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Improvement of the Operational Reliability in a Line of Production of Pulp to Paper

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Abstract

The proposed model of operational management aims to treat simultaneously the reliability of the equipment, the process of maintenance and the operational costs. The continuous production of pulp is supported by practices of best sourcing developed by the back-office of the operational management using the in-sourcing and the outsourcing of the front-office so that they can add more value to the Organization through the lower cost. Thus, it is presented an operational model that integrates three different dimensions based on the information collected from the repairing orders and the operational circumstances where they occurred. One of the dimensions determines the factors that have more influence on the risk of damage and the non-availability of the equipment; the other one dimensions the teams dedicated in regimen of in-sourcing and their competences for the daily attendance of the reactive repairs using, if necessary, the failure maintenance and the proactive necessities in result of the on-line or off-line surveys made to the equipment; finally, the third dimension of the model aims at the planned subcontracting of teams in regimen of outsourcing for the simultaneous attendance of a minimum and maximum set of equipment in failure waiting for a manufacturing stop for a perfect maintenance.

Key words: *information, risk, operational reliability, best sourcing, costs*

Preamble

According to Detragiache [1] the management of the maintenance aims essentially to keep the equipment in a functioning state and considers that the tasks of the management must be done according to several factors: economical, technical and probabilistic. Tsang [2] identifies four strategies of maintenance management. The first one is related to service-delivery options, the second one to the organization and work structuring, the third one refers to the maintenance methodology and, finally, the fourth one to the support systems. The above mentioned author considers that the decision on outsourcing depends on the operational context and the strategy of the core business. The organization of the maintenance and the front-office of the repairs can be specialized or made flexible in a centralised or decentralised way. Finally, in addition to the importance of the education and training of the staff, he refers the systems of maintenance management and the e-maintenance.

Reason [3] mentions the human error and Kantowitz *et al.* [4] emphasize the factors associated to that error. Swain [5] classifies them in errors of omission, execution, derivation, sequence and delay. A substantial amount of the operating expenses is related to the requirements of the customers. However, when there are materials or services that weren't previously foreseen by the back-office logistic and financial costs frequently rise in value. Therefore, Souris [6] and Mirshawka et al. [7] refer that the costs created by the maintenance function are only the tip of the iceberg. The direct costs enclose the maintenance process and derive from the time of intervention and the hourly rates, from the materials and applied spare parts. To this respect Sena and Pereira [8] and Sena [22] consider the models developed by Garden [9] and Kececioglu [10] are important in the decisions of equipment management based on the maintenance costs. The indirect costs include the repairing time of the equipment, the losses of production, the lack of quality and the losses due to the non-execution of the stated deadlines. In the processes flow shop certain indirect costs are avoided through a minimum and imperfect repairing related by Pham and Wang [11]. However, the imperfect repair, in contrast with the perfect one, implies that the component in failure keeps the same age (or condition) after repaired. Cuignet [12] presents a model that is articulated around a process characterized by 36 good practices that aim to reach the excellence of the maintenance management. Among the several practices we must point out the importance of the information obtained on-line and off-line concerning the evolution of the curve P-F of the failure processes that Moubray [13] refers to.

Thus, besides the value of the rendered service immediately understood by the customers, referred by Parasuraman [14] and Lapierre [15], it is also important to consider the interconnections with the value management in order to approach the management of the commitments and the satisfaction of the necessities through the always scarce resources. Finally, we must refer the similarity of the methodology used in the integrated model of improvement considered in this work and the continuous process described originally by Deming [16] which establishes the relation cause-effect P - to plan, D - to execute, C - to verify - to act (Plan-Do-Check-Act).

Reaching the Operational Model

The reliability level and the risk of damage of the equipment determine the operational needs of the maintenance services. Considering a steady continuous productive process (flow shop), as in this case study, we can verify that the rate of damages and the level of daily attendance of the repairing orders is approximately constant throughout the time.

Therefore, the first dimension of the model, supported by the theory of the proportional hazards, aims to determine the factors influencing more the risk of failure and the average time of occurrence in the different equipment families: static, rotary and linear. After the determination of the intrinsic and extrinsic factors that influence the risk of damage of the equipment, proactive actions of the maintenance and the operation of the equipment are implemented in order to provide a reduction of the intensity of these factors.

The second dimension of the model uses the queuing theory in order to dimension the amount of resources and the size of the teams of in source maintenance that are necessary for the attendance of the damages that occur daily in each one of the equipment families. The sizing is characterised through the intervals of time between each one of the arrivals of reactive or proactive repairing orders registered in the CMMS for each one of the maintenance services: mechanical, electrical and instrumentation. Besides the arrivals of the repair orders it is also necessary to characterise the performance of the services attendance. Thus, the attendance of the repair orders of the different equipment is quantified through the duration of the work and the average number of executants used in each one of the teams of the maintenance service, also appealing to the information collected through the CMMS.

Finally, we have the third dimension of the model because in the permanent work industry, as the production of pulp, there is the need for working (in a controlled way) with the equipment in failure until it is repaired for not to harm the operational availability and the direct and indirect costs. Thus, the number of equipment working in these conditions and waiting for a perfect repair is proportional to the interval of time between the stops of the manufacturing areas. These repairs can be, in the majority of the cases, planned and prepared and previously sub-contracted to outsourced teams, as referred by Saints [17]. The number of teams that will repair in simultaneous the minimum and the maximum of equipment in failure waiting for a manufacturing stop is optimised in function of the cost, the added value in each repair and the time of execution.

