Wastewater Pump Station Failure Reliability Modelling

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Abstract

More than ten thousand unique configurations of Water Corporation's Wastewater Pump Stations can be assembled using the current component models installed. Performance measures are needed in order to evaluate each unique pump station. This study examines how reliability performance measurements of Wastewater Pump Stations can assist in the prioritisation of funding and development of the Water Corporation Asset Class Plan. Reliability analysis was undertaken on failure and maintenance data from 2008-2017 for 126 Perth Metro Type 40 Wastewater Pump Stations predominantly aged between 20-40 years old. The outputs were used to produce quantitative performance measures through the simulation of a reliability block diagram, which is representative of a Wastewater Pump Station. Results have been verified against field data and demonstrate the capability of using reliability modelling to estimate the performance of Wastewater Pump Stations.

Outputs from the reliability analysis indicated a majority of components had a higher probability of experiencing failure in its early life, and the least reliable component was the pump when considering only ragging failure. Furthermore, the results between the simulation and field data suggest the potential of using mean unavailability and total down time as performance measures to evaluate a Wastewater Pump Station.

1. Introduction

The Water Corporation owns and operates over one thousand Wastewater Pump Stations (WWPSs) across Western Australia. Most WWPSs have unique configurations as there are a range of types, as well as components. This study develops performance measures which are capable of evaluating each unique WWPS based on quantitative outputs such as estimated total down time or number of outages. A reliability model from a previous study by Hodkiewicz and Zhao (2007) is further refined with the use of actual field data to validate its accuracy. This study also conducts a reliability analysis and develops reliability parameters on the following WWPS components: power supply, switchboard, level sensor, pump/motor, pipes and alarm system.

The performance measures developed contribute to the Asset Class Plan (ACP) which is being established to meet the Water Corporation's Asset Management objectives. The ACP includes information related to asset investment, capital upgrades, refurbishment and renewals, and the maintenance strategy needed to minimise breakdown and non-compliance with asset performance expectations.

The ACP addresses the cost effectiveness and reliability objectives of the Wastewater Pump Station Asset Class Strategy. These involve making investment decisions and meeting stakeholder expectations of having no more than one overflow in ten years for each pump station.

The scope of this study covers the following:

- Collection of data from various sources on failure data within the last ten years.
- Comparison and update of the individual components' reliability parameters.
- Assessment of the effect of maintenance strategies on the reliability of the assets.
- Formulation of reliability performance measures for WWPSs that contribute to the development of Water Corporation's Asset Class Plan.

2. Methodology

The methodology was performed as follows:

1. Identified population of WWPS component models and makes.
2. Obtained unique identifiers for WWPS assets (Functional Locations).
3. Functional locations were used to obtain corresponding corrective and preventive work orders. Corrective task codes were classified as a failure and preventive task codes as a suspension.
4. Identified useable work orders data by filtering, sorting and cleansing work orders based on task code(s).
5. Work orders were used to calculate Time Between Failures (TBF) and Time To Repair (TTR).
6. Generated failure and repair Weibull distributions for each component.
7. The reliability parameters of these distributions were used as inputs to construct a Reliability Block Diagram (RBD) which describes the nature and relationships of the components within a WWPS.
8. Obtained simulation results of WWPS at system, subsystem and component level.
9. Validated simulated performance against actual performance.

The process of data collection for WWPSs involved three Water Corporation databases: Asset Management and Operations Support Software (AMOSS), SAP system and Data Historian (PI) database. The analysis was conducted through two analytical software packages: statistical software package R and Isograph Availability Workbench (AvSim).

Step one and two involved using AMOSS which stores operational and attribute data relating to pump stations while step three and four used SAP; a computerised maintenance management system that stores asset information such as WWPS-related work orders. Step five and six was completed in R and step seven and eight in AvSim. The last step involved extracting actual performance data from PI, which tracks the operation and condition of an asset.

3. Results and Discussion

A sample size of WWPSs was selected using a top-down approach, meaning broad categories were established and further refined in greater detail. WWPSs were first distinguished by their regions, followed by the type of the pump station. A population of 126 Perth Metro Type 40 WWPSs were selected as a sample size as it was found to be the largest population type of WWPSs, as well as encompassing majority of the component models and makes. Most of the WWPSs in this category are between 20 and 40 years of age.

