NTNU – Trondheim
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Department of Production and Quality Engineering

Examination paper for TPK4140 Maintenance Management

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Examination date:	**15 December 2014**
Examination time (from-to):	**09.00 – 13.00**
Permitted examination support material:	**D (**No printed or hand-written support

material is allowed. A specific basic calculator is allowed)

Other information:

Students are free to answer the written examination in Norwegian or English.

Written examination result counts 60 % and mandatory work counts 40 % of the final grade awarded.

Language:	**English**
Number of pages:	**5 (front page included)**
Number of pages enclosed:	**0**
Evaluation deadline:	**15 January 2015**

Exam paper quality check:

Checked by:

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10.12.2014 KE Dalle

Date Signature

Problem 1 (25 %)

a) Explain the meaning of:

- Proactive maintenance
- The P-F interval
- Life cycle cost
- TPM

b) Explain the difference between unplanned maintenance and preventive maintenance. Discuss the meaning of "class of condition monitoring".

c) Present a maintenance objective for an offshore company which want to be leading in condition monitoring and proactive maintenance.

d) Present a maintenance management model/loop. Will safety be a part of this loop?

Problem 2 (25 %)

a) Explain the meaning of OEE. How can risk and accidents influence the OEE value?

b) Discuss the difference between maintenance cost and value added maintenance, and explain how you can calculate availability cost and profit loss.

c) Present how we can reduce the maintenance cost and downtime with utilisation of Integrated Planning.

d) Present minimum 5 KPIs (Indicies) for maintenance for an offshore company. Explain how analyses of KPIs can be a part of a maintenance audit.

Problem 3 (25 %) – (Only a), b) &c))

Figure 1 shows a process system with a valve arrangement to control the volume and pressure in a vessel. The basic process control system comprises a level transmitter (LT) to report level to a computer (CPU1). The computer processes the signal, and sends signal to the level control valve (LCV). If the basic process control system fails, the level in the vessel may start to increase. In this case the pressure will also start to increase, and a pressure transmitter (PT) sends information regarding the pressure to a second computer (CPU2), which processes the information, and a signal is sent to the process shutdown valve (PSDV). In case of failure of the process shutdown system, a mechanical pressure safety valve (PSV) is designed to open and send the process medium to a flare.

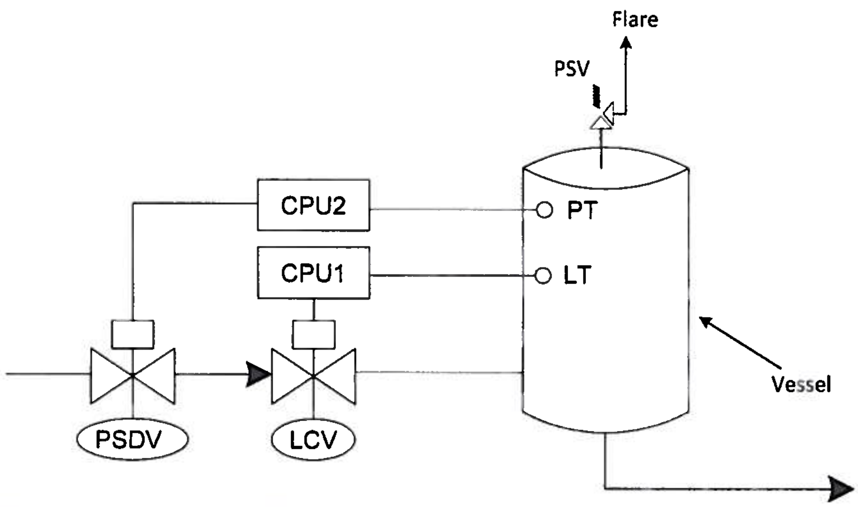

Figure 1 Process system with valve arrangement

In this problem we will only consider the LCV and the PSDV. Other components are not considered explicitly. Upon a failure of the LCV we assume that there always will be a production disturbance, and the cost of this is C_{Trip} = **50 000 NOKs**. If the PSDV is functioning, we assume that safety is controlled, but there will be a production loss of C_U = **20 000 NOKs** per hour while production is down. Mean downtime is initially considered to be **MDT = 8 hours**. If the PSDV is not functioning, this results in a safety critical event. The cost of such an event depends on the functioning of the PSV. However, an average consideration is made, and it is assessed that a failure of the PSDV in average will cost C_H = **10 million NOKs.**