Concepts that Support the Model of Operational Management

The concepts used in the model of operational management considered in this work aim to treat simultaneously the reliability of the equipment, the process of maintenance management and the operational costs. To characterise the reliability of the equipment, the proportional hazards model introduced by Professor Cox [18] and used, among others, by Pereira [19] is used. The advantage of this model in the maintenance management compared to the parametric statistical models is due to the fact of being able to determine, besides the average time between failures, the periods of time when the risk of damages increases when the equipment is submitted simultaneously to the intensity of different factors (covariates) that influence the occurrence of the damages associated to a certain way of failure. The proportional hazards model is presented in the expression 1.

$$h\ (t; Z) = h_0\ (t).\mathrm{e}^{\ (Z1.\beta1\ +\ Z2.\beta2\ +\ ...\ +\ Zn.\beta\ n)} \qquad (1)$$

where $h_o(t)$ represents a function of risk arbitrary and not specified in function of the time; Z represents the line vectors in n covariates measures; β represents the column vector of the n regression coefficients to determine and, finally, t the time between failures.

In this way, it associates the survival time to the number of arrivals of repair orders and to the attendance of repairs and the chances of subcontract to attend in simultaneous the work peaks. So the maintenance process is characterized using the concepts related to the queues.

Tavares *et al.* [20] refer that the standard of the random arrivals and the attendances can be characterised by the observation of a distribution of theoretical probability of the M/M/s type. When the rate of arrivals (λ) does not vary it is considered independent of the state of the system. When there is more than a server there can be only a line for all the servers with an infinite length if there aren't physical limitations as it happens in the case in study. The line used in this work is of the type FIFO (first in, first out) because it is a continuum productive system where high availability and safety of the equipment are required and, at the same time, also a high quality of the products. The service rate (μ) indicates the average number of "customers" who can be attended by each server per unit of time. The service rate, as the rate of arrivals, when it does not depend on the number of elements in the system is independent of its state. The measures that must be referred to are the average length of the line (L_q), the average number of equipment in the system (l), the average time of waiting in the line (W_q), the average time of waiting in the system (w) and, finally, the average rate of occupation of the service (ρ).

Table 1 presents, in accordance to the notation of Kendall, some of the expressions used for the measures of performance of the queues (M/M/s) without memory or exponential.

After sizing the operational teams of the daily maintenance of the operational context it also becomes necessary to increase the resources during the stops, programmed or not, of the manufacturing areas. During those periods there is the chance of attending at the same time several equipments whose condition of failure is known by the maintenance services and therefore they wait for a stop to execute a perfect repair. Jardine [9] considers, relatively to the organizational decisions of the maintenance function, the subcontracting of resources as a way to minimise the costs of maintenance per unit of time. The expression presented in (2) determines the optimum number of executants corresponding to the minimum cost $C(n)$.

$$C(n) = n\,C_f + [nm\int_{nm}^{\infty} \mathrm{f}(r)\,\mathrm{d}r + \int_0^{nm} r\,\mathrm{f}(r)]C_w + [\int_{nm}^{\infty} (r-nm)\,\mathrm{f}(r)\,\mathrm{d}r]\,C_s \qquad (2)$$

Table 1. Mathematical expressions for the measure of performances

Parameter	Expression of calculation	Observations
Occupation rate (ρ)	$\lambda / S\mu$	$\rho < 1$
Elements in the line (L_q)	$P_0\,(\lambda/\mu)^S\,\rho / S\,(1-\rho)^2$	-
Time in the line (W_q)	L_q / λ	-
Probability of disoccupation of the S servers (P_0)	$1 / [\sum_n^{s-1}(\lambda/\mu)^n/n! + (\lambda/\mu)^S/s!(1-\lambda/s\mu)]$	Sum from n =0 up to(s-1)

The works per unit of time obey to a function f(r) of rectangular density of probability where r represents the number of works; m is the number of works processed per unit of time; n represents the number of teams (servers) or technicians and C the costs. C_f represents the fixed costs by technician and per unit of time and C_w and C_s represent, respectively, the average costs of the internal workmanship (in sourcing) and also the external (outsourcing) for the execution of a work.

Case Study

Context

The services of maintenance that support the production of the pulp are assured by three big operational areas of specialization: the mechanics, the electricity and the instrumentation. The repair orders are done by the Production or by the Maintenance itself through the system CMMS-SAP/R3 [23] and they are sent to each one of the three services. It is during the period between 8h00 and 17h00 from Monday to Friday that there is the biggest amount of repairing orders and therefore a bigger operational activity justifying thus the study of the operations and the sizing of the operational resources. As we are dealing with hundreds of equipment that can fail the population is, in this case, infinite and, on the other hand, there is a single line is only for each one of the servers (maintenance technicians) of the maintenance services. The figure 1 presents the model of queuing for each service of maintenance.

