BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LX No. 2/2008	23 - 31	Seria Tehnică

Best Management Practices to Improve Operational Reliability

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Abstract

The industry of production of pulp for paper is characterized by the process of continuous production and any interruption or fortuitous variation due to failures or damages of the equipment is, normally, taken care of immediately by the respective services of maintenance. Independently of the greater or smaller appeal of the maintenance services management in respect to outsourcing, the equipments failures and repair rates are measured, respectively, by the MTBF (mean time between failures) and the MTTR (mean time to repair or replace). Both of them characterize the process of the arrivals of the repairing orders and the correspondent service. This work presents a practical application of the theory of the "queues" for the sizing of the operational maintenance function through exponential model M/M/S (Kendall notation) and an optimization process that considers the outsourcing opportunities taking in account the workload and the costs of the maintenance works to carry out simultaneously during the planned shut-downs of the manufacture areas.

Key words: *queues, services, operational reliability, costs.*

Presentation and Introduction

The application of the queuing theory is generalised through a wide variety of operational contexts usually related to attendance places as, for example, cash desks in supermarkets, banks, general tolls in roads and bridges among others. In this work its application in the sizing of the resources of the services of the industrial maintenance is done. The increase of the productivity of the services, such as those rendered in the repairing of failures (damage) of the productive equipment in the different specialities of the maintenance function assumes a decisive role in the improvement of the competitiveness. The operational functions of the industrial maintenance reponsible for the minimization of the unavailability of the productive equipment are related to the total time spent in the repairing of the failures and the organisation of the maintenance services. If on one hand, a high number of resources can lead to a faster attendance of the damaged equipment, on the other hand it can lead to an increase of the operational costs of the system and to a lesser operational productivity

Thus it appears an interesting "trade-off" between the level of the necessary service of maintenance for the productive equipment and the respective capacity of the attendance system, taking also in account that the value per hour corresponding to the sales market of each hour of production can reach in this study case about 30000 euros (thirty thousand euros).

This study case concerns the equipment of the line of production of pulp (fiber line) through the Kraft process of an industrial unit with a capacity of 520000 tons/year that uses about one thousand and five hundred driving action systems and it is composed of the areas of the chips feeding, digester(s), screnning, brown stock washing, production of chlorine dioxide, bleaching, pulp stock preparation, dryer machine(s) and finishing lines. In this operational context we can verify that in the attendance of failures and damage of the equipment in the line of production of pulp are used common operational resources of maintenance concerning electricity and instrumentation and the mechanical speciality is divided into two operational zones.

In the present work it is important to characterise the measures of performance of the functioning of a system through the cost and queuing theory.

Main Concepts

In this chapter we are going to introduce the concepts related to the equipment reliability and maintainability and also those related to the queues in industrial maintenance and to the outsourcing opportunities.

The average rate of failures can be estimated by dividing the number of failures verified during a certain interval of running time by that same interval. According to Pereira [1], when the average rate of failures is approximately constant, it is determined the average time between failures (MTBF) through the inverse of the rate of failures verified and we use this value as a mesure (metric) of the reliability of the equipment (material). On the other hand the average rate of repairings is used as a mesure (metric) of the rhythm of the equipment repairing being represented by the average number of repairing operations done by unit of time. The average time of repairing operations (MTTR) is determined by the inverse of the repairing rate that was verified. Canuto [2] understands that the failure of a component of an equipment is a working state which leads to an longer or shorter process of degradation until the damage, when the component leaves undone the function required to it. In this way, the period of time that can elapse between failures and damage can consist of seconds, for example the electronic components, or even hours as it is the case of some mechanical equipment components. This concept corresponds to the operational practice of the industries of continuous labouring, as it is the case of the production of pulp for paper, since the concentration of the resources allocated for the function of maintenance during the normal work schedule (from 8h00 until 17h00) is bigger, therefore it becomes, necessary its optimization in the diagnosis of failures and in the attendance of the damage, being, by this way, possible to reduced the resources and the costs out of that schedule.