A particular Type 40 pump station containing the components shown in *Table 1* was selected for the process of validation. *Table 1* summarises the Mean Time To Repair (MTTR), Weibull failure distribution parameters (eta and beta) and number of events which occurred within the last ten years for the Type 40 WWPSs. The majority of the components in *Table 1* have two rows of task codes, with the first row representing corrective task codes while the second row represents preventive task codes.

Component	Type: Make Model	Failure Mode	Task Code	No. of Events	Beta β	Eta η (hrs)	MTTR (hrs)
Alarm System	SCADA	All	Repair Alarm System SCADA Maintain	462	1.30	1.8	1.7
Motor Starter	Auto Trans-former	All	Repair Motor Starter Starter Maintain	399	1.18	2.0	1.9
Power Supply	N/A	All	Repair Power Supply	418	1.13	2.7	2.6
Level Controller	Ultra-sonics: Hawk	All	Repair Level Control Level Control Maintain	319	1.30	3.0	2.8
Switch-board	MK5	All	Repair Switchboard Fault Switchboard Maintain	200	2.00	3.1	2.8
Pump	Flygt	Ragging Failure Mode Only	Derag Pump & Clear Blockage Pump Station Cleaning	4062	1.38	3.7	3.4
Motor	Flygt	All	Repair Electric Motor Motor Maintain	398	2.40	7.8	6.9
Pipe	N/A	All	Repair Pipe Maintain Pipe	16	1.30	8.3	7.7
Pump	Flygt	Other Pump Failure Modes	Repair/Replace Pump & Others Pump Maintain & Overhaul Pump	630	1.32	16.7	15.4

Table 1 MTTR of a particular type of Type 40's major components.

Table 2 summarises information related to the Mean Time Between Failures (MTBF). *Table 2* also shows components with duty-standby configurations such as motor starter, motor and pump are assigned a beta value of one (random failure) as they are indistinguishable from the work orders. Most components in *Table 2* have a beta value less than one, which indicates "wear-in" failure where the probability of failure is greater in the early stages of its service life.

Component	Type: Make Model	Failure Mode	Task Code	No. of Events	Beta β	Eta η (hrs)	MTBF (hrs)
Pump	Flygt	Ragging Failure Mode Only	Derag Pump & Clear Blockage Pump Station Cleaning	4062	1.00	4.86 E-04 (λ)	2057
Alarm System	SCADA	All	Repair Alarm System SCADA Maintain	462	0.67	12784	16828
Motor Starter	Auto Trans-former	All	Repair Motor Starter Starter Maintain	399	1.00	5.51 E-05 (λ)	18139
Power Supply	N/A	All	Repair Power Supply	418	0.69	19004	24361
Level Controller	Ultra-sonics: Hawk	All	Repair Level Control Level Control Maintain	319	0.67	21893	29145
Pump	Flygt	Other Pump Failure Modes	Repair/Replace Pump & Others Pump Maintain & Overhaul Pump	630	1.00	1.16 E-05 (λ)	86400
Switch-board	MK5	All	Repair Switchboard Fault Switchboard Maintain	200	0.73	222911	270712
Motor	Flygt	All	Repair Electric Motor Motor Maintain	398	1.00	6.34 E-07 (λ)	1576800
Pipe	N/A	All	Repair Pipe Maintain Pipe	16	2.78	17228247	15336986

Table 2 MTBF of a particular type of Type 40's major components.

The RBD model in *Figure 1* represents a real life WWPS, with component structures and interactions reflected. Most components are connected in series but motor starters, motors and pumps are connected in parallel to portray duty standby configurations and operating strategy of a pump station as per the Water Corporation Design Standard 32. Only one motor starter, motor, and pump is required to operate at a time. Each block represents a component and possesses reliability parameters shown in *Table 1* and *Table 2*. By knowing the reliability parameters of each component's model and make, this allows different combinations of WWPSs to be assembled. Hence a unique WWPS can be evaluated.