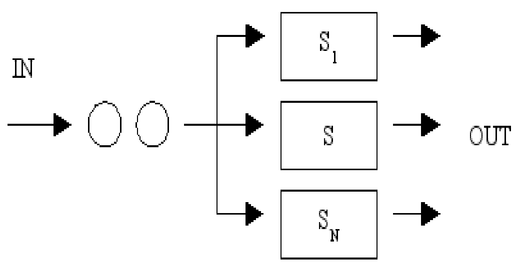

Fig. 1. Model of queuing for each service of maintenance

In this case study, at the plant of pulp of Portucel Setubal, the manufacturing area of the bleaching of the pulp was selected due to its importance in the productive process and to the high number of failures observed so that, in these conditions, we can experiment the proportional hazards model. The bleaching area similarly to the other manufacturing areas is composed by equipment families with similar functions and also different ones. Therefore, the model of the queuing was also applied to all the line of pulp production. In the family of the static equipment, we analyse the pipes, the pullers of the electric feeding and the sensors (instruments) on-line. In what concerns the rotary equipment, the electric motors, the centrifugal pumps and a conveyor are analysed and, finally, in the family of the equipment with linear movement we analyse the hydraulic cylinders and the automatic valves. Each one of the families with similar functions is considered together in the study.

The failure modes of the components of the equipment

The failure modes are almost always associated to the slow or faster processes of degradation of the materials of the equipment components when subject to the operational conditions demanded by the productive process. Canuto [21] refers that the incapacity of given equipment to fulfil its operational function is a part of a process of degradation similar to that presented in figure 2 and depends, at least, on the time that elapses between the beginning of a failure until the damage. Moubray [13] characterises as P-F the time that elapses between the beginning of a failure process and the damage of the component.

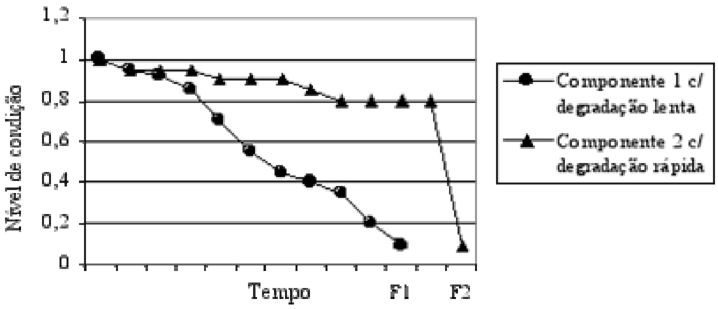

Fig. 2. Evolution of two types of degradation processes

The failure modes associated to the wearing down because of corrosion, erosion and abrasion, the misalignment, the unbalance, the lubrication, the fixing/pressing, the dirtiness, the fatigue, the evaporation, the ventilation and the filtering are included in the process of slow degradation. In relation to the faster process of degradation the failure modes associated to them are the shock, the overloads, the electric isolation, the calibration, the tightness, the induction and, in general way, all the degradation processes associated to the damages in the software or the hardware of control of the equipment in the productive process. We must notice that during the collecting of data for the present work, we verified that the most frequent were the damages proceeding from processes of failure with slow degradation during the functioning without interruptions of the equipment. But, on the contrary, in the situations of functioning after the pulling out of the equipment, we verified some damages proceeding from the processes of fast degradation.

When an equipment works without interruptions until it fails and it is not affected by other external factors, as it happens in functioning tests, the failure and the following damage are only intrinsic to the components of the equipment, so this situation differs from the industrial productive reality. Here the equipment is also subjected to upstream and downstream factors, besides the way of conduction and the maintenance practices that affect it. Taking in account the above mentioned the operational situations where the damages occurred must be typified as well as the failure modes of the equipment components and, in order to act on the factors (covariates) that originated them.

Characterisation of the covariates used for the damages

The covariates used in the proportional hazards model are independent and they must reflect the effect that some factors will have in the reliability of the equipment components. Covariates Z are discrete representing measured values and the presence or the absence of a given factor. The next factors can be 0 or 1 if a given condition is verified, or not, or even a value obtained through a measurement in the equipment before it damages.

The proportional hazards model evaluates, through the covariates, the importance of each one of the selected factors and their influence in the process of damages of the equipment components and, consequently, the hazard function at a given instant. Among the main factors there are those inherent to the process of production such as the temperature, the consistency and the pH of the pulp and even the materials used in the equipment, its localization and the way it works. There were also chosen factors associated to the production level, as the load, the consumption, the number of manoeuvres and cycles, the percentage of opening, the volume and the speed and, finally, factors that are a result of the functioning conditions as the vibration, the temperature, the differential of pressure and the real state of the equipment.

There are still chosen factors that aren't inherent to the production process, however, they are essential to the good working of the equipment, as the ventilation, the quality of the industrial compressed air, the filtering and even external factors, as the way of conduction and the type of maintenance of the equipment.

Finally, factors that are external to the process of production and to the equipment are selected, as it is the case of the year's season. The factors "conduction" and "maintenance" of the equipment must be explained because they are important in the industrial context of the process, and consequently they influence the operational reliability through the way as the operators of the production execute the procedures of start and the beginning of functioning of the equipment and, on the other hand, due to the type of actions of the maintenance services on the equipment before it breaks down. Therefore the "conduction" factor is distinguished with zero or one if the failure occurred during the normal operation or after starting. "Maintenance" is also characterised by zero or one attributed to the curative or the detector practices verified or not before the failure of the equipment. In any circumstance the magnitude of the factors of the presented covariates is always measured or evaluated immediately before the occurrence of the damages.

