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Research Article

Effects of Maintenance Policies on Production Costs and System Reliability in a Canned Food Factory

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Abstract

This paper presents a procedure for modeling and analysis of maintenance operations in a factory. A canned food production facility was analyzed in detail and the effects of different maintenance policies on production system performance was determined. It was found that selection of an appropriate maintenance policy significantly reduced production costs and increased equipment availability, production line reliability and its output rate. The procedures outlined and the models used in this paper can be used by operational managers and maintenance engineers to increase performance of their production lines.

Keywords: Production line, preventive maintenance, corrective maintenance, reliability centered maintenance, reliability.

Bir Konserve Fabrikasında Bakım Politikalarının Üretim Maliyetlerine ve Sistem Güvenilirliğine Etkileri

Öz

Bu makale, bir fabrikadaki bakım işlemlerinin modellenmesi ve analizi için bir prosedür sunmaktadır. Bir konserve üretim tesisi detaylı olarak analiz edilmiş ve farklı bakım politikalarının üretim sistemi performansına etkileri belirlenmiştir. Uygun bir bakım politikasının seçilmesinin üretim maliyetlerini önemli ölçüde azalttığı ve ekipman kullanılabilirliğini, üretim hattı güvenilirliğini ve çıktı oranını artırdığı bulundu. Bu makalede özetlenen prosedürler ve kullanılan modeller, üretim hatlarının performansını artırmak için operasyon yöneticileri ve bakım mühendisleri tarafından kullanılabilir..

Anahtar Kelimeler: Üretim hattı, önleyici bakım, düzeltici bakım, güvenilirlik merkezli bakım, güvenilirlik.

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1. Introduction

Maintenance is one of the major problems in manufacturing industry. Machinery must be maintained regularly to avoid failures, which cause significant losses in production and company revenues. Maintenance of the equipment must be planned well, and appropriate tools must be utilized to schedule the related activities on the right time to avoid time losses due to schedules. Mobley (1990) indicated that between 15-40 % of operation costs may be directly or indirectly attributed to equipment maintenance. Literature abounds with research papers related to maintenance operations and optimization. Dekker (1996) presents a review on the applications of maintenance optimization models. Sarkar, et al (2011) presented a survey of maintenance policies for the past 50 years. The survey summarizes, classifies, and compares various existing maintenance policies based on about 170 research works. Each kind of policy has been identified with different characteristics, advantages, and disadvantages with several contributions. The paper investigates different policies which are appropriate to the organizations and for further study.

Vatn et. al (1996) presented an optimal maintenance schedule for the components of a production system based on multiple objectives, including cost, safety, and environmental factors. Krajewski and Sheu (1994) proposed a decision model for evaluation and comparisons of alternative corrective maintenance policies. The model includes simulation and economic analysis. While simulation is used to predict costs and performance of the corrective maintenance policy, economic analysis is used to determine the net present value and breakeven between alternative maintenance policies. A detailed case example is also presented. Löfst (1999) has also analyzed effects of different maintenance policies in industrial settings. The effects of corrective and preventive maintenance policies have been evaluated for different cases. Ben-Daya and Makhdoum (1998) analyzed various preventive maintenance policies with an integrated production and quality model. Savsar (2000) analyzed the effects of maintenance policies on the productivity of flexible manufacturing cells (FMC) by simulation modeling of the FMC. Komonen (2002) presented a cost model for maintenance operations in industry for profitability analysis and benchmarking. Waeyenbergh and Pintelon (2004) discussed the development of maintenance concept in industry based on a case study. Yang, et al. (2019) presented a two-phase preventive maintenance policy considering imperfect repair and postponed replacement with an objective of maximizing the revenue generated by the performance-based contracting (PBC). They apply the model to a case from a steel converter plant, and the results show that the proposed policy outperforms some existing maintenance policies in terms of net revenue.

Shalaby (2019) developed a model to integrate production planning, preventive maintenance, and process/product inspection decisions under reliability constraints. They have used genetic algorithms for the optimization purpose. Yang, et al. (2019) presented a two-phase preventive maintenance policy for the case of imperfect repair and postponed replacements. Gadallah and Almokadem (2019) developed a model for inspection decisions under equipment reliability constraints. Savsar (2005) analyzed performance of a flexible manufacturing system (FMS) operating under different failure rates and evaluated effects of different maintenance policies. Savsar (2008) presented a model and a detailed procedure for the analysis and improvement of maintenance operations for an oil filling plant. Savsar (2011a and 2011b) analyzed maintenance operations with a specific case in a plant. Savsar (2012) also developed a model and a scheduling procedure for maintenance operations of fuel dispensers. Savsar (2013) presented a model and a procedure for the analysis and Scheduling of maintenance operations for a chain of gas stations. Several other research papers look into the effects of applying different types of predictive, proactive, preventive, opportunity and condition-based maintenances in order to reduce the effects of random failures, which result in unexpected corrective maintenances.

