Wastewater Treatment Plant Availability Modelling

Benjamin Redman

School of Mechanical Engineering

BP

Abstract

Availability is important to any process as it ensures that equipment is operational when required. The BP Kwinana wastewater treatment plant is critical to the operation of the refinery so a high level of availability is required. This paper will discuss the implementation of theoretical modelling as a tool to improve the availability of the waste water treatment plant as a practical and operational system. Results indicate that although an accurate simulation could not be achieved, the model proved a useful tool for evaluating potential changes to the system and identifying critical elements.

1.0 Introduction

The aim of this project is to evaluate the use of a simulation model in a real industry application. The design, operation and maintenance practices are used to construct an availability model based on refinery data. This model is used to predict the long term mechanical availability of the BP Kwinana wastewater treatment plant (WWTP). It is also used to highlight critical areas and evaluate potential improvements. Additionally the model is used in conjunction with an effluent model to evaluate the process availability of the WWTP.

The Kwinana WWTP treats all oily wastewater from the refinery before it is discharged into the ocean. The plant is required to process up to 5 megalitres of wastewater a day and to remove oil and chemicals. The necessity to adhere to strict environmental standards on wastewater quality makes the WWTP critical to the current and future operation of the Kwinana refinery.

The WWTP is a highly complex system with almost 200 essential equipment items in an array of combinations including parallel, series and varied logic arrangements. Simulation is a common method for analysing complex circuits. Alternative methods such as fault tree anaylsis and Markov analysis are not appropriate for these types of systems.

Currently BP is using similar simulation techniques elsewhere in its global operations. A recent reliability study was conducted at the Whiting refinery wastewater treatment plant to assess the use of numerical models in making asset management decisions [01]. BP Kwinana has conducted a preliminary trial using Avsim and found it to be beneficial. Thus prompoted the initiation of this current study. Avsim is a commercially availability software package which uses Monte Carlo simulation to model the preformance of the plant over a designated life time.

2.0 Model Construction

The construction of an availability model requires the consultation and collaboration of numerous sources. This ensures the development of a realistic plant simulation. The method employed in this availability study can be seen in Figure 1.

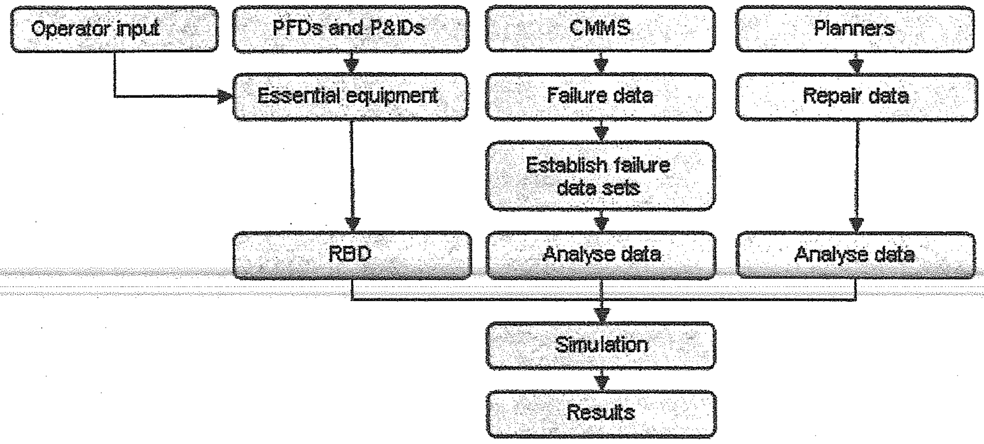

Figure 1:The availability model construction process

2.1 Reliability Block Diagram Construction

The first step is to create a reliability block diagram (RBD) of the WWTP. This is achieved through consulting piping and instrumentation diagrams (P&ID's) and process flow diagrams (PFD's) in consultation with operators and engineers. This ensures that the model accurately reflects equipment configurations, operating logic and includes all equipment essential to plant operation. Buffer blocks are also included to allow for the intermediate storage potential in the system and the time delays experienced in the plants organic processes [02]. These blocks must be populated with variables that represent the reliability and affect the availability of the system. These variables are determined from failure and repair data.

2.2 Failure Data

Failure data was primarily obtained from the refineries central maintenance management system (CMMS), MAXIMO. A program developed for this project, is used to filter work orders from MAXIMO. These work orders are used to genreate the failure data required for the model[1].