Characterization of the arrivals and the attendance of the repairing orders

The number of arrivals of repairing orders for each one of the maintenance services is a random variable and follows a distribution of Poisson for the following reasons: the number of the arrivals that occur are independent; the probability of occurring an arrival in a short period of time is proportional to the duration of that interval and it does not depend on the number of arrivals verified out of this interval; the probability of occurring more than an arrival in this short period is insignificant.

Therefore the negative exponential distribution is used to represent the time between arrivals of the repairing orders and the respective time of attendance (repairing). It was also verified that the variation coefficient is approximately 1 and the value of the median is inferior to the average.

Thus, the figure 3 presents an example of the linearity between each one of the periods of accumulated times of the arrivals of the repairing orders for the mechanical work.

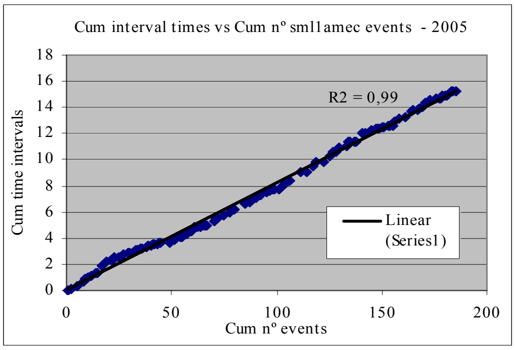

Fig. 3. Verification of the linearity between the intervals of time

We also verified the linearity presented in figure 4 between the accumulated times i of the intervals of time of the arrivals and each one of them.

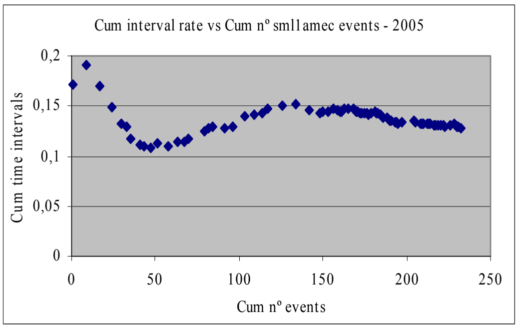

Fig. 4. Verification of the linearity of the arrivals rate

The average time between the arrivals of the repairing orders in the bleaching area and all the pulp line is presented in table 2.

Table 2. Average time between the arrivals (MTBF) of the repairing orders

Area(s) / Services	Mechanical	Electrical	Instrumentation
Bleaching	4 hours	19 hours	9 hours
Pulp line	1.7 hours	5.7 hours	5 hours

A good correlation between the expected theoretical exponential values and the real values of the repair times was verified (figure 5).

The repair time includes the logistic and the diagnosis time, which correspond to 40% to 55% of the average time of the repairs. So, in table 3 the weighed average time obtained for the sizing of the teams that can have one or more executants is presented.

In the repair operations of some equipment it is necessary more than one worker. This fact was verified due to the characteristics of the equipment, of the operations to execute or even when it is possible to reduce the repair time. The table 4 presents the number of weekly operations in the bleaching area and the ratio of the works done only by one worker of each maintenance service.

Table 3. Weighed average time of the repairs (MTTR) by speciality

Specialities	Mechanical	Electrical	Instruments
Weighed Time	3.75 hours	3.3 hours	3.1 hours

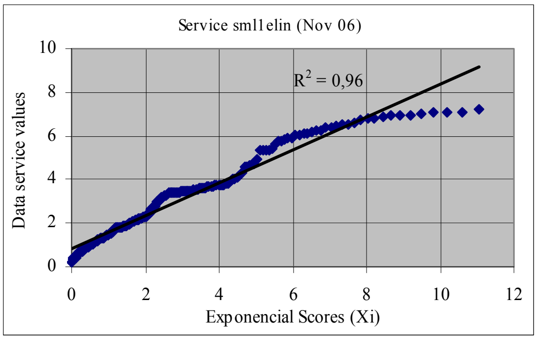

Fig. 5. Exponential relation of the duration of operations

Table 4. Ratio of the number of repairing operations with one executant

Services	Mechanical	Electrical	Instrumentation
Amount of weekly operations	10	2	5
Ratio with one executant	30 to 35%	70 to 80%	

In the mechanical speciality 50% to 55% of the repairs need two technicians for its execution. In the electrical and instrumentation specialities two workers are necessary in about 20% - 25% of the repair tasks. The attendance services, in the case of the mechanical speciality are configured in terms of the capacity of the servers, as it is presented in figure 6.

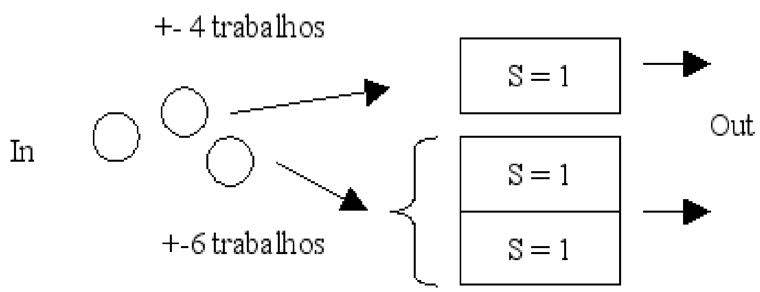

Fig. 6. Multi-channel system with server agglutination

Obtained Results

The following results are related to the application of the three partial models used in this work: proportional hazards, queuing and chances of an occasional subcontract. The first one is applied to the damage verified in the different equipment families; the second is applied because of the damages and the repairs that must be done; and, finally, the third is used in situations of work peaks that occur in the stops of the production.