In this paper, maintenance operations of a canned food factory have been analyzed and several procedures are applied to improve system operations and increase productivity. The factory produces a variety of canned food, including beans, peas, mushrooms, olives, corn, and sausages. In addition, they have different production lines for bottled water, vinegar, and a variety of sauces, including tomato catchup, chili sauce, hot sauce and tomato paste. The canned food is produced in 220g, 400g and 450g cans. We have concentrated on the 400g canned food production line since bulk of the production, about 93%, is in this type. The factory has two lines (can making line and can filling line), both of which are continuous, and the machines are connected in series. Hence, failure of one machine causes the stoppage of the whole line, adversely affecting the production rate of the factory. Thus, it is important to analyze the maintenance system to improve production rate of the factory. The current maintenance schedule causes too much downtime and is not optimized.

The reliability of the can filling line is too low. The process can barely keep up with demand. The objective was to improve the system reliability, increase the daily production and reduce the maintenance cost. The maintenance policies that the factory currently applies were studied and reliability and availability of the system were calculated. The performance of the factory was improved by introducing new maintenance policies to reduce the failure rates of the equipment. The current system, as well as the proposed system were modeled by using Arena Simulation Software and the improvement in production rate due to proposed changes was analyzed in order to see if the proposed changes were justified.

New maintenance plans were proposed that increased machine reliability and availability while minimizing the maintenance cost. The factory consists of two lines: The can making line and the can filling line. In the following sections, we discuss the basic operations on these lines and the maintenance procedures for the current case and for the proposed maintenance policy cases.

2. Overview of the Production Line

As it was mentioned previously, canned food factory operates with two production lines. One of the production lines is dedicated to making cans. Figure 1 illustrates a typical can and its components. The processes of the **can making line** includes ***slitting*** (cutting tin sheets into blanks of desired dimensions), ***welding*** (welding two ends of the rectangular blank to form a cylindrical shape), lacquering applying a varnish coat to the inner face of the welded blanks), ***curing*** (curing and drying of varnish while moving to the flanging machine), ***flanging*** (flanging both ends of the can for seaming), seaming (one end of the can is seamed by a seamer), ***palletizing*** (every 2940 cans are placed on a pallet and moved by a forklift to the empty can storage area). In reliability and maintenance analysis, this line was considered as single process and failure/repair data was collected for the whole line accordingly.

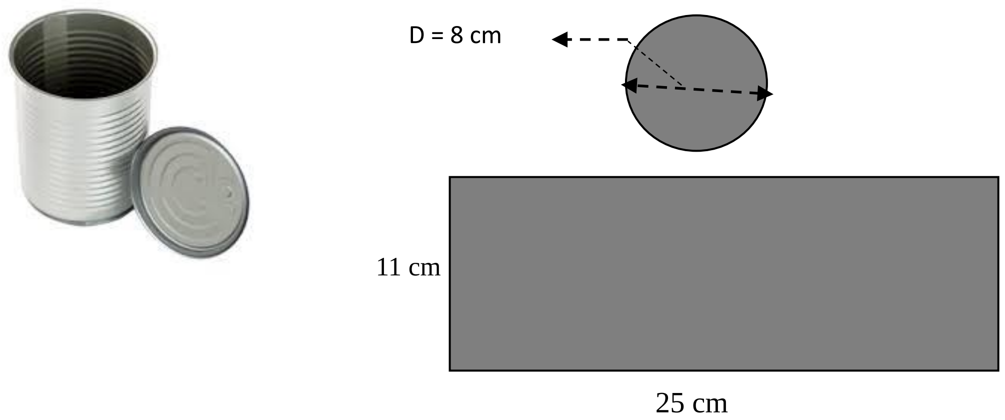

Figure 1. A typical can with its components for 400g canned food

The second line is the **can filling line**, which consists of several stages as illustrated in Figure 2. Description of each process is given in Table 1. The ***process line*** in the can filling line represents the main food preparation and filling section which includes soaking, washing, blanching, de-stoning, inspection, solid filling, and liquid filling. Failure data was collected for this line as a single process, like the can making section. The rest of the processes on can filling line are given in Figure 2 and described in Table 1.