The LCV is assumed to have an increasing failure rate function, $z(t)$. The effective failure rate is assessed to be $\lambda_E(\tau) = 0.71\ \tau^2 / \mathrm{MTTF}^3$, where τ is the preventive maintenance interval, and MTTF is the mean time to failure for the LCV if no preventive maintenance action is performed. For the LCV we assume that **MTTF = 2 years** (one year equals 8760 hours). The cost of a preventive maintenance action for the LCV is C_{PM} = **15 000 NOKs**. The cost of a repair action upon a failure of the LCV is C_{CM} = **30 000 NOKs.**

The PSDV is assumed to have a constant failure rate equal to $\lambda = 10^{-5}$ **per hour**. Since the PSDV has a hidden function, it is proof tested with intervals of length τ, and the resulting probability of failure on demand is given by **PFD** = $\lambda\tau/2$. The cost of a proof test is assumed to be C_{PT} = **3 000 NOKs.**

To distinguish the two maintenance intervals we will in the following introduce the notation τ_{PM} to denote preventive maintenance interval of the LCV, and τ_{PT} to denote proof test interval of the PSDV.

Initially we assume that $\boldsymbol{\tau_{PT} = 6}$ **months.**

a) Derive the cost function used to optimize the maintenance intervals, i.e., a function of both τ_{PM} and τ_{PT}.

b) Find an optimal value of τ_{PM} given that we have a fixed value of $\tau_{PT} = 6$ months. Make a sketch of the cost function as a function of τ_{PM} to verify the optimal value.

c) Now, we are going to reconsider the proof test interval, τ_{PT}. Find an optimal value of τ_{PT} given that τ_{PM} is the same as in problem b) above.

Problem 4 (25 %)

It is proposed to use condition monitoring to reveal potential failures of the LCV. A portable acoustic device could be mounted on the LCV to reveal damages in the valve seat. The cost of an inspection by the acoustic devise is C_I **= 2 000 NOKs**. If a potential failure is revealed during inspection, the cost of improving the valve is assumed to be the same as for the preventive task, i.e., C_{PM} **= 15 000 NOKs**.

It is assumed that a potential failure in average could be revealed after one and a half year, i.e., the rate of potential failures is assumed to be $f_P = 7.6 \cdot 10^{-5}$ **per hour**. The probability of revealing a failure as a function of the inspection interval τ_I is denoted $Q_0(\tau_I)$. $Q_0(\tau_I)$ is tabulated in Table 1.

Table 1 Tabulated values of $Q_0(\tau_I)$

τ_I	$Q_0(\tau_I)$
500	2.6E-04
1000	6.8E-03
1500	2.8E-02
2000	6.2E-02
2500	1.0E-01
3000	1.5E-01
3500	1.9E-01
4000	2.3E-01

The effective failure rate is now given by $\lambda_E(\tau_I) = f_P\, Q_0(\tau_I)$ and the rate of improvements upon potential failures is given by $\rho_E(\tau_I) = f_P\,(1-Q_0(\tau_I)) \approx f_P$.

a) Modify the cost equation and find the optimal inspection interval, τ_I. Does condition monitoring pay off. You may use the simplification formula for $\rho_E(\tau_I)$, and you may assume **MDT = 8 hours** and τ_{PT} **= 6 months**.

b) Apply the RCM decision logic for the following situations: (i) the LCV given that acoustic monitoring is appropriate, (ii) the LCV given that acoustic monitoring is not appropriate, and (iii) the PSDV.

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c) Discuss how reduction of the six big losses is a part of continuous improvement, and explain shortly how RCM can be used for reducing the six big losses.

d) Describe a modern maintenance organisation structure and a future CMMS (Max 1 page).