Results on the reliability of the equipment

The following results are related to the data collected during the year of 2005 corresponding to the period of maintenance outsourcing.

The significant covariates 1, 2, 7 and 9 presented in the table 5 were obtained using the software of Pezullo [24].

Table 5. Sample of the outputs of the proportional hazards method software

var	coeff	Std err	p	Lo95%	Hi5%
1	-4.6503	1.8378	0.00114	-8.2523	-1.0483
2	-0.3038	0.1189	0.0106	-0.5368	-0.0708
7	8.4829	4.3138	0.0492	0.0279	16.9379
9	4.5303	1.3995	0.0012	1.7873	7.2733

In figure 7 the survival function of the pipes is presented which is representative of the damages and the operational circumstances where they occur.

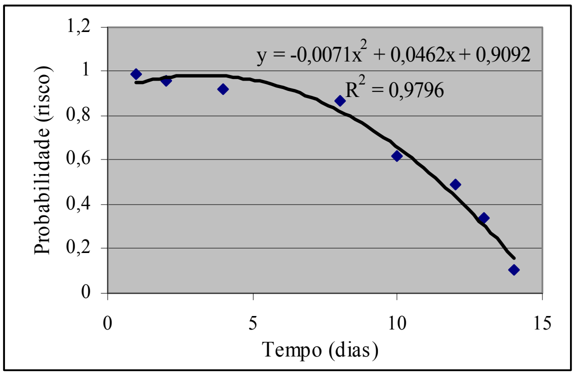

Fig. 7. Survival function of pipe lines

In this case the significant covariates are the way of conduction of the equipment, the vibration level, the used materials and, finally, the type of maintenance actions before damages calculated through the dimension of the p-value. Thus, table 6 summarises for the considered covariates and according to the expression 1 the coefficients of regression β and the values obtained for Z in each one of the equipment families.

So the figure 8 groups the different equipment families in function of the number of days after which the risk of damages is superior to 0.5.

Table 7 presents the number of workers for the different maintenance services dedicated in 2005 to the pulp line (fiber-line) during the outsourcing for the attendance of the damages above mentioned.

Thus, taking in account the 2007 regression coefficients showed above some maintenance actions were carried out in order to decrease the risk of damage. Those actions include sealing checks, condition monitoring controls for filters, conveyors and hydraulic cylinders or actuators protection, among others.

Beyond the actions above, most of them of the responsibility of the maintenance, production must pay attention to the importance of the operations of conduction of the equipment in the phases of starting the installations. We considered in particular the moments at which opening and closing automatic valves is necessary as well as the production variations that can compromise the good functioning of the equipment as for example the conveyer of pulp (C800), the oil-hydromechanical cylinders, the hydraulic pumps, the pipes and the sieves of the system of laundering and counter-laundering of the pulp.

Table 6. Significant covariate values

Equipment	Significant Covariates	Coef. (β)	Average (Z`s)
Pipes	Maintenance actions	4.53	0.5
	Value of the vibration level	0.304	16.4
	Material	8.48	0.9
Hydraulic cylinders	Production variations	0.074	42.6
	Velocity of the pulp and the cylinders	1.81	0.49
Electric cells	Maintenance actions	4.07	0.36
	Seasons of the year	4.4	0.21
	Number of manoeuvres	2.958	0.57
Centrifugal pumps	Operations of the production at the start	1.793	0.72
	Extrinsic causes of failure	1.312	0.62
Electric motors	Maintenance actions	2.27	0.32
	Operations of the production at the start	4.064	0.84
Automtic valves	Operations of the production at the start	0.73	0.66
	Value of the vibration level	0.05	13.6
Conveyor	Production variations	1.58	0.59

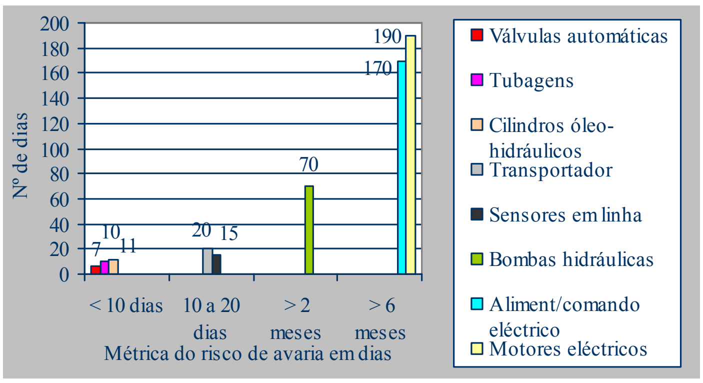

Fig. 8. Grouping of the equipment with a risk of damage superior to 0.5

Table 7. Number of executants in outsourcing by service

Services	Mec.	Electricity	Instrumentation	Total
No. of workers	17	5	5	27

Beyond the local verifications the equipment during the starts, we also took in account the regularity of the actions in function of the results. The surrounding temperature of the rooms of the electric switchboards especially during the summer period, because it has a significant effect on the damage of the electric components, and the systems AVAC were verified. On the other hand, the measurement of vibrations, normally accepted and used in the condition monitoring of the rotary equipment, was also used for the evaluation of the severity of the charge in the pipes and in the equipment installed on-line for the regulation, measurement and control of the productive process. Due to the implementation of the related operations during the second semester of 2007 and on the contrast of the first semester, the necessities of repairing and the backlog (in hours) of the maintenance services, the example of sml1amec presented in figure 9, decreased during the period.

