Analysis And Obsolescence Management In Industrial Maintenance

4.1. KPI development

A research was carried out on the KPIs already developed, looking for one that allowed to establish a relation between the work carried out by the maintenance and the volume of work done by an industrial unit. Given that there was no KPI to correlate maintenance activities with the volume of work performed by a company, it was necessary to analyze the possible data collection at a plant and to understand how they could be related, allowing an adequate correlation between these factors. The KPI to be developed should be able to be easily calculated using the data currently collected by the maintenance function and by the production function. The KPI developed, can be defined as a two-phase operation. The first phase relates to the work performed in maintenance, by comparing both reactive and proactive operations, in one equation. The second phase is done in a similar manner, instead this time, the work done in both reactive and proactive operations is compared with the work done in production. These two phases can be called, respectively, Reactive-Proactive Ratio and Maintenance-Production Ratio, or RPR and MPR, respectively. The required calculation can be done as shown in equations 1 and 2.

$$\mathrm{RPR}=\frac{\mathrm{T_{reactive}}}{\mathrm{T_{proactive}}}\times\frac{\mathrm{N_{reactive}}}{\mathrm{N_{proactive}}}\times\frac{\mathrm{C_{reactive}}}{\mathrm{C_{proactive}}} \qquad (1)$$

$$MPR = \frac{T_{reactive+proactive}}{T_{production}}\times\frac{N_{reactive+proactive}}{N_{set-ups}}\times\frac{C_{reactive+proactive}}{C_{production}} \qquad (2)$$

Their variables are as follows:

- $T_{reactive}$: Total time during reactive maintenance operations, during a certain time period;
- $T_{proactive}$: Total time during proactive maintenance operations, during a certain time period;
- $T_{production}$: Total time during actual operation, during a certain time period;
- $N_{reactive}$: Number of reactive maintenance operations, during a certain time period;
- $N_{proactive}$: Number of proactive maintenance operations, during a certain time period;
- N_{set-up}: Number of set-ups, during a certain time period;
- $C_{reactive}$: Cost of reactive maintenance operations, during a certain time period;
- $C_{proactive}$: Cost of proactive maintenance operations, during a certain time period;
- $C_{production}$:Cost of production, during a certain time period.

Both values need then to be evaluated in regard to the value they present. Table 1 and Table 2 show the intervals in which these should be evaluated. After calculating both RRP and MPR, it is needed to match the values calculated to a decision matrix. The decision matrix is shown in Fig. 2.

Table 1. RPR evaluation parameters

RPR	Evaluation
0≤RPR≤0,15	Equipment in very good conditions
0,15<RPR≤0,25	Equipment in good conditions, however, it can be assessed if either the process or the equipment may have some issues, depending on variable values.
0,25<RPR≤0,5	Equipment in reasonable conditions. An evaluation should be made in order to determine possible causes from either equipment or process.
RPR>0,5	It is mandatory to check what needs to be done to reverse the malfunctions that may have occurred.

Table 2. MPR evaluation

MPR	Evaluation
0<MPR≤0,01	Production going smoothly, with the equipment performing as desired.
0,01<MPR≤0,03	Production going well with the equipment having a reasonable performance.
0,03<MPR≤0,05	Production with reasonable performance, however, may be necessary to assess possible improvements to the process.
MPR>0,05	Possible causes for performance failure should be assessed and take immediate actions to mitigate those same causes.

