Simulation Model for Availability Estimation of Water Supply Pumping System

Pratheeba Paul[1] Paul Robert T[2]
[1, 2]Professor
[1]Dept of Civil Engg [2]Dept. of Industrial Engg.
[1]Hindustan Institute of Technology & Science, Padur, INDIA
[2]College of Engineering, Anna University, Chennai, INDIA

Abstract---Availability of drinking water supply system is an important measure to be considered as desired quantities of water should be delivered from a water supply pumping system to all consumers at their tapping points throughout its design life. The uncertainty in the performance characteristics of mechanical components in the water pumping system such as motor, pump, and control valves affect the system availability. The reliability and maintainability of the components in the pumping system have an impact on the availability of this critical infrastructure. A Fault Tree analysis integrated with a simulation model to determine the availability of the water supply pumping system is presented in this paper. Several failure modes of various components in the water supply system are studied. The simulation results help to identify the critical pumping system elements that need more maintenance effort.

Keywords - Water supply Pumping System, Fault Tree, Simulation, and Availability.

I. INTRODUCTION

Water supply pumping systems are critical mechanical systems that require extensive maintenance to ensure that the system is available and also reliable to deliver the required quantity of water to the consumers. The availability assessment of such system directly relates to its function, i.e., delivery of the specified quantity of water to a specific location at the required time under the desired pressure [1]. Availability demonstration of a water pumping system is concerned with the availability of all the electro-mechanical components in this system, which can be computed from the failure probabilities of these components. Availability is a design parameter which is a function of reliability and maintainability. Research has addressed several studies on reliability of such systems. In general, the reliability of water supply system is dependent on the operating behavior of the components of the pumping system. Deshpande [2] presented an analytical method based on loss-of-demand probability for reliability analysis of pumping systems. Duan and Mays [3] proposed a methodology for the reliability analysis of pumps for water supply systems which considered mechanical failures and modelled the availability capacity of a pumping station as a continuous-time Markov process. Ostfeld, Koran and Shamir [4] have demonstrated the use of stochastic simulation for reliability analysis of water supply system, taking into account the hydraulic reliability considerations. However the mechanical reliability is important in order to ensure hydraulic reliability.

Duan and Mays [3] and Cullinane, Lansey and Mays [5] have proposed availability models to evaluate the performance of given water supply system... These approaches allow a modeler to compute the reliability of a system and account for factors such as the probability and duration of pump failure. It is found from the literature that availability analysis of pumping system with mechanical components such as motor and the pumps has been carried out considering the two states of the system, i.e., working condition and shutdown condition [5]. Failure analysis of a water distribution infrastructure with pipe network and junction joints that deteriorate over time was carried out by Pratheeba Paul and Ambujam [6]. Failure Modes and Effect Analysis (FMEA) was done to rank the components and failure events based on risk priority index and the critical components and the critical failure modes were identified using Pareto ranking. Literature review reveals that the availability demonstration of pumping system for delivery of drinking water is seldom reported. In this study, the availability assessment considering the different modes of failure of pumping system used for the supply of drinking water to the customers is carried out. A simulation model to determine the availability of the water pumping system is presented. The proposed approach takes in to account the random failure of its multiple components to evaluate the pumping system performance.

II. AVAILABILITY AS A PERFORMANCE MEASURE

Availability is defined as "the item's capability of being used over a period of time", and the measure of an item's availability is "that period in which the item is in a usable state" [7]. Availability is expressed as the probability that a system or component is performing its required function at a given point in time or over a stated period of time when operated and maintained in a prescribed manner [8]. Availability *A(t)* of a component at time *t* is the probability that it is in a working condition at time *t*, given that the component was as good as new at time zero. The Availability may be defined as:

$$A_{inh} = \frac{MTBF}{MTBF+MTTR} \quad (1)$$

It is the probability that a system will operate satisfactorily at any time when used under stated conditions in an ideal support environment without consideration for preventive action. The "ideal support environment" refers to, exists when the stipulated tools, parts, skilled manpower, manuals, and other support items required are available [8]. It is based on the failure distribution and the repair-time distribution. And so it is viewed as an equipment design parameter, and reliability-maintainability trade-offs can be based on this interpretation.

III. PERFORMANCE VARIABLES FOR AVAILABILITY DEMONSTRATION

The key performance variables relating availability to reliability and maintainability are concerned with the measures of time that are subject to equipment failure. These measures are mean time between failures (MTBF) and mean time to repair (MTTR). Designing for availability thus incorporates an assessment of 'expected performance' with respect to the performance measures of MTBF and MTTR, in relation to the performance capabilities of the equipment [7]. Hence the data required for the study are the failure rate, which is the reciprocal of MTBF, and the repair time. They are defined as given below:

- *Failure rate*: The failure rate is assumed to relate to the useful-life (constant failure rate) phase and to include all those failures, which cause changes in the operating states.
- R*epair time*: This is the time required to reach the faulty component and to repair it or replace it by a new component. The *mean time to repair* (MTTR) is the expected time to perform a restoration task on a system after a malfunction, whether or not the system is down for all or part of the restoration.