The study of the queues refers to the work of K. Erlang that, at the beginning of 20th century, dedicated himself to the study of a new technology at that time, the telephone – the queues that waited for connecion were extremely important, according to Brockmeyer *et al.* [3]. The essential elements of a queue system are the source or population, the line and the service or attendance. The population creates the "customers" of the system and it is considered infinite when the number of elements in the system, at any time, is a very small percentage of the population, as it happens in big industrial units with thousands of equipment.

Tavares *et al.* [4] refers that the standard of the arrivals is usually described through the distribution of the number of arrivals per unit of time and, being these arrivals random, they can be characterised by an experimental observation or trough a distribution of theoretical probability. On the other hand, when the arrivals rate (λ) does not vary, it can be considered as independent of the state of the system. The number of queues, their length and their discipline are important characteristics. When there are more than one server it can exist a single line for all the servers (as it is in the case in study) or a line for each server, having an infinite length when there are not any physical limitations, as it is the case. Finally, the disciplines of the line used in this work is of the type FIFO ("first in" "first out") because it deals with a continuum productive system and where it is required a high availability of the equipment and, at the same time, a high product quality. The configuration of the service express the way as the attendance is organized and the rate of service (μ) indicates the average number of "customers" who can be attended by each server per unit of time. The service rate, as well as the arrivals rate, when it does not depend on the number of elements in the system, is said to be independent of its state.

The measures of performance of a queue must characterise its functioning, either from the point of view of the "customer" or from the point of view of the "service". The measures that must be mentioned 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, average rate of occupation of the service (ρ). The table 1 presents some of the expressions used in the calculation of the measures of performance for the queues of type M/M/S.

Table 1. Mathematical expressions for the measures of performance.

Parameters	Expressions of calculation	Observation
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 inoccupation 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 until (S-1)

Defined and optimized the necessary dimension of the operational teams of maintenance in relation to a certain operational context, it appears, however the necessity of having more resources when stoppage or planned shot-downs occur in the production areas. In those periods of time, there is the chance of attending at the same time the equipment whose condition of failure is known by the services of maintenance and, for this reason, they wait to stop.

Jardine [5] proposed, regarding the organizational decisions of the maintenance functions the subcontracting (outsourcing) of resources as a way of minimizing the costs of maintenance per unit of time. Through the expression (1) it is calculated the best number of executants (servers) of the maintenance that lead the cost down to a minimum C(n).

$$C(n) = n\,C_f + \left[n\,m\int_{n\,m}^{\infty} f(r)dr + \int_0^{n\,m} r\,f(r)dr\right]C_w + \left[\int_{n\,m}^{\infty}(r - n\,m)f(r)dr\right]C_s \qquad (1)$$

The works per unit of time obey to a function $f(r)$ of probability density, where r represents the number of works, m is the number of works processed team (server) per unit of time, n represents the number of teams or technicians and C the costs. C_f represents fixed costs per technician and per unit of time and C_w and C_s represent, respectively, the average costs of the internal and external manpower for the execution of one work.

Study of a Case - The Sizing of the Teams of Industrial Maintenance in a Continuous Labouring process

The services of maintenance of the production of pulp for paper are assured by three big operational specialized areas: the mechanics, the electricity and the instrumentation. The orders of repairing are done by the Production or by the Maintenance itself through the system CMMS

- SAP/R3 [6] and they are sent to each one of the three main specialities which identifies through the technical and adequate nomenclature the manufacturing area and the location of the damaged equipment, as well as the date and the hour of the repairing order. The continuous functioning of the equipment is also attended in what concerns the small urgent works and the eventual provisional repairs during the night and the weekends through rotating turns of a smallest dimension in the specialities above mentioned which are not considered in this work for the obvious reasons.

Besides these smallest teams there is still an assistance team that in spite of being absent from the factory can de called at any time when at night or at the weekends the repairing demand more than one maintenance technician of a certain specialty.

Therefore it is during the period between 8h00 and 17h00 and from Monday until Friday that it is verified the greater amount of repairing orders and, consequently, a greater volume of the operational activity of the maintenance, so it is necessary to study the operations and to dimension the respective operational resources.

