Optimization of Availability and Cost for the Heating System in an Oil Refinery through CTNHSMP and SA

Paulo Alves Firmino, M.Sc.
Márcio das Chagas Moura, M.Sc.
Enrique López Droguett, Ph.D.

9th International Probabilistic Safety Assessment and Management Conference (PSAM 9), Hong Kong-China on May 18-23, 2008

Heating System

- *A considerable attention has been devoted to the development of optimal preventive maintenance policies;*

- *HS plays an important role by directly influencing the refinery mean availability;*

Heating System

- *HS comprises one subsystem of two motor-driven pumps and one turbine-driven pump;*

- *The former is responsible for heating 100% of water that comes from AFWT, whereas the latter is kept on standby and able to perform the motor-driven subsystem’s function in case of failure;*

Heating System

- *HS has components that might have intensity functions dependent on the process (global) time;*
- *Moreover, some of these components exhibit non-exponential times to failure;*
- *Assumptions commonly used:*
  - *Perfect repair – Renewal Process;*
  - *Minimal repair – Non-homogeneous Poisson Process;*
  - *General or imperfect repair – Generalized Renewal Process;*
  - *Memoryless Markovian Process;*
  - *Homogeneous semi-Markov process;*

Heating System

- *Non-homogeneous semi-Markov processes rise as an alternative to these models;*

- *To develop an optimal preventive maintenance policy for the standby turbine-driven pump subsystem in order to optimize the heating system mean availability and maintenance costs;*

- *Simulated annealing;*

Presentation Outline

- *Continuous time Non-homogeneous semi-Markov processes (CTNHSMP);*
- *Mathematical programming problem;*
- *Simulated Annealing;*
- *Example of application;*
- *Conclusions;*

CTNHSMP

- *In a CTNHSMP, transitions between two states may depend not only on such states and on the sojourn times (x), but also on both times of the last (τ) and next (t) transitions, with x = t - τ ;*

- *According to Moura and Droguett(2008), the state probabilities $\phi_j(t)=Pr[Z_t=j \mid Z_0]$ are given by:*

$$\phi_j(t) = \phi_j(q0)\exp\left(-\int_0^t \lambda_j(ql, q0)\,dl\right)$$
$$+\int_0^t h_{rj}(q\tau)\exp\left(-\int_0^{t-\tau} \lambda_j\big(q(\tau+l), q\tau\big)dl\right)d\tau.$$