Due to the amount of equipment included in the model it is necessary to group equipment into common failure data sets. The classifications are determined by similar equipment (such as single stage centrifugal pumps) or similar operating conditions (such as variable speed pumps). This is done to simplify the model by reducing the number of data sets in the model from 196 to 43. Weibull analysis is used to fit a distribution to each data set and allows a wear characteristic and a mean time to failure (MTTF) to be calculated for each equipment type [03]. A failure data set for a chemical dosing pump and its Weibull distribution is shown in Figure 2.

---

[1] A more detailed description of this process can be obtained in the thesis

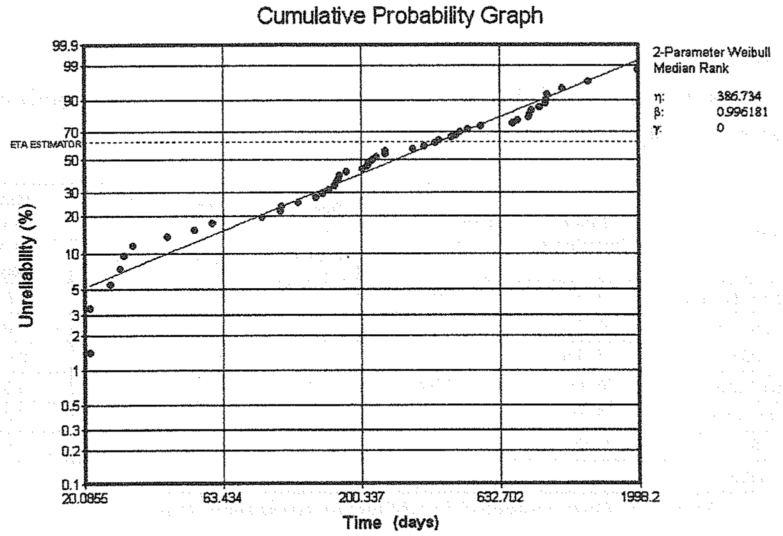

Figure 2: A Weibull distribution of a failure data set. The The distribution has a β of 1 suggesting a random failure mode and a charateristic life of 387 days.

2.3 Corrosion Model

A novel method was developed that transposed corrosion rate measurements into an estimate for a MTTF for static equipment[2]. Results found that the MTTF using the corrosion model is more conservative than the using the failure data. In addition the method produces values for a single failure mode (corrosion) and neglects other possible failure contributers. As a result it is not included in this WWTP model.

2.4 Repair Data

Ideally repair data can be collected from labour records and time sheets. However due to inconsistencies in time sheets, repair data (specifically the mean time to repair) was obtained from the experienced WWTP Planner. The Planner is responsible for planning all work conducted on the WWTP, including inspections, labour and spare parts [04]. A distribution is applied to the mean value to allow for the variations in repair times. For all repairs it was assumed that all required spare parts and tools were available and the items are repaired to an as new condition. Not all maintenance conducted on the WWTP is breakdown and the current preventative maintenance schedule is also included in the model.

2.4.1 Preventative Maintenance Data

Tanks and pressure vessels are inspected at regular intervals. These inspections require the equipment to be out of service. All other components are inspected once a week and remain online. For each inspection a mean task time is allocated and a normal distribution applied.

---

[2] A detailed description of the method can be obtained in the thesis

3.0 Results and Discussion

3.1 Reliability Data

Figure 3 shows the results for seven of the failure data sets anaylsed. These values were used to populate the individual reliability blocks in the model.

ID	Description	Failure Distribution	Characteristic Life (days)	Beta Value (wear out behaviour)	Mean Time To Repair (MTTR) (days)	Mean Inspection Task Time (days)	Inspection Interval (days)
DO	Dissolved oxygen probe failure	Weibull	243	1.02	1	0	1
F1	ASU blow off valve failure	Weibull	563	0.84	2	0.01	7
J1	Pump type 1 failure	Weibull	1938	1.08	30	0.01	7
L4	Equipment type 4 failure	Weibull	1744	1.00	21	0.01	7
LI	Level indicator failure	Weibull	1862	0.99	2	0.01	7
M1	Motor type 1 failure	Weibull	1014	1.04	14	0.01	7
OTK	Other tank failure	Weibull	760	1.50	21	1	3600

Figure 3: Data collected for different equipment types

Many of the failure types displayed a beta value of approximately one. This suggests that the equipment is subject to random failure indicating that conditioning monitoring could be applied to the equipment. Provided failure modes could be identified, cost-effective and applicable monitoring can be applied.