The empty cans are moved by ***palletizer and de-palletizer*** for filling operation. Empty cans are de-palletized before entering the filling line. In the filling line, empty cans are sterilized by hot water and steam while preparing the beans. The liquid solution is prepared prior production hours. This is followed by ***seaming*** (seaming the other end of the can after it is filled and printing a date code on the lid). Rest of the processes can be seen in the table and the figure provided. To analyze maintenance operations, data related to equipment failures and repair were collected over a period of one year and fit to distributions using ARENA software, which has a data fitting capability.

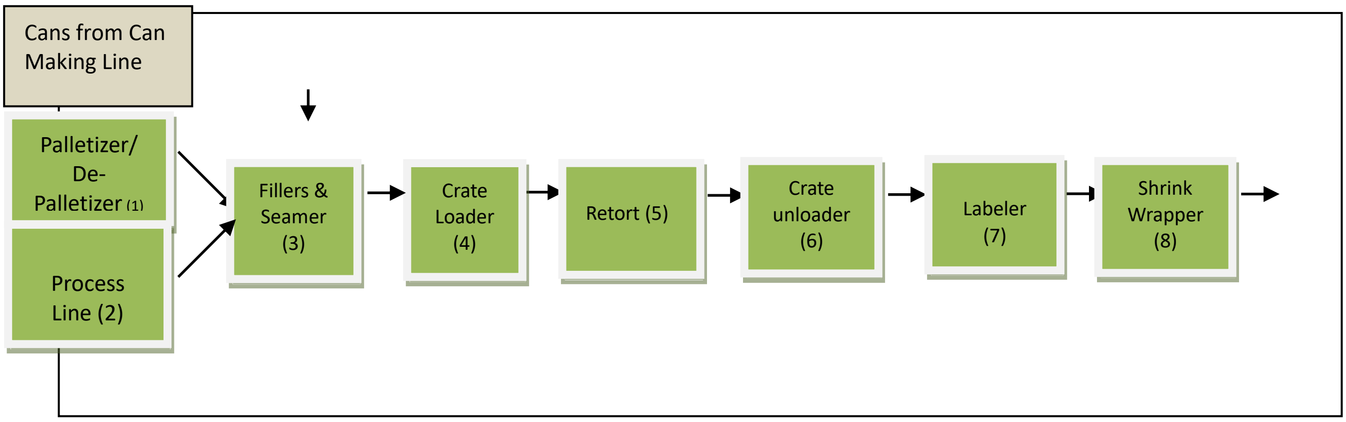

Figure 2: Schematic illustration of the structure of can filling line.

Table 1. Can filling line processes and process description

Process Name	Process Description
Soaking	The food is soaked for 8-14 hours in a hopper depending on the type of food (peas, kidney beans, mushroom, etc.). The factory has 5 hoppers, each with capacity of 3000 Kg (meat and corn do not go into process).
Reel washing	The food is cleaned by showering and the excess water is drained. The food is transported to the blancher by a bucket elevator.
Blanching	The food is blanched for 5 to 30 minutes to release gases and enzymes.
De-stoning	The food is moved to the de-stoner to remove stones.
Inspection belt	The food is sorted manually to remove any dark or broken pieces. The food is held in the filling hopper.
Solid filling	The empty cans are filled with solid food.
Liquid filling	A liquid solution is added to the can; it is vacuumed by shower filler machine under a temperature of 75 °C to 85 °C. This process makes the expiry date of the canned food longer and protects consumers.
Seaming	The other lid is seamed to the can using double seaming.
Coding	A code is printed on the lid of the can using the coding machine to show the production and expiration dates of the product.
Crate loading	700 cans are put on a crate, and 7 layers of crates are taken to sterilizing the stage by a trolley.
Sterilizing	The can in the crates is sterilized under a temperature of 121ºC. This process takes between 10 and 70 minutes depending on the type of product and the type of liquid used. Then, it is cooled suddenly to kill the remaining bacteria. The cans are then dried.
Crate unload	The cans are unloaded from the crate to the labeler.
Labeling	The cans are labeled by the labeling machine.
Label inspect.	Labels are checked to determine if they are applied correctly.
Packaging	12 cans are kept in a tray. Two trays are wrapped together by the shrink wrapper. Every 20 cartons are put one a pallet by 2 workers and 1 forklift.
Storing	The final products are stored for four days before a sample is taken to carry out three types of tests (physical, chemical and biological), ensuring that the product meets standard and is ready for distribution.