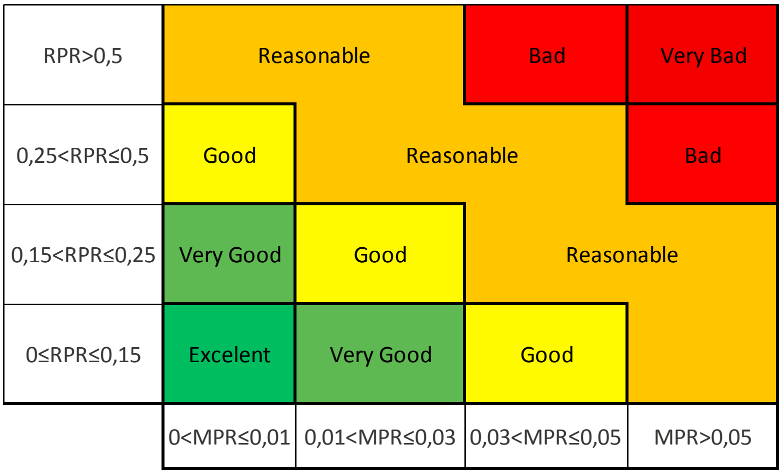

Fig. 2. KPI decision matrix

4.2. Obsolescence model development

The models purpose is to make an assessment of the obsolescence state of electronic components of the equipment present in the production line. In the case study developed ahead, the equipment in question is cheese slicing machines and although these have a lot of mechanical components, these are easily replaceable. Electronic components, due to their nature and modern market, may not be so easily replaceable.

Just like the KPI, this model is also made of two phases. The first phase evaluates in terms of obsolescence which component is more critical to equipment to perform its function. The second phase evaluates the repercussions of actions to mitigate said obsolescence may have in the production system. In this model, each variable will assume a value from 1 to 4, from worst to best. This value will then be multiplied by a decision weight, measured as a percentage, is then added to other variable values to obtain a result for that phase. Table 3 and Table 4, show the variables and criteria used to assess the values to be used. Some concepts to retain for this model are:

- Book value (BV): The financial value of the asset, after netting it against its depreciation;
- Replacement asset value (RAV): The cost required to restore a certain asset to its original state.

After calculating the values for both phases, it is needed to compare the values with a decision matrix. Fig. 3 shows this decision matrix. After this procedure, one should obtain the most appropriate approach, in order to address obsolescence issues in some selected components.

Table 3. First phase model variables

Variable	1	2	3	4	Decision weight
Replacement capacity	There are no alternatives to the component analyzed.	No alternatives to the component on the market but still available in stock.	Component can only acquired in third parties and/or still available on stock	Component can still be acquired through its main supplier and/or still available on stock.	40%
Age assessment	x>5 years	5≥x>3 years	3≥x>2 years	2≥x≥0 years	10%
Machine relevance	Equipment does not function without component	Equipment function in manual mode without the component.	Equipment works on automated mode without component with limitations.	Equipment works without limitations, without the component.	40%
BV/RAV Ratio	x<25%	25%≤x<50%	50%≤x<75%	75%≤x	10%

Table 4. Second phase model variables

Variable	1	2	3	4	Decision weight
Equipment replacement forecast	x>5 years	5≥x>3 years	3≥x>2 years	2≥x≥0 years	15%
Component price	≥5% of RAV	3%≤x<5% of RAV	1%≤x<3% of RAV	<1% of RAV	25%
Retrofit difficulty	Component replacement as well as major changes in the equipment. (ex: total rewiring)	Component replacement and considerate changes in the equipment (ex: some rewiring and programming)	Component replacement and minor changes in the equipment.	Mere replacement of component	30%
Retrofit cost	≥10% of RAV	5%≤x<10% of RAV	2%≤x<5% of RAV	<2% of RAV	30%

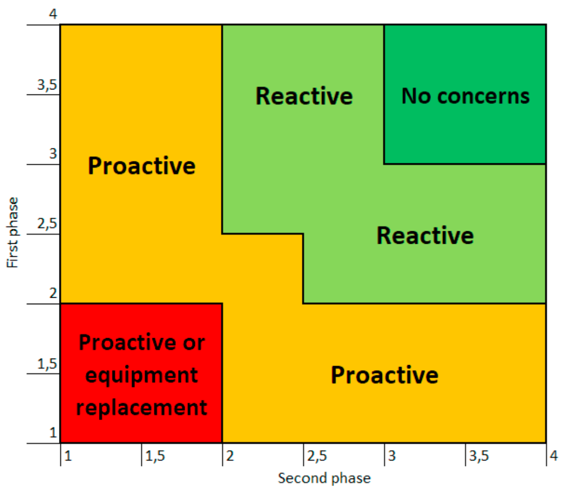

Figure 3. Obsolescence model decision matrix

5. Results and discussion

5.1. KPI implementation

The KPI test was divided into different time slots. The first test involved doing a monthly analysis for both RPR and MPR. In each proceeding test, the time slot grew, to quarter, half a year, up to a full year. This is to see the different results that may be obtained when using different time scales.