There is less data available on pump breaks. Damelin, Shamir and Arad [9] used some field data in a simulation of a water distribution system with only pump failures and fitted an exponential distribution for pump break inter-arrival times. The failure data were based on inter-arrival times of working hours, which did not include times when the pumps were inoperative due to scheduled outages for maintenance.

In this study, the failure and repair time data were collected from the in house maintenance history available in the pumping station and from the published data [10]. The procedure for identifying the possible failures events/modes in the pumping system is based on the analysis of data obtained from the maintenance section of the station. Several failure modes and events that can cause complete or partial failure of pumping station are identified. Fault tree is then constructed for pumping system failure with all possible failure events and is shown in Fig.1.

IV. SIMULATION MODEL

In order to determine the system availability of the water supply pumping system considered in the study, it is necessary to develop a model based on the failure history data and the inter dependency of the various failure modes. The availability characteristic of the pumping system depends largely on the failure behaviour of all the components in the pumping system. The first step is to identify the dominant failure modes for the water supply pumping system. The dependency between the failure modes for the occurrence of a failure event is then studied by constructing the fault tree. Monte Carlo simulation experiment is carried out to estimate availability.

A. Assumptions Made In the Model

The following assumptions are made in the simulation model of the pumping system.

- The time between failures follow exponential distribution.
- The repair times follow exponential distribution.
- One repair crew is continuously available.
- Each component after a repair action returns to 'as good as new' state.
- Pumping system design life is 30 years.

B. Simulation Scheme

Initially the values of failure times and the repair times of the various components and failure events are generated from the exponential probability density function. The failure event is classified as critical or not based on whether it causes system failure or not. If a failed component causes the pumping system to completely fail, then that component is taken for repair immediately. Else, the component is made to wait for service. The system is restarted after that component is repaired. Since design life of the water pumping station is about thirty years, simulation is terminated after the simulation time reaches thirty years. The logic flow chart of the simulation carried out on this water supply pumping system in order to evaluate the availability of the pumping system is shown in Fig. 2.

V. RESULTS

The design life of the water supply pumping system is thirty years and so simulation is terminated after the simulation time reaches thirty years. The simulation is replicated over a number of 100 runs and the water pumping system availability is estimated to be 0.8745. The effect of deterioration due to age of the system on its availability is then studied. The impact of age on the availability of the water supply system is given in Table 1.

Age (yr)	**A_{inh}**	**Age (yr)**	**A_{inh}**	**Age (yr)**	**A_{inh}**
5	0.9784	15	0.9281	25	0.8922
10	0.9427	20	0.9024	30	0.8745

Table. 1: Effect of Age on Availability

VI. CONCLUSION

A simulation based model to evaluate the system availability of a water supply pumping system is presented. Dominant failure modes are investigated using Fault Trees and important model parameters such as the mean time to failure and mean time to repair are considered. Simulation is performed for a period of thirty years since the design life of pumping system is thirty years. The water supply pumping system availability is estimated to be 0.8745. The proposed model can be used as a guide to set goals for effectiveness of the water supply system and to evaluate and challenge the current maintenance policy. Changes in the motor and pump-related parameters can be studied as options for downtime reduction. The alternatives such as minimizing the MTTR and increasing the MTBF of the components and their effects on the system performance can be studied.

REFERENCES

[1] Duan N.M.J, Lansey K.E. and Mays L.W. "Optimal reliability based design and analysis of pumping systems of water distribution systems", Jl. of Hydraulic Engg, Vol. 116. No. 2, pp.211-229, 1990.

[2] Deshpande A.W. "Reliability analysis of pumping system", Journal of Indian Water Works Association, Vol.22, No.1, pp.69-73, 1990.
[3] Duan N. and Mays L.W. "Reliability analysis of pumping systems", Jl. of Hydraulic Engg, Vol.116. No.2, pp.230-248, 1990.
[4] Ostfeld A., Kogan D., and Shamir U., "Reliability simulation of water distribution systems-Single and multi-quality", Urban Water, Vol.4, pp.53-61, 2002.
[5] Cullinane M.J, Lansey K.E, and Mays L.W. "Optimization –availability based design of water distribution networks", Jl. of Hydraulic Engg, Vol.118. No.3, pp.420-441, 1992.
[6] Pratheeba Paul, and Ambujam, N.K. "Failure Analysis and Simulation based Performance evaluation of Water Distribution System", European Journal of Scientific Research, Vol.53, No.3, pp.369-384, 2011.
[7] Rudolph Fredrick Stapelberg, "Handbook of Reliability, Availability, Maintainability and Safety in Engineering Design", Springer-Verlag, London, 2009.
[8] Charles E.Ebeling "An Introduction to Reliability and Maintainability Engineering", Tata McGraw Hill, New Delhi, 2013.
[9] Damelin E., Shamir, U. and Arad, N. "Engineering and economic evaluation of the reliability of water supply", Water Resources Research, Vol.8, No.4, pp.861-877, 1972.
[10] Lees F.P. "Loss prevention in Process industries", Butter Worths Publications, New York, 2003.

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