3. Analysis of Maintenance Operations

To analyze and improve maintenance operations of the canned food factory, it was necessary to first analyze the current practice, which included both corrective and preventive maintenances at required and scheduled times. The maintenance process analysis and improvement steps are outlined below:

1. Equipment failure and repair data are collected as time between failures for each machine and the repair times.
2. Expected values are calculated for the time between failures and the repair times (M_{ct}).
3. Mean time between failures (MTBF) are converted to failure rates (λ). MTBF=1\λ.
4. Mean time between preventive maintenances (PM) and PM rates are determined (f_{pt})
5. Cost related information are estimated to determine maintenance costs.
6. Total maintenance costs are calculated for each machine for both the corrective maintenance (CM) and the preventive maintenance (PM).
7. Production loss costs due to maintenance operations are estimated by estimating production rate per time unit and the revenue per product.
8. A model is used to determine the relation between CM and PM. This model helps to determine the effects of additional PM on the reducing CM. The following formula is used for this purpose, where λ=equipment failure rate; f_{pt} = Maintenance rate; and $MTBM_c$ is the combined mean time between maintenances when both CM and PM are applied.

$$MTBM_c=1/(\lambda+ f_{pt}) \quad [1]$$

9. Alternative maintenance policies are proposed, which reduce the need for CM.
10. Alternative policies are evaluated with respect to the total costs including the CM, the PM, and the production loss costs.
11. Production line reliabilities are determined based on parallel-series reliability calculations.
12. Equipment availabilities are estimated based on inherent, achieved, and operational availability measures to be discussed later.
13. Performance of maintenance policies are compared to the current practice with respect to costs, system reliability and equipment availabilities.

To analyze the production system, data related to equipment failures were collected over a period of two years and summarized in the form of failure distributions. Table 2 shows the time to failure distributions, mean time between failures (MTBF) and mean repair times for the production machines on the can filling line and the can making plant as a single process based on the failure data collected for a period. Mean Time Between Failures (MTBF) in Table 2 are calculated directly from the expected value of each distribution, which was exponential in all cases here estimated by the ARENA software (Kelton, et al. 2015).

Table 2. Mean time between failures (MTBF) of the machines and their repair times.

Machine	Time to Failure Distribution (Days)	MTBF (Days)	Failure Rate (λ)	Repair time (Minutes)- M_{ct}
Palletizer/De-Palletizer	EXPO (11.7)	11.7	0.085	30
Process Line	EXPO (7.87)	7.87	0.127	30
Fillers and Seamer	EXPO (5.5)	5.5	0.182	60
Crate Loader	EXPO (19.8)	19.80	0.051	5
Retort	EXPO (18.3)	18.3	0.055	30
Crate Unloader	EXPO (24.7)	24.7	0.04	5
Labeler	EXPO (7.05)	7.05	0.142	60
Shrink Wrapper	EXPO (14.5)	14.5	0.069	60
Can Plant	EXPO (4.66)	4.66	0.215	60

The factory applies two types of maintenances: Corrective Maintenance (CM) and Preventive Maintenance (PM). Corrective maintenances are unscheduled maintenance actions performed because of system failure to restore the system back to its initial condition. Failure rate is the inverse of MTBF given by λ = 1/MTBF. The failure rates are also given in Table 2. Average repair times are also given in the table in minutes. Most of the failures require relatively short repair times. Preventive maintenances are scheduled maintenance actions performed to retain a system in its specified condition. The canned food factory currently performs preventive maintenances once a month (every 26 days) during non-production hours and each maintenance takes 10 hours. Thus, the rate (or frequency) of preventive maintenance is given by f_{pt} =1/26 =0.0385 preventive maintenances/day.

Cost Calculations:

CM is done by one mechanical technician, one electrician and one helper. PM is done by two mechanical technicians, two electricians and two helpers. PM is applied during non-production days, and it lasts for 10 hours. Mechanical technicians and electricians are paid 680 $/month. Helpers are paid 200 $/month. Time duration for the preventive maintenance is 26 days/month*12 months/year*10 hours/year=3120 hours/year. Production rate of the filling line = 140 cans/min. Production rate of can making line=160 cans/min. Revenue/can = 0.93182 $/can. Thus, the CM and PM costs are calculated using the following formulas and the notations for each equipment.

Let:

N_f= Number of failures per year
T= Operation time per year (this was 3120 hours)
MTBF=Mean time between failures (MTBF=1/ λ)
M_{ct}=Mean corrective time per failure
C_h= repair cost per hour
M_p=Number of preventive maintenances per year
MTPM= Mean time between preventive maintenances.
f_{pt} = Meant preventive maintenance rate; f_{pt} =1/MTPM
M_{pt}= Mean preventive maintenance time per preventive maintenance action.
Q= Production rate in number of units or cans/min.
R= Revenue per unit or can

CM Cost/year= (Number of Failures/year)*(Repair Time per Failure)*(Cost per Time Unit).