The population is considered infinite because the question is that in this in case we must consider hundreds of equipment that can be come damaged and, on the other hand, the line that corresponds to each one of the maintenance specialities is interpreted as single line for all the servers (maintenance technicians) of that speciality. The figure 1 presents the model of queue for each one of the specialities.

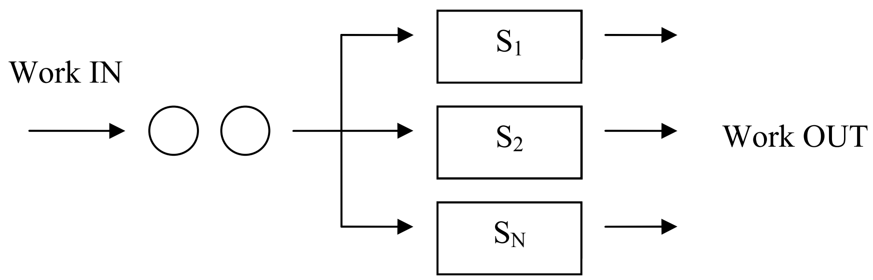

Fig. 1. Model of queue for each speciality of maintenance

For the sizing of maintenance teams through the queuing theory, besides the need of specifying a period of time to establish the distribution of probability of the arrivals of the repairing orders, in particular in the area of bleaching, and subsequently for all the fibre-line production it is done a study of the time of repairing of the different equipment that constitutes the entities and whose dimension is considered as infinite, including hundreds of them.

The negative exponential distribution is used for the representation of the times between the arrivals of the repairing orders and the respective times of attendance (repairing) because it was verified that the variation coefficient (quotient between the standard deviation and the mean) was approximately 1.

The arrivals of fortuitous repairing orders directed to each one of the maintenance specialities, between 8h00 and 17h00, is a random number and it follows a distribution of Poisson for the following reasons: the arrivals that occurred during more than a period of time of about six months (between 2004 and 2005) are independent; the probability of occurring an arrival in short period of time is proportional to the duration of the period of time and it does not depend on the number of arrivals verified outside this period of time; the probability of occurring more than one arrival in this short period of time is insignificant. The table 2 presents the results obtained for one of the manufacturing areas, the bleaching, and for all the areas of the line of production of pulp for paper mentioned in the presentation of this work.

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

	Mechanical	Electric	Instruments
Bleaching	4 hours	19 hours	9 hours
Fibre-Line	1.7 hours	5.7 hours	5 hours

Regarding the operations that concerned the fortuitous repairings and taking into account the great variety and amount of types of equipment to repair in all the areas of the line of production of pulp, the data were only observed and collected in the area of bleaching of the pulp because it is the area which registers the most difficult maintainability. It was then possible to agglutinate transversally, for each one of the specialities, the times of repairing as well as the proportion of the time spent in the repairings. The table 3 presents the results of the average times obtained for each one of the great specialities of maintenance.

Table. 3. Average times of repairing and respective proportions by speciality

Time groups	Mechanical	Electric	Instruments
A	Until 3 hours		
	0.70	0.85	0.95
B	Between 3 and 5 hours		
	0.25	0.15	0.50
C	More than 5 hours (until 8 hours)		
	0.05	-	-

The times of repairing presented include the logistic times and those of diagnosis, when they occurred and the fact that they include between 40% and 55% of the average time of the repairings. Finally, the weighed average times to consider for the sizing of teams that can have more than one maintenance worker are presented in table 4.

Table 4. Weighed average times of the repairings (MTTR) by speciality

Specialities	Mechanical	Electric	Instruments
Weighed times	3.75 hours	3.3 hours	3.1 hours

We have still to consider that in the execution of the operations repairing of some equipment it is necessary more than one worker.

This fact occurs due to the characteristics of the equipment or of the operations to do or when it is possible to increase the number of executants to reduce the repairing time.

Table 5 presents the maximum number of weekly works in the bleaching area and the proportion of the works in each one of the specialities with only one worker.