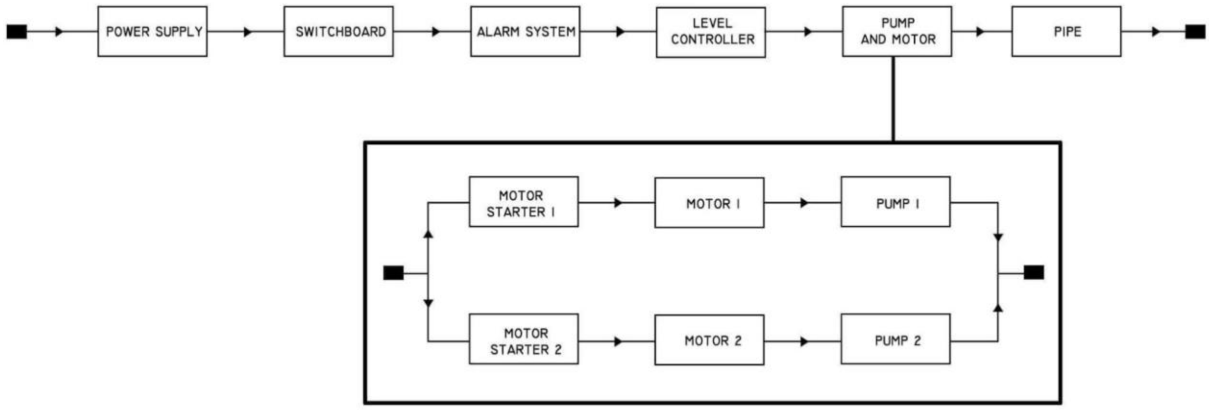

Figure 1 AvSim model of a wastewater pump station.

For validation purposes, the WWPS's system simulation lifetime was set to be five years. The output shown in *Table 3*, simulation column, displays the simulated total down time and other performance measures at the system and component level for a typical Type 40 WWPS. The actual performance of a specific WWPS was extracted from the Water Corporation PI database to evaluate the accuracy of the simulated performances, as shown in the 'actual' column in *Table 3*. Both the simulated model and actual WWPS possess the same number and type of components.

	Simulation			**Actual**
	WWPS	**Pump Unit 1**	**Pump Unit 2**	**Pump Unit 2**
Total Down Time (hrs)	19.8	153.5	153	214.3
Total Down Time Std (hrs)	10.2	47.7	47.9	-
Mean Unavailability (For Five Years Period)	0.1%	0.4%	0.4%	0.5%
Expected Number of Outages	8.1	26.3	26.2	105
Mean Time to First Outage (hrs)	3988	1652	1682	-
Mean Time Between Outage (hrs)	5419	1669	1673	-
Mean Time to Repair (hrs)	2.5	5.9	5.9	-

Table 3 Simulated performance and actual performance for a typical Type 40 WWPS at the end of the five years period.

The actual performance of pump unit one is not included in *Table 3* as it was taken out for replacement in one of the five years for a significant period of time. As the current RBD model does not take into account the waiting period required for spares, it is only able to compare the actual performance and simulated results for pump unit two.

The result between the simulated performance and actual performance shows the potential of using mean unavailability and total down time as a performance measure. This is demonstrated in the actual total down time as it is within two standard deviations of the simulated result. However, the actual number of outages is around four times the simulated number of outages. The underlying cause of this occurrence is due to a large amount of "Reset and Test" conducted in the actual pump unit two. "Reset and Test" was not considered in this study as it is not a typical failure mode which requires maintenance intervention.

4. Conclusions and Future Work

The work completed to date suggests the capability of RBD modelling in providing a quantitative performance measure at both WWPS and component levels. Quantitative outputs such as mean unavailability or total down time can be used to the determine performance of each unique WWPS, thereby prioritising funding allocation for the assets. The results further suggest the effectiveness of reliability modelling as the outcome was within a tolerable limit. However, additional comparisons of simulation outputs with actual data, both at system and component are required to further validate the results.

Further work within this study involves simulating different configurations of WWPSs, identifying the bottleneck of the system and considering preventative maintenance strategies in the RBD models to assess the effectiveness of maintenance strategies on the reliability of assets.

Future work beyond this study will involve optimising the use of the Isograph Availability Workbench software by including the Reliability Centred Maintenance (RCM) module to consider the cost aspect of maintenance. This can be used alongside AvSim, such that maintenance strategies are optimised through both cost and availability.

5. Acknowledgements

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6. References

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