Table 5 and Table 6 show the data collected for these tests, which were obtained from analysis to one of the production lines in the cheese slicing sector, which was the most critical sector of the factory and where this study was conducted.

Table 7 and Table 8 show the results obtained for the monthly, quarter, half a year and year studies, respectively. Regarding these tests, it can be observed that the bigger the time period in study, the result is less subject to outliers. Another aspect that can be said about this KPI, is that it can give a broader view of the results for maintenance and production in the same step. For example, months 6, 10, 11 and 12 have an evaluation of "Reasonable", despite their RPR being higher than 0,5, while on the other hand, month 7 has a poorer evaluation than month 9, despite the RPR for the latter being considerably higher, because of the different production parameters for each month. For the other studies, it can be seen that the results have been more levelled.

Table 5. Maintenance data for RPR and MPR calculation

Month	Number of reactive	Time of reactive (t.u.)	Cost of reactive (m.u.)	Number of proactive	Time of proactive (t.u.)	Cost of proactive (m.u.)
1	14	265	6 503	19	1 068	22 191
2	21	406	9 007	18	1 644	30 862
3	19	309	6 061	28	5 262	95 803
4	43	900	20 349	21	2 280	57 450
5	24	515	10 938	17	690	17 614
6	79	1 854	38 622	21	1 464	27 801
7	101	2 036	39 166	22	4 770	87 447
8	45	1 363	26 859	18	4 248	77 448
9	69	2 463	47 613	23	858	15 884
10	34	988	23 808	19	1 434	27 898
11	29	849	16 024	18	582	10 600
12	69	1 635	33 361	20	900	17 839

Table 6. Production data for MPR calculation

Month	Number of set-ups	Production time (t.u.)	Production cost (m.u.)
1	25	27 510	915 644
2	26	26 458	860 868
3	33	34 228	1 157 107
4	21	25 993	776 756
5	31	32 160	929 301
6	31	33 698	930 666
7	28	36 004	1 114 306
8	28	36 103	1 222 894
9	22	25 135	794 052
10	24	27 565	929 690
11	32	30 285	1 009 933
12	29	31 535	1 067 314

Table 7. RPR and MPR results for the monthly study

Month	RPR	MPR	Evaluation
1	0,05	0,002	Excellent
2	0,08	0,005	Excellent
3	0,00	0,020	Very good
4	0,29	0,037	Reasonable
5	0,65	0,002	Reasonable
6	6,62	0,023	Reasonable
7	0,88	0,094	Very bad
8	0,28	0,030	Reasonable
9	25,81	0,044	Bad
10	1,05	0,011	Reasonable
11	3,55	0,002	Reasonable
12	11,72	0,012	Reasonable

Table 8. RPR and MPR results for the quarter, semester and year study

Analysis	Time	RPR	MPR	Evaluation
Quarter	First	0,099	0,008	Excellent
	Second	2,220	0,014	Reasonable
	Third	2,632	0,054	Very bad
	Fourth	7,234	0,007	Reasonable
Semester	First	0,201	0,011	Good
	Second	1,663	0,023	Reasonable
Annual		0,688	0,017	Reasonable

5.2. Obsolescence model

For this stage, components from three of the slicing lines were chosen. These components had previously been assessed by the factory as potential hazards for obsolescence. Table 9 shows the data collected from these production lines.