Table 5. Proportion of the number repairing works with one executant

Specialities	Mechanical	Electric	Instruments
Number of weekly works	10	2	5
Proportion	30 to 35%	70 to 80%	

In the speciality of mechanics about 50% to 55% of the repairing service is done by two technical executants, the same happens in the electric and instrumentation specialities about 20% to 25%. The attendance services in the case of the mechanical speciality must then be configured in terms of capacity of the servers, as it is showed in the figure 2.

For the area of bleaching of pulp for paper where there is a significant number of repairing orders and where the repairing times are more significant, the results obtained for the number of servers (executants) in the mechanical specialty using the model M/M/S are the ones presented in the table 6.

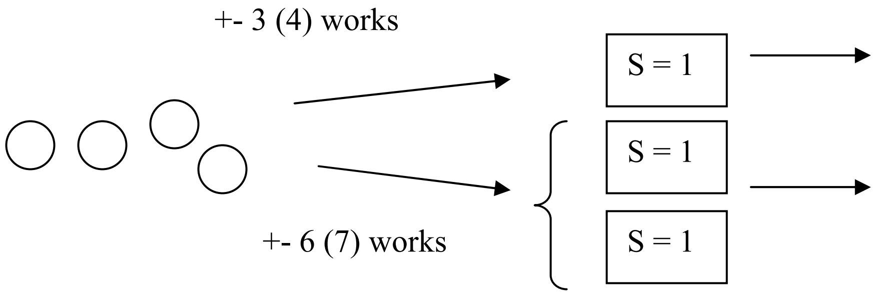

Fig. 2. System multi-channel with agglutination of servers

Table 6. Results of the measures of the performance of the bleaching system

Performance metrics/measures	Results
Number of servers (*S*)	2 mechanics
Waiting time in the system (*W*)	4.8 hours

For the electric speciality, whose MTBF is the bigger one (about 19 hours), the results obtained do not suggest the necessity of an electricity specialists for the attendance of fortuitous repairing orders in the area of bleaching and, finally, it is justified an instrumental worker for that manufacturing area.

Knowing the characterisation of the repairing orders of the different equipment of all the line of production of pulp (fiber line) and admitting that the values of the times of attendance of the repairings in the area of bleaching are the least favourable, the results of the performance of the functioning of the system through the queues of type M/M/S for the mechanical speciality are presented in figure 3.

In this case 10 workers are necessary taking in account the presuppositions presented above to attend the fortuitous mechanical repairing in the fibre line.

For the electric and instrumentation specialties it was calculated the value of 3 technical executants for each one of those specialities to take care of the orders of fortuitous repairing, taking in consideration that it is necessary 2 technicians simultaneously to attend 20% to 30% of the work orders.

In the case of the maintenance operations that wait for a programmed stopping (shot-down) of the equipment in the manufacturing area, which are usually of short duration (between 4 and 16 hours of the maintenance), due to the costs associated to the losses of production, it becomes necessary to appeal to outsourcing services (subcontracting technicians) to attend simultaneously the high quantity of equipment that waits of a definitive repairing.

In practice there are several situations where it was only possible to do provisional repairs in the equipment with this one functioning since to attend the required definitive repairs it is necessary the stopping of the manufacturing area. It is also verified, through the data of the CMMS of the maintenance, in the case SAP/R3, that the greater or the lesser amount of works that wait for a stopping is proportional to the dimension of period of that elapses between the stoppings.

In our case, the average quantities of works with a fortuitous origin that wait for the stopping of the area of bleaching and of all the line of pulp production (fibre line) are presented in table 7. Considering that every week there is a minimum and a maximum number of works in these circumstances in relation to the greater or the lesser period of time between programmed stoppings, these can be represented through a function of probability density of the type uniform or rectangular.