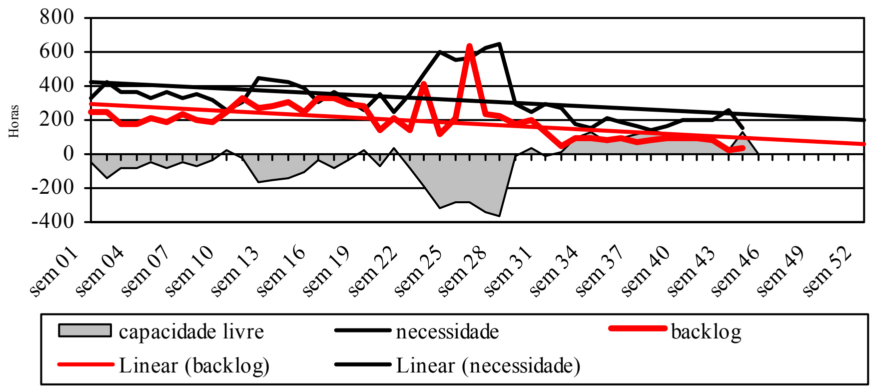

Fig. 9. Evolution of the backlog of the service sml1amec in 2007

Results on the sizing of the teams

The needs of executants of the mechanical, electrical and instrumentation services are presented in the table 8 to attend, according to the expressions presented in the table 1, the level of failures (arrivals) before the implementation of the actions of operational improvement.

Table 8. Workers by maintenance service

Areas	Mec	Electrical	Instrumentation
Bleaching	2	-	1
Total of pulp line	10	3	3

The occupation rate is about 0.37 if all the works were attended by a single worker but this situation does not happen for about 30 to 35% of the works. Thus, the total number of executants to attend the reactive and proactive works is 10 corresponding to 2 teams with 1 worker and to 4 teams with 2 executants. Table 9 presents the summary of some results obtained using the simulator of the University of Malta for 2005 data during the normal working period (8h00-17h00) in the fiber-line production at the plant of Portucel Soporcel, in Setubal.

We also know that there is a minimum and a maximum number of works that wait for a definitive or perfect repair whose amount varies in function of the interval of time that elapses between stops, programmed or not, of the manufacturing areas. Thus, table 10 summarizes the data in the line of pulp (fiber line) for the application of expression 2 used to minimise the operational costs in the planned or short duration (up to 8 hours) stops.

Table 9. Sizing of the teams in fiber-line

Maintenance Services	Numberof servers (teams)	Works with one executant	Number of necessary executants	Maximum time system (W)	Maximum work line (Lq)	Maximum wait line (Wq)
Mechanical	6	30%	10	47,2	4	4,8
Electrical	2	70%	3	29,1	4	9,3
Instruments	2	70%	3	27,1	4	8,6
Total	10	-	16	-	-	-

Table 10. Summary of the data used in the model of subcontracting

Variables	Amount of works (r)	Average works processed by 2 executants/hour (m)	Average internal cost by work (C_w)	Average external cost by work (C_s)	Fixed costs by man/hour (C_f)
Mínimum	16	0.25	96 euros (4x12x2)	120 euros (4x15x2)	20 euros
Maximum	30				

Under these circumstances the average number of processed works per hour by the teams of maintenance is 0.25. The average cost of the works done by the executants already dedicated to the maintenance services is 96 euros and the value of the external teams (outsourcing) is 120 euros considering the hourly rates of the market. The fixed cost (Cf) represent the value corresponding to the structure of the back office of the execution services that includes the work of investigation and analysis of the failures, the planning and the preparation of the works and also the supervision and the control of the quality of the execution. The figure 10 presents the minimum cost of the workmanship in function of the number of workers, n, who varies from 20 up to 60 to use in the different maintenance services with a frequency of 3 to 4 months.