CM Cost=N_t*M_{ct}*C_h = (T/MTBF)*M_{ct}*C_h [2]

PM Cost=N_p*M_{pt}*C_h= (T/MTPM)*M_{pt}*C_h [3]

Production Revenue Loss =Q*M_{ct}* (T/MTBF)*R [4]

Since the preventive maintenances are done during nonproduction times, there is no production loss cost due to preventive maintenances. Based on the combined mean time between maintenances ($MTBM_c$), including both CM and PM, as given by the equation [2] above, when the preventive maintenance rate (f_{pt}) is increased, the corrective maintenance rate (λ) must decrease. Effectively, increasing PM rates, the need for CM reduces proportionally assuming overall maintenance rate is kept constant. If the PM is performed monthly, in 26-days intervals, the failure rate would be the current λ_c as given in the fourth column of Table 3. By keeping the overall $MTBM_c$ constant, two alternative improvements to the maintenance procedures are proposed. The first alternative policy is to have a PM every 13 days (twice a month) during non-production period, with a rate of f_{pt1}=1/13 and the resulting failure rate of λ_1 given as ***Policy 1*** in the Table 3. If the PM could be made more frequently at 5-days intervals with a rate of f_{pt2}=1/5, which was possible for the Fillers and Seamer Machine and the Can Plant, the resulting failure rate λ_2 would be as in ***Policy 2*** in Table 3.

Table 3. Effects of preventive maintenance policies on equipment failures (three cases)

Machine	MTBM (Days)	Current Ploicy f_{ptc}	Current Policy λ_c	Policy-1 f_{pt1}	Policy-1 λ_1	Policy-2 f_{pt2}	Policy-2 λ_2
Palletizer/De-Palletizer	8.07	1/26	0.085	1/13	0.047	1/13	0.047
Process Line	6.04	1/26	0.127	1/13	0.089	1/13	0.089
Fillers and Seamer	4.54	1/26	0.182	1/13	0.143	1/5	0.020
Crate Loader	11.23	1/26	0.051	1/13	0.012	1/13	0.012
Retort	10.74	1/26	0.055	1/13	0.016	1/13	0.016
Crate Unloader	12.66	1/26	0.040	1/13	0.002	1/13	0.002
Labeler	5.54	1/26	0.142	1/13	0.103	1/13	0.103
Shrink Wrapper	9.30	1/26	0.069	1/13	0.031	1/13	0.031
Can Plant	3.95	1/26	0.215	1/13	0.176	1/5	0.053

Table 4 shows the costs associated with the current preventive maintenance policy and the resulting failure rates as well as the costs associated with production losses. The costs are calculated using the formulas given in maintenance procedures above in equations [2[-[4]. For example, the CM cost per year for the palletize/de-palletizer process would be calculated as: (3120/MTBF)*M_{ct}*Cost/hour=[3120(hours/year)/117(hours)]*(0.5hours)*(6 $/hour)=20 $/year. It should be noted that for this process one mechanic, one electrician and one helper is used with a total cost of 1560 $/month or 1560/26= 60 $/day or C_h=6 $/hour, since the system was operated 10 hours per day. M_{ct} is given in Table 2, and 3120 is the total operation hours per year. Similarly, all costs and revenues have been calculated and presented in the tables. The production loss cost was determined based on the time lost due to CM maintenance each year and the production rate of the line, which was 140 cans/min, and the revenue per can, which was 0.93182 $/can. The total Cost is obtained from the totals in the last row of the table as: Total Cost=CM cost + PM cost + Production revenue loss = 1401.00 + 1441.44 + 1,827,671.52 = 1,830,513.96 $/year. Majority of the cost is due to production revenue loss as a result of equipment failures.