M/M/S queuing model – Fibre Line in the mechanical speciality

Data			Results	
λ =	0,588	(mean arrival rate)	L =	2,220836524
μ =	0,2667	(mean service rate)	L_q =	0,016112115
s =	6	(10 servers)		
			W =	3,776932864
Pr(W > t) =	0,769896		W_q =	0,027401556
when t =	1			
			ρ =	0,367454068
Prob(W_q > t) =	0,010079			
when t =	1			

n	P_n
0	0,109986721
1	0,242490409
2	0,267312262
3	0,196449956
4	0,108279504
5	0,047745293
6	0,017544202
7	0,006446688
8	0,002368862
9	0,000870448
10	0,00031985

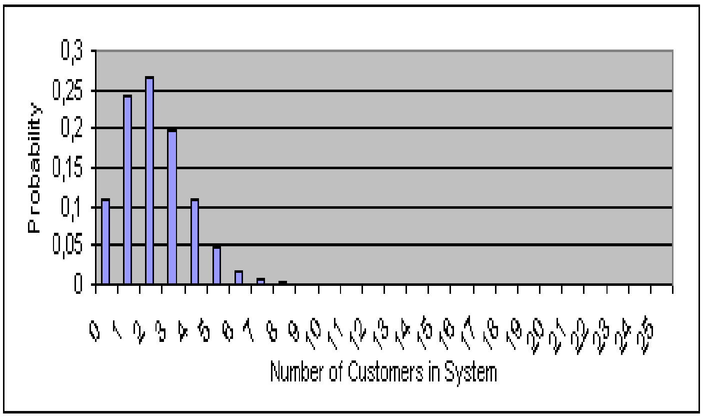

Fig. 3. Number of servers and measures of performance

Table 7. Minimum and maximum quantities of works that wait for a stopping

Area(s)	Mechanical	Electric	Instruments
Bleaching	1	0	1
	7	1	2
Fibre line	10	2	4
	20	4	6

The MTTR found in the different specialities of maintenance is of about four hours absorbing an average number of 2 technicians in each work. Admitting the situation of a programmed stopping of the fibre line of eight hours, the table 8 summarizes the data for the application of the expression (1).

The expression (1), after doing the numerical substitutions more adequate to the operational reality, takes the general configuration presented below in (2):

$$C(n) = nC_f + \left[0{,}25n\int_{0,25n}^{30}\frac{1}{14}dr + \int_{16}^{0,25n}\frac{1}{14}r\,dr\right]C_w + \left[\int_{0,25n}^{30}(r - 0{,}25n)\frac{1}{14}dr\right]C_s \qquad (2)$$

Table 8. Summary of the data for the application of the expression (1)

	Amount of works (r)	Average of works processed by workers/hour (m)	Average of the internal cost per work (C_w)	Average of the internal cost per work (C_s)	Fixed cost per Men/hour (C_f)
Minimum	16	0,25	(4x12x2) 96 euros	(4x15x2) 120 euros	20 euros

Figure 4 presents the results obtained for values of "n" between 20 and 60. The optimum cost is between 3193 and 3244 euros for a total of 25 to 30 worker teams in the different maintenance specialities.