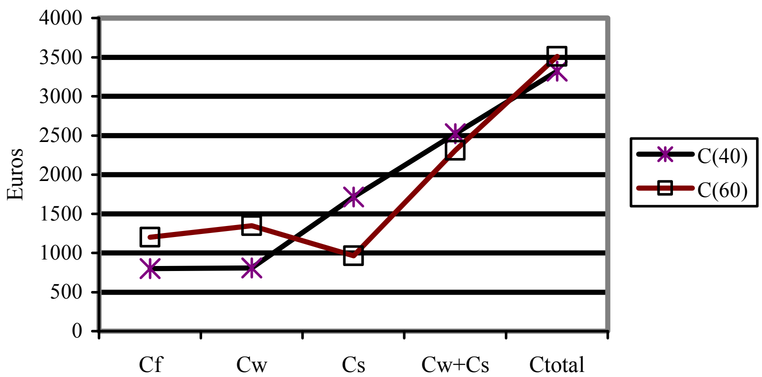

Fig. 10. Sizing and cost of the teams in the programmed stops

In this case the optimum cost is situated between 300 and 3500 euros for a total of 20 to 30 teams of executants composed by 2 elements each one, that is to say 40 to 60 executants of the different specialities of the maintenance services. Besides the cost we must also consider the qualifications and abilities necessary to contract for the execution of the required repairs, substitutions, calibrations or mechanical, electric and instrumentation experiments. Thus, it was verified that the main functional failures and the consequent probabilities of more frequent damages are the ones that interact with the specialities in the domain of the “fluid tightness and conduction” , as the pipe locksmiths and welders; the locksmiths and instrumentalists of valves and equipment of “regulation and control” of the process; then the “driving actions and transmissions”; the mechanical technicians and electricians and, finally, the specialists for the hydraulic cylinders, calibrations and alignments.

Final results and validation

At the end of 2007 and after the implementation of the more important actions in 5.1 in consequence of the application of the proportional hazards model, the survival function that is presented in figure 11 for the pipes was obtained. In the remaining equipment families it was also obtained, similarly to the pipes, a greater number of working days for the same risk of damages.

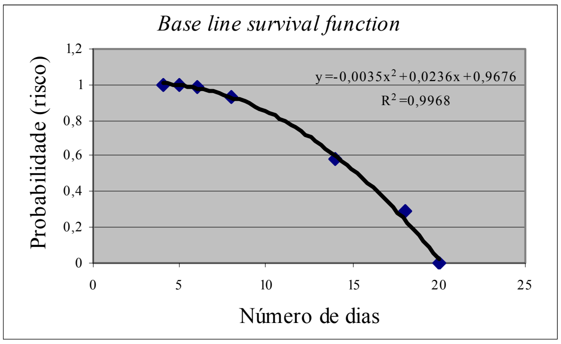

Fig. 11. Function of survival after the implementation of actions

Thus, in function of the results obtained in 2007 after the implementation of the foreseen actions to oppose the effect of the significant covariates that had been in the origin of the damages of the studied equipment, we present the figure 12 with the results now achieved and comparable to those of the figure 8. In both cases the interval of time in days for a probability of occurrence of damages equal to 0.5 is presented.

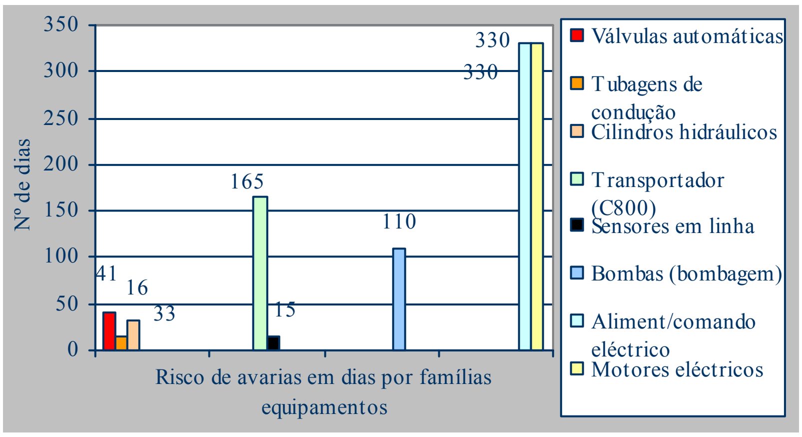

Fig. 12. Grouping of the equipment according to the risk of damages superior to 0.5

Table 11 presents the number of damages expected in 2007 and the reduction relative to 2005.

Table 11. Number of expected damages in 2006/2007 compared to 2004/2005

Static			Rotary			Linear	
Pipes	Cell`s	Sensors	Pumps	Motors	Conveyor	Valves	Cilynders
9	1	21	1	1	6	15	9
> 50%	> 60%	-	> 70%	> 60%	> 70%	> 50%	> 70%

The number of stops (down-times) also decreases, as it is presented in table 12. The stops and the consequent starts were, as we referred, considered significant factors in the risk of damage of some of the equipment families.

Table 12. Evolution of the number of stops of the bleaching

Stop	Responsability	2004	2005	2006	2007 (June)
External	Other areas	63	74	76	30
Internal	Production	48	49	36	7
	Maintenance	82	49	44	7
Total		193	172	156	44

Thus, one of the equipments that contributed the most for the reduction of the number of stops in the area in study was the transporter called C800.

Therefore, the table 13 summarizes the results related to the rate of the arrivals of the repair orders and the respective average time verified in the bleaching and in the line of the pulp (fiber-line) previous to the implementation of the measures and the actions suggested in this work and those obtained after its implementation.

Table 13. Evolution of the rate and the average time between failures

Time period	Areas	Arrivals rate	Average time	Arrivals rate	Average time	Arrivals rate	Average time
		Mec		Electrical		Instrumentation	
Before	Bleach	0.25	4	0.053	19	0.11	9
	Pulp	0.59	1.7	0.18	5.7	0.2	5
After	Bleach	0.21	4.3	0.17* / 5.8*			
	Pulp	0.52	1.9	0.76* / 1.3*			

*The services of electricity and instrumentation were merged in 2007

As a consequence of the reduction of the rate of damages verified since the end of the first semester of 2007, the backlog of the different maintenance services (mechanical, electrical/ instrumentation) was inverted for a situation of overcapacity as it was showed in figure 13.