Table 4. Costs due to PM, CM, and production losses (***Current Maintenance Policy***)

Machine	CM Cost ($/year)	PM Cost ($/year)	Production Loss Cost ($/year)
Palletizer/De-Palletizer	80.00	288.28	104363.84
Process Line	118.93	288.28	155153.36
Fillers and Seamer	340.36	144.16	444020.70
Crate Loader	7.88	72.08	10278.78
Retort	51.15	144.16	66724.42
Crate Unloader	6.32	72.08	8239.25
Labeler	265.53	72.08	346399.13
Shrink Wrapper	129.11	72.08	168433.26
Can Plant	401.72	288.28	524058.77
Total	1401.00	1441.44	1827671.52

4. Evaluation of Alternative Maintenance Policies

In order to reduce the operation costs due to maintenances, two new preventive maintenance (PM) policies were proposed. The first alternative PM Policy 1, which was the application of PM twice a month (every 13 days) with a preventive maintenance rate of f_{pt}=1/13=0.077 maintenances per day on all machines and the second PM Policy was to apply the PM every week (every 5 working days) on selected machines. Table 5 shows the calculated cost values for alternative Policy 1, which resulted in a reduction in failure rate (λ) for each machine as calculated by equation [1]. Total $MTBM_c$ is kept constant and the new λ value was calculated for the new f_{pt} value. The total cost for Alternative PM Policy 1 was calculated as: Total Cost = CM cost + PM cost + Production revenue loss = 993.44+2,879.88+1,29,5990.76= 1,299,864.08 $/year. Alternative Policy 1 reduced costs by 29% from the current policy costs.

Table 6 shows the calculated cost values for alternative PM Policy 2, which was the application of PM weekly on Fillers and Seamers Machine and the Can Plant, which received PM every 5 working days with a PM rate of f_{pt}=1/5=0.20 PM per day. All other machines received PM twice a month with an f_{pt}=1/13 as it was done in Policy 1. This was expected to result in more reduction in failure rates for the two machines and thus the costs. The total cost for Alternative PM Policy 2 was calculated as: Total Cost = CM cost + PM cost + Production loss cost = 532.63+ 3513.52+ 694,840.01= 698,886.15 $/year. The total cost was reduced from the present situation by 61.8% by this second PM Policy. While the PM costs were increased from 2879.88 to 3513.52, the production revenue loss was reduced 1,295,990.76 to 694,840.01, which was a huge reduction.

Table 5. Cost values for the equipment due to PM, CM, and production losses (Policy 1).

Machine	CM Cost (KD/year)	PM Cost (KD/year)	Production Loss Cost (KD/year)
Palletizer/De-Palletizer	44.04	575.96	57450.83
Process Line	82.97	575.96	108240.35
Fillers and Seamer	268.44	288.00	350194.69
Crate Loader	1.88	144.00	2459.94
Retort	15.19	288.00	19811.42
Crate Unloader	0.32	144.00	420.42
Labeler	193.61	144.00	252573.12
Shrink Wrapper	57.19	144.00	74607.25
Can Plant	329.80	575.96	430232.75
Total	993.44	2879.88	1295990.76

Table 6. Cost values for the equipment due to PM, CM, and production losses (Policy 2).

Machine	CM Cost (KD/year)	PM Cost (KD/year)	Production Loss Cost (KD/year)
Palletizer/De-Palletizer	44.04	575.96	57450.83
Process Line	82.97	575.96	108240.35
Fillers and Seamer	38.00	748.80	49619.31
Crate Loader	1.88	144.00	2459.94
Retort	15.19	288.00	19811.42
Crate Unloader	0.32	144.00	420.42
Labeler	193.61	144.00	252573.12
Shrink Wrapper	57.19	144.00	74607.25
Can Plant	99.39	748.80	129657.38
Total	532.63	3513.52	694840.01

Finally, a third PM policy was proposed, which was to apply PM just before a failure was expected to occur on a machine. This procedure is also referred to as ***Reliability Centered Maintenance (RCM)***. In this case, a PM is applied according to the expected failure times of equipment based on MTBF. Table 7 shows the MTBF of the equipment and the suggested mean time between preventive maintenance (MTBPM), which is just before a failure occurs for each machine. This is rather a hypothetical situation since it is not known when the failure will occur. However, we plan to apply the PM before the expected time of the failure. If a failure occurs before the PM, a CM can be applied. Using the formula $MTBM_c=1/(\lambda+f_{pt})=1/((1/MTBF)+(1/MTBPM))$, with the current $MTBM_c$ and the new MTBPM, new MTBF values are obtained. Failure rate λ, which is the inverse of the new MTBF achieved as a result of new PM, are given for each equipment or the process in the last column of Table 7, i.e., λ=1/New MTBF. Finally, Table 8 shows the cost figures for PM, CM, and production revenue losses for this last PM Policy, which is based on RCM. The total cost for this Alternative PM Policy 3 was calculated as: Total Cost=CM cost+PM cost+Production revenue loss= 383.64+1440.00+500,491.48 = 502,315.12 $/year. The total cost was reduced by 72.56% from the original or the currently used PM Policy by using RCM policy.