CTNHSMP

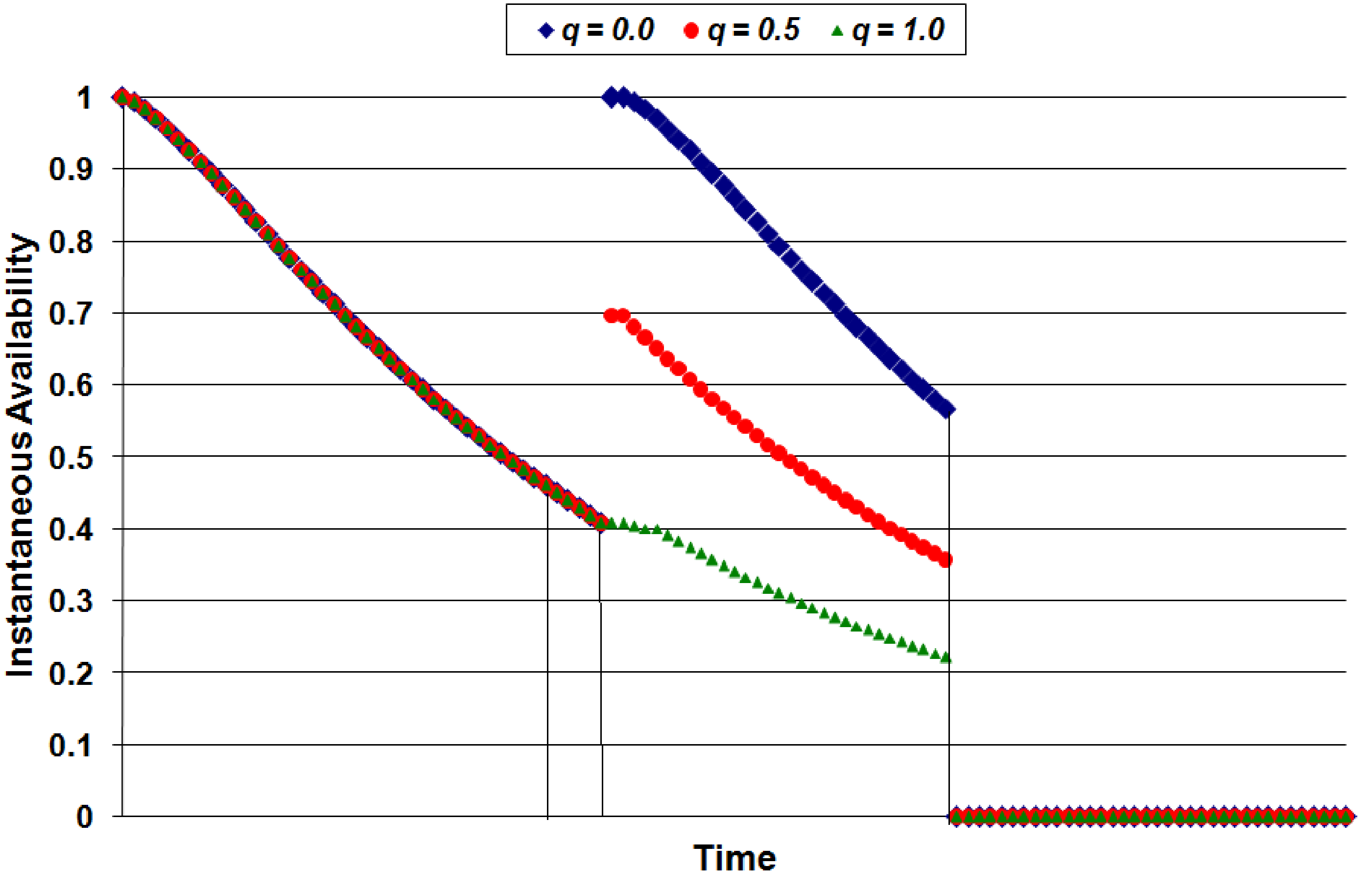
- *where:*

$$h_{rj}(t) = \sum_{i=1}^{N} \phi_i(q0) \exp\left(-\int_0^t \lambda_i(ql, q0)\, dl \right) \lambda_{ij}(qt, q0)$$

$$+ \sum_{i=1}^{N} \int_0^t h_{ri}(q\tau) \exp\left(-\int_0^{t-\tau} \lambda_i(q(\tau + l), q\tau)\, dl \right) \lambda_{ij}(qt, q\tau)$$

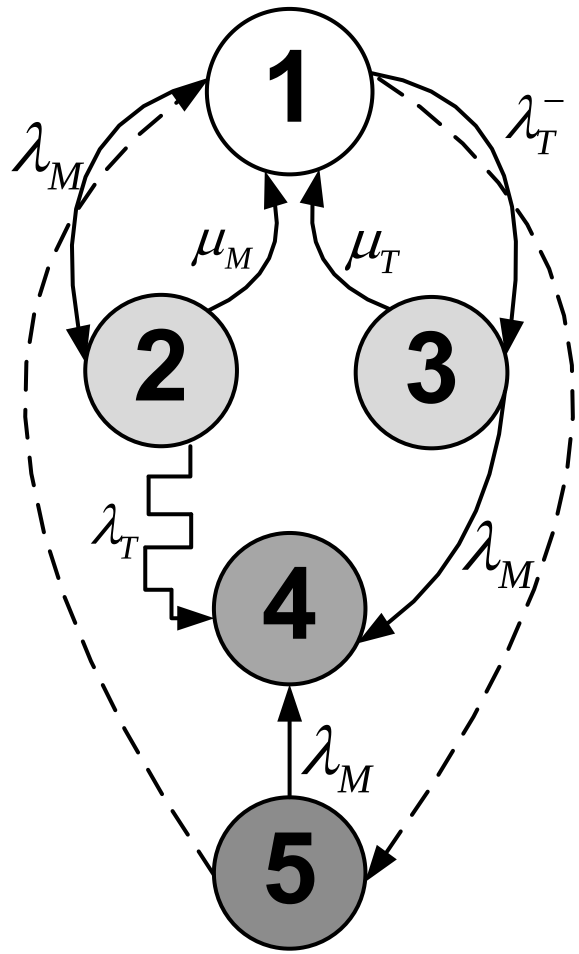
- *$x = t - \tau$ – sojourn time;*
- *$h_{rj}(t)dt$ - pr{to reach state j in (t, t+dt)};*
- *$\lambda_{ij}(t,t_{tr})dx$ – transition rate of a CTNHSMP;*
- *q – rejuvenation parameter: measures the effectiveness of a maintenance action;*