Table 9. Slicing machines characteristics

Production line	Year of acquisition	RAV (m.u.)	BV (m.u.)	Obsolescent components
1	2002	243 500		2
2	2003	274 000		2
3	2005	306 000	50 997	1

There are four lines of production in the factory. However, one of the lines shows no signs of becoming obsolescent. From the remaining three, two of them show an absent book value. This is because both of these lines have already been completely amortized. Due to confidentiality reasons, the components will be identified by a number composed of two digits, in which the first number codes the line, while the second symbols the component, separated by a dash. Table 10, Table 11 and Table 12 show the results obtained for the first phase, in all production lines.

Table 10. First phase results for Line 1

Variable	1-1	1-2
Replacement capacity	3	3
Age assessment	1	1
Machine relevance	1	1
BV/RAV Ratio	1	1
Total	1,8	1,8

Table 11. First phase results for line 2

Variable	2-1	2-2
Replacement capacity	3	3
Age assessment	1	1
Machine relevance	1	1
BV/RAV Ratio	1	1
Total	1,8	1,8

Table 12. First phase results for line 3

Variable	3-1
Replacement capacity	1
Age assessment	1
Machine relevance	1
BV/RAV Ratio	1
Total	1

Given the close time period in which these machines were bought, the similarity in function of the components, and a similar value for RAV, their results are exactly the same for the first phase for lines 1 and 2. On the other hand, despite being younger than the other two lines, line 3 gets a total of 1, because the component in question is not available either from its original supplier, third parties or is in stock. Table 13, Table 14 and Table 15 show the results obtained for the second phase in the production lines.

Table 13. Second phase results for line 1

Variable	1-1	1-2
Equipment replacement forecast	3	3
Component price	2	2
Retrofit difficulty	1	1
Retrofit cost	2	2
Total	1,85	1,85

Table 14. Second phase results for line 2

Variable	2-1	2-2
Equipment replacement forecast	3	3
Component price	3	2
Retrofit difficulty	1	1
Retrofit cost	2	2
Total	2,1	1,85

Table 15. Second phase results for line 3

Variable	3-1
Equipment replacement forecast	3
Component price	2
Retrofit difficulty	1
Retrofit cost	3
Total	2,15

All lines are within at least 3 years into being replaced. That is the reason why the value for "Equipment replacement forecast" is shared among all components. Given the state assessed on line 3 for the first phase, it was required to plan with the supplier a budget for a retrofit to be done in the near future. Table 16 shows the results when compared with the decision matrix.

Table 16. Results for the obsolescence model

Component	First phase	Second Phase	Type of approach
1-1	1,8	1,85	Proactive or equipment replacement
1-2	1,8	1,85	Proactive or equipment replacement
2-1	1,8	2,1	Proactive
2-2	1,8	1,85	Proactive or equipment replacement
4-1	1	1,8	Proactive or equipment replacement

All the components assessed need to at least have a proactive approach to their obsolescence management. However, for all the lines assessed, it is required to maybe replace the equipment altogether. This last choice, however, is too costly in the short term, so it would be preferable to instead, try to do a retrofit to all the machines, and in time try to find replacement alternatives to those same machines.

6. Conclusions

The main motivation for this paper was to develop two tools that would aid a maintenance department in their day to day management. It can be said that this was achieved with success. Despite these two tools have been created in a dairy processing plant, they can be adapted into any sort of industry depending on its more specific needs.

The KPI is more advised to be used in quarters. Since improvements in maintenance can take some time to assess, given its random nature, this way it is less susceptible to outliers that can throw the results out of proportion. This does not mean, however, that it cannot be used in shorter or even longer time periods. Also, the benchmarks established for this KPI can be changed depending on the industry it is being applied.

The same can be said about the obsolescence model. Despite being applied to a set of electronic components, it does not mean that it cannot be used with mechanical components as well. However, the sample used to analyze was quite similar throughout, which is the main reason why most values occurred to be quite similar to each other. Also, just like the KPI, this tool can be adapted in regards to the objectives that a different organization may have. For example, an organization may give a higher or lower "Decision weight" to any of the variables it may so desire, as well as changing the evaluations from the decision matrix to one more suited to their needs.

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