Table 7. Parameters for Alternative PM Policy based on ***Reliability Centered Maintenance***

Machine	MTBF	MTBPM	New MTBF	Failure Rate-λ (Failures/day)
Palletizer/De-Palletizer	11.7	11.6	26.51	0.038
Process Line	7.87	7.77	27.15	0.037
Fillers and Seamer	5.5	5.4	28.49	0.035
Crate Loader	19.799	19.70	26.17	0.038
Retort	18.3	18.20	26.20	0.038
Crate Unloader	24.7	24.60	26.11	0.038
Labeler	7.05	6.90	28.27	0.035
Shrink Wrapper	14.499	14.40	26.33	0.038
Can Plant	4.66	4.56	29.62	0.034

Table 8. Cost values due to PM, CM, and production losses ***(Policy 3-RCM).***

Machine	CM Cost (KD/year)	PM Cost (KD/year)	Production Loss Cost (KD/year)
Palletizer/De-Palletizer	35.32	288.00	46,064.04
Process Line	34.48	288.00	44,966.92
Fillers and Seamer	65.68	144.00	85,704.84
Crate Loader	5.96	72.00	7,775.12
Retort	35.72	144.00	46,597.12
Crate Unloader	5.96	72.00	7,793.80
Labeler	66.24	72.00	86,397.04
Shrink Wrapper	71.12	72.00	92,757.68
Can Plant	63.20	288.00	82,434.92
Total	383.64	1440.00	500,491.48

5. Reliability Analysis of the Lines

Reliability is the probability that the system will perform in a satisfactory manner for a given period of time, when used under specified operating conditions. Reliability is calculated by the following equation for the exponential time to failures.

$$R(t) = e^{-\lambda t} \quad [5]$$

where λ is the failure rate of the equipment given in Table 2 and t is the time period of operation during which equipment reliability is to be calculated. Based on the failure rates of the machines given previously in Table 2, reliability of each machine is calculated for a period of one day (t=1). Related reliabilities are shown in Table 9. In order to see the effects of four maintenance policies on machine reliabilities, failure rates (λ_c, λ_1, λ_2, λ_3) under each maintenance policy are used to determine the machine reliabilities (R_{pc}, R_{p1}, R_{p2}, R_{p3}) under the same four maintenance policies. The subscript c indicates the current maintenance policy. The results are shown in Table 10. Machine reliabilities have been increased for each alternative as a result of new alternative PM policies. As it is seen in Table 10, equipment reliabilities are significantly increased with the new maintenance policies. The reliabilities have increased to more than 96% for all equipment and process when RCM (PM Policy 3) is applied. These increases are directly reflected in an increase in line reliability and consequently in system productivity.

Table 9. Failure rates and reliabilities of machines over a period of one day-current plan.

Number (i)	Machine	Failure Rate λ_i (Failure/day)	Reliability over one day (%) $R_i(t)$
1	Palletizer/De-Palletizer	0.085	91.81
2	Process Line	0.127	88.07
3	Fillers and Seamer	0.182	83.38
4	Crate Loader	0.051	95.07
5	Retort	0.055	94.68
6	Crate Unloader	0.040	96.03
7	Labeler	0.142	86.78
8	Shrink Wrapper	0.069	93.34
	Can Plant	*0.215*	*80.69*

Table 10. Failure rates and reliabilities of each machine for the Three Alternatives.

Machine	λ_c	R_{pc} (t)	λ_1	R_{p1} (t)	λ_2	R_{p2} (t)	λ_3	R_{p3} (t)
Palletizer/De-Palletizer	0.085	0,919	0.047	95.40	0.047	95.40	0.038	96.30
Process Line	0.127	0,881	0.089	91.52	0.089	91.52	0.037	96.38
Fillers and Seamer	0.182	0,834	0.143	86.64	0.020	97.99	0.035	96.55
Crate Loader	0.051	0,950	0.012	98.80	0.012	98.80	0.038	96.25
Retort	0.055	0,946	0.016	98.39	0.016	98.39	0.038	96.26
Crate Unloader	0.04	0,961	0.002	99.79	0.002	99.79	0.038	96.24
Labeler	0.142	0,868	0.103	90.17	0.103	90.17	0.035	96.52
Shrink Wrapper	0.069	0,933	0.031	96.99	0.031	96.99	0.038	96.27
Can Plant	0.215	0,807	0.176	83.85	0.053	94.83	0.034	96.68

System Reliability for the Can Filling Line:

Based on equipment reliabilities, reliability of each line is calculated depending on the structure of the line. In case of the can plant, which is considered as a single process in our study, system reliability is given in the last row of Table 9 as 80.69% for a single day under the current operational state. For the can filling line, system reliability is calculated based on the structure of line with equipment being in parallel and in series structure. Calculations are made for each maintenance policy. In the can filling line, the line structure is shown in Figure 2. Palletizer and the Process Line operate in parallel, while rest of the machines operate in series with these two. Thus, using the parallel-series unit configurations for reliability calculation, reliability of the can filling line is obtained under the current operational state and under the three maintenance polices. Time duration is considered as t=1 day. In the calculations below, $R_i(t)$ represents the reliability for equipment i and λ_i represents the failure rate of equipment i. In order to simplify the formulation, the t value in the parenthesis is dropped since it is equal to 1 for all equipment.

For ***n parallel*** equipment or components, system reliability is given by:

$$R_s(t)=1-\{[1- R_1(t)][1- R_2(t)]\ldots\ldots[1- R_n(t)]\} \quad [6]$$

For ***n series*** equipment or components, system reliability is given by:

$$R_s(t)=[R_1(t)][R_2(t)]\ldots\ldots[R_n(t)] \quad [7]$$

Current Operational State and Maintenance Plan

From Table 9 and Figure 1, reliability of the can filling line is calculated as follows:

$$R_{sc}(t) = [1-(1-R_1)(1-R_2)] (R_3) (R_4) (R_5) (R_6) (R_7) (R_8)$$
$$= [1-(1-0.9181)(1-0.8807)](0.8338)(0.9507)(0.9468)(0.9603)(0.8678)(0.9334) = 0.5781 = 57.81\%.$$

Proposed Maintenance Plan-Alternative 1:

From Table 11 and Figure 7, reliability of the filling line under PM policy 1 is as follows:

$$R_{s1}(t) = [1-(1-R_1)(1-R_2)] (R_3) (R_4) (R_5) (R_6) (R_7) (R_8)$$
$$= [1-(1-0.954)(1-0.9152)](0.8664)(0.9880)(0.9839)(0.9979)(0.9017)(0.9699) = 0.7322 = 73.22\%.$$

Proposed Maintenance Plan-Alternative 2:

From Table 11 and Figure 7, reliability of the filling line under PM policy 2 is as follows:

$$R_{s2}(t) = [1-(1-R_1)(1-R_2)] (R_3) (R_4) (R_5) (R_6) (R_7) (R_8)$$
$$= [1-(1-0.954)(1-0.9152)](0.9799)(0.9880)(0.9839)(0.9979)(0.9017)(0.9699) = 0.8281 = 82.81\%.$$

Proposed Maintenance Plan-Alternative 3:

From Table 11 and Figure 7, reliability of the filling line under PM policy 2 is as follows:

$$R_{s3}(t) = [1-(1-R_1) (1-R_2)] (R_3) (R_4) (R_5) (R_6) (R_7) (R_8)$$
$$= [1-(1-0.9630) (1-0.9638)](0.9655)(0.9625)(0.9626)(0.9624)(0.9652)(0.9627) = 0.7989 = 79.89\%.$$

From these results, it is calculated that system reliability is increased by 26.65% under the PM Policy 1; by 43.24% under the PM Policy 2, and by 38.19% under the PM Policy 3. The increase in reliability is directly reflected in productivity increase. In this case Policy 2 was better than RCM Policy. The results are summarized in Table 11.

Table 11. Production line reliabilities under different maintenance policies

Maintenance Policy	Line Reliability
Current Policy-Apply PM Monthly	57.81%
Alternative Policy 1-Apply PM Bimonthly	73.22%
Alternative Policy 2-Apply PM weekly	82.81%
Alternative Policy 3-Apply RCM (Reliability Centered Maintenance)	79.89%

6. Conclusions

This paper has analyzed maintenance operations in a canned food factory. A procedure is outlined to determine the effects of different maintenance policies on the production line performance, which was measured by production costs and system reliability. Four different maintenance polices, including the current policy, have been evaluated and the results are compared. The factory practiced corrective maintenance and monthly preventive maintenances. Three new preventive maintenance policies were proposed, including reliability centered maintenance (RCM). It was found that reliability centered maintenance significantly improved production line performance with respect to cost factors. However, applying weekly PM performed better than all other policies with respect increasing system reliability. The procedure outlined and the basic models and calculations used in this paper could be followed by operation managers and maintenance engineers to improve performance of their production systems with respect to maintenance operations.

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