CTNHSMP



- *Impact of different types of repair on the instantaneous availability*

CTNHSMP for the Heating system



CTNHSMP

- *The proposed approach gives a preventive maintenance policy which maximizes the mean availability of a CTNHSMP. It also takes into account the impact q of each maintenance action on the system:*

$$\overline{A} = \frac{1}{t} \sum_{k \in \{A\}} \int_0^t \phi_k(\tau)\, d\tau$$

- *The optimization procedure is accomplished by using simulated annealing;*

Mathematical programming problem

$$\text{Maximize } F = \alpha \cdot \bar{A}(T \mid \boldsymbol{t}) - \beta \cdot [\, c_p \cdot n_p \cdot E(T_p) + c_c \cdot E(T_c)] \,/\, K$$

$$T, K > 0,\ \ \alpha\ \ [0, 1],\ \ \beta = 1 - \alpha \text{, and } n\ \ \mathbf{N},$$

- *T is the mission time;*
- ***t** : a preventive maintenance policy for the standby subsystem;*
- *A(T* **|** ***t**): system mean availability in T;*
- *n_p: number of preventive maintenance actions;*
- *c_p and c_c: costs per time unit to perform preventive and corrective maintenance;*
- *$E(T_p)$: expected time to perform one preventive maintenance;*
- *$E(T_c)$: expected time to perform one corrective maintenance;*
- *α and β: weighting parameters for A(T* **|** ***t**) and C(T* **|** ***t**), respectively;*

Simulated Annealing

- *SA mimics the annealing of solids;*

- *The probability of changing from another point inside a neighbourhood decreases as the simulation time increases;*

- *Parameters:*
  1. *IT: initial temperature of the solid;*
  2. *CR: cooling rate of the solid;*
  3. *TL: a temperature level for which the solid is considered cooled;*
  4. *VL: a variability measure for which the entropy of the solid is considered minimal;*
  5. *BT: burn-in time;*
  6. *NS: neighbourhood size.*

Heating System Optimization

- *Required Data – Estimation of parameters of CTNHSMP $\lambda_{ij}(l,t)$:*

Transition $i \to j$	**Estimators of the sojourn time distributions $\lambda_{ij}(l,t)$**
$1 \to 2$	**Weibull (10.0, 1.5)**
$1 \to 3$	**Exponential (1E-03)**
$2 \to 1$	**Exponential (1.0)**
$3 \to 1$	**Exponential (1.0)**
$2 \to 4$	**Weibull ((-0.08 *t*) + 10.0, 2.0)**
$3 \to 4$	**Weibull (5.0, 2.0)**
$4 \to 5$	**Weibull (10.0, 1.5)**

Results and discussion

- *Case 1:*

Par	*q*	*α*	*β*	*K*	*T*	*E(T p)*	*Δ*	*C p*	*C c*
Value	**0**	**1**	**0**	**1000**	**180**	**1**	**10**	**40**	**100**

- Maintenance actions are expected to be approximately evenly spaced through the mission time and as frequent as possible;
- Proposed policy: ***t*** = (9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00, 9.00);

Metric	Value
number of runs	20
best	0.99886139
median	0.998455868
mean	0.998354488
standard deviation	0.000369214
worst	0.997644825

Results and discussion

- *Case 2:*

Par	q	α	β	K	T	$E(T_p)$	Δ	C_p	C_c
Value	0.75	0.9	0.1	1000	180	1	10	40	100

- Proposed policy:

$\boldsymbol{t}$ = (89.00,19.00, 9.00, 9.00);

Metric	Value
number of runs	20
best	0.78884366
median	0.78657693
mean	0.78629562
standard deviation	0.00163005
worst	0.78345701

Conclusions

- *The modelling of the system dynamics via continuous time non-homogeneous semi-Markov processes combined with the concepts of generalized renewal processes in measuring the impact of maintenance actions provide a more realistic approach;*

- *The adoption of a heuristic, such as Simulated Annealing, allows one for specializations of the mathematical programming problem;*

- *…*

Optimization of Availability and Cost for the Heating System in an Oil Refinery through CTNHSMP and SA

Paulo Alves Firmino, M.Sc.
Márcio das Chagas Moura, M.Sc.
Enrique López Droguett, Ph.D.

9th International Probabilistic Safety Assessment and Management Conference (PSAM 9), Hong Kong-China on May 18-23, 2008