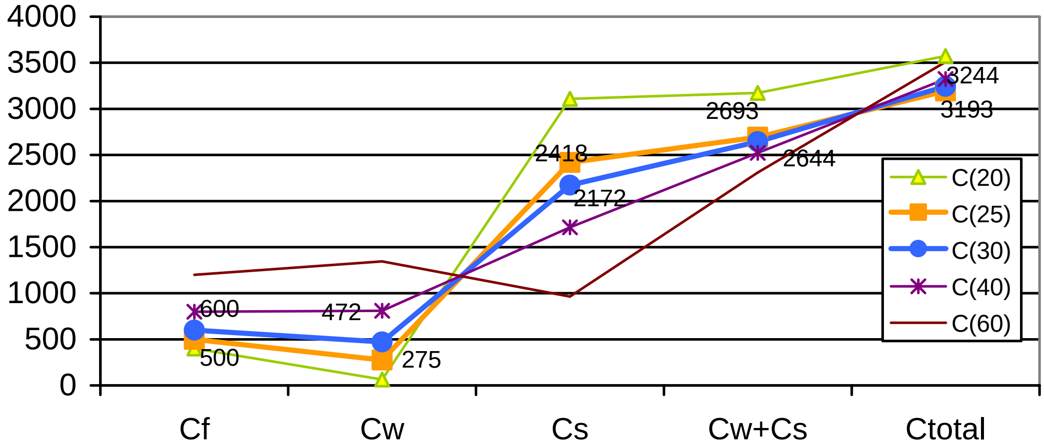

Fig. 4. Variation of the costs in function of the number of technicians

Conclusions

The queuing theory based on the model M/M/S is applicable to the operational sizing of the daily function of the maintenance, particularly to the industries of continuous labouring that produce pulp for paper, because the fortuitous repairing orders follow approximately a distribution of Poisson and the respective services of attendance of the repairings of the several types of equipment can be represented by a negative exponential distribution. In the above mentioned case of the line of production of pulp in an industrial unit with a capacity of production of 520000 tons/year of pulps for paper, it was calculated the necessity of 10 executants in the mechanical speciality and 3 for each one of the services of fortuitous repairings in the electric and instrumentation specialities. On the other hand, it is also to appeal for subcontracting (outsourcing) opportunities during the stoppings in the manufacturing areas to face the load of work associated to the equipment that waits for a repairing due to failures and, therefore, need a definitive repairing. The amount of work in these conditions depends on the greater or minor period of time that elapses between consecutive stoppings and according to the model used, the total operational costs of the maintenance function are more affected by the fixed costs per technician and per unit of time, than by the related "mix" (internal and sub-contracted) used in the processing of each one of the programmed works (operations). It was still calculated that it would be necessary 25 to 30 worker teams in the different specialities of the maintenance to take care, simultaneously and respectively, of the minimum and maximum numbers of works that follow a rectangular distribution. Finally, we note that one of the most important aspects in this type of work in the domain of the investigation and the operational management is the correct collecting of data in the operational context in study, their treatment for the application of a model and, later, the validation of the results obtained.

References

1. Pereira, F.J.D. – *Models of reliability in dynamic equipment*, thesis submitted to the attainment of the degree of Doctor in engineering mechanics for FEUP, 1996.
2. Canuto, R.M.F. – *Maintenance Centered in the Reliability*, thesis submitted to the attainment of the degree of Master in instrumentation, industrial maintenance and quality for UNL-FCT, 2002.
3. Brockmeyer et al. – *The life and works of K. Erlang*. Danish Academy of Technical Science, Copenhaga, 1948.
4. Tavares, V.L. et al. – *Operational Inquiry*. McGgraw-Hill of Portugal, Lda, Alfragide, 1996.
5. Jardine, A.K.S. – *Maintenance, Replacement and Reliability.* Pitman Publishing, 1979.
6. * * * SAP, *Sytems Applications and Products in Processing Date*. Walldorf, Germany, 1972.

Cele mai bune practici de management pentru îmbunătățirea fiabilității operaționale

Rezumat

Industria producătoare de pastă de lemn pentru fabricarea hârtiei este caracterizată de un proces de producție continuă şi orice întrerupere sau variație inopinată datorată avarierii sau defectării echipamentului este, de regulă, remediată imediat de către respectivele servicii de mentenanță. Independent de mărimea apelului la managementul serviciilor de mentenanță în raport cu externalizarea, defectele şi rata de reparație ale echipamentelor sunt exprimate respectiv prin timpul mediu dintre defectări (MTBF) şi timpul mediu de reparare sau înlocuire (MTTR). Ambii caracterizează procesul de intrare a ordinelor de reparare şi a serviciilor corespunzătoare. Prezenta lucrare prezintă o aplicație practică a teoriei firelor de aşteptare pentru dimensionarea funcției de mentenanță operațională pe baza modelului exponențial M/M/S (notația Kendall) şi un proces de optimizare ce ia în considerare oportunitățile de externalizare ținând seama de sarcinile de lucru şi de costul lucrărilor de mentenanță de realizat simultan în timpul opririlor planificate ale zonelor de fabricație.