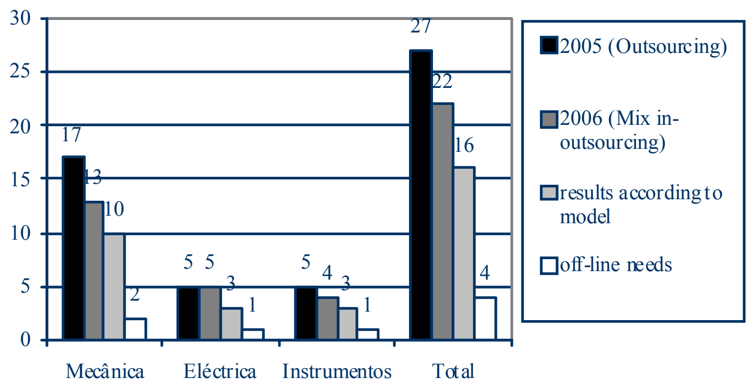

Fig. 13. Result of the sizing of the number of maintenance operators

So the reduction of the number of daily executants dedicated to the repairs of the pulp line (fiber-line) is justified: 27 in 2005 and 22 in 2006 and 16 according to the queuing theory model. We must still consider 4 executants more for the attendance of the systematic maintenance planning (PM) including the lubrication (off-line needs).

Finally, the objective of the monthly down-time of 2.8 hours is presented in figure 14 estimated by the Management of the plant of pulp in 2007 for the area submitted to the experiment of the operational model. The averages of the 2006 down-time before the application of the model and its evolution from January to October 2007 are also presented. In April 2007 4.15 hours were provoked by a damage of a electrical conversion station extrinsic to the manufacturing area.

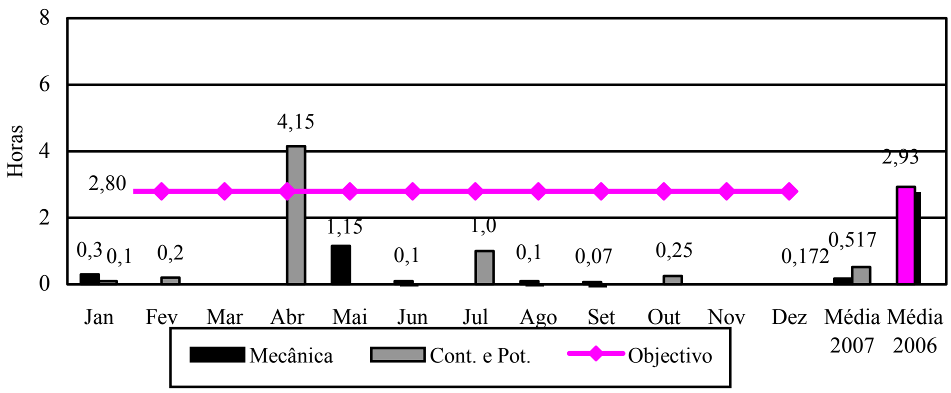

Fig. 14. Evolution of the down-time of the bleaching in 2007

Conclusions

We can conclude from the results achieved through the analysis of exponential semi-parametric survival times concerning the main failure modes of each one of the equipment families (static, linear rotary) selected from a manufacturing area and common to all the other areas of all lines of production of pulp (fiber line) that operational actions were identified with a bigger added value from the Maintenance to the Production and vice versa. In parallel, and in function of the number of damages and repairs of the equipment that occurred, whose time was exponential, they were sized through the M/M/s model the daily in sourcing needs of maintenance and, occasionally, in outsourcing through the rectangular distribution, the necessities in the planned stops of short duration in order to minimise the operational costs.

The partial models used (proportional hazards, queuing and operational costs) were integrated because a relationship of cause-effect among them is established and, therefore, they provide to the operational back-office a methodology of continuous improvement of the Plan-Do-Check-Act type. In the particular case of the equipment in study it was verified in 2007, with the application of the model, the increase of the average time between failure from 1,5 to 3 times and 8 times in the case of the transporter C800.

Extrapolating the results of the reliability in the sizing of teams to all the pulp line, we get a reduction of the front-office of the different maintenance services of about 25% in relation to the period of outsourcing of 2005 and a proportional reduction of the costs. Thus, as a final conclusion, it was verified in 2007 that the integration of the presented exponential models can be applied to the industrial maintenance and, therefore, they support an innovative way of bests-sourcing leading to the better practices "of management for the improvement of the operational reliability".

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Îmbunătățirea fiabilității operaționale pe o linie de producție a hârtiei din celuloză

Rezumat

Modelul de management operațional propus urmăreşte să trateze simultan fiabilitatea echipamentelor, procesul de mentenanță şi costurile operaționale. Este prezentat un model operațional ce integrează trei dimensiuni diferite bazate pe informația colectată din ordinele de reparație şi circumstanțele operaționale în care au apărut. Una dintre dimensiuni determină factorii ce au mai multă influență asupra riscului de avarie şi de ne-disponibilitatea echipamentului; cea de a doua dimensionează echipele dedicate în regime de "in-sourcing"; în fine, a treia dimensiune a modelului urmăreşte subcontractările planificate ale echipelor în regim de "outsourcing".