The use of plant-specific data within the simulation model is beneficial to achieving a practical result. However, the amount of time required to collect, cleanse and refine the data is not cost-effective for regular model building for routine maintenance decisions. Although, models are becoming more common when making decisions on large capital projects [05]. Significant improvements in detailed recording and capturing of equipment failure data would lead to models becoming more convenient to construct [06]. This would make them a practical tool for analysing and evaluating the decisions affecting the operation of the plant. Nevertheless, given the time currently taken to construct the model, it is more efficient to rely on refinery personnel's experience for decision making. The time spent modelling may be justified when there are conflicting opinions or a number of options to consider. The benefits of modelling process include:

- increasing the understanding of the plants operation and process flow, leading to a more informed choice in making plant decisions.
- exposing limitation in the current collection of relibaility data, allowing for improvements.
- aiding in the capturing the knowledge and experience of refinery personnel, which is generally poorly recorded.

3.2 Availability Results

The average availability of the WWTP was calculated to be 45% over a 20 year lifetime. The results of the simulation can be seen in Figure 4. Currently the availability of the WWTP is not measured. However the calculated model value is lower then expected. One possible reason for the low availability is the large number of possible bypasses and storage combinations that are used in practice to avoid system downtime. To model all these possible scenarios would be extremely time consuming and would be of little benefit to a practical availability study. The relative contributions of the critical components are highlighted in the model and have been validated by BP personnel [07].

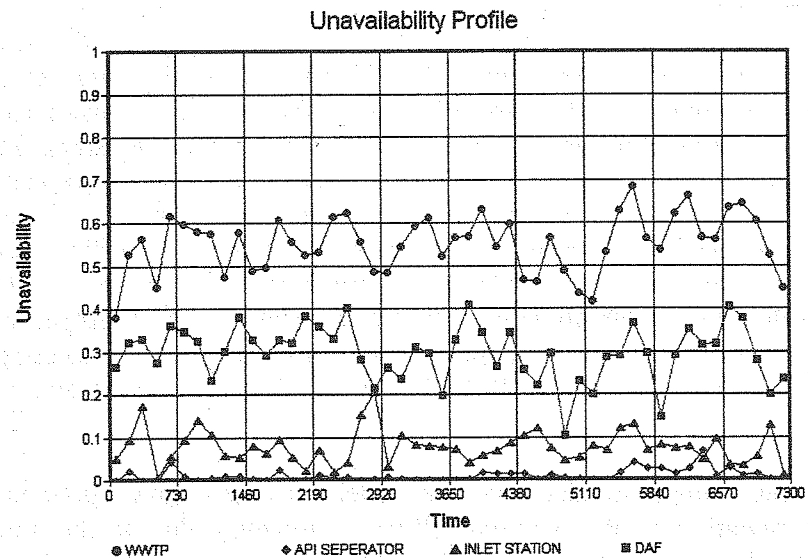

Figure 4: Model results showing the unavailability in percentage of the WWTP. The graph also shows the unavailability of other units within the WWTP, which combine to produce the overall system result.

3.3 Application of Model

3.3.1 Criticality Assessment

The model is used to evaluate the critical bottlenecks in the plant. Figure 5 shows a criticality rating of the key components in the system based on unavailability [08]. This table identifies the Dissolved Air Flotation (DAF) Froth Skimmers as the most critical components.

Description	Total Down Time (days)	Mean Time To Repair (days)	Number Of Expected Failures	Mean Unavailability Over Lifetime
DAF Froth Skimmer	3442	120	28	47%
DAF Froth Skimmer	3137	120	27	42%
Biox Sludge Digestion Air Blower	957	14	68	13%
Biox Sludge Digestion Air Blower	957	14	67	13%
API Bottom Sludge Scraper	503	90	6	6%
ASU Air Blower	426	14	29	5%
API Bottom Sludge Scraper	425	90	5	5%
ASU Air Blower	421	14	29	5%

Figure 5: Criticality ranking of the worst components in the model based on unavailability

3.3.2 Potential Improvements

The model is used to evaluate potential improvement to the plant. Firstly, increasing the storage capacity of the plant is analysed. For example if a large storage tank (3 day storage capacity) is placed at the beginning of the plant to accept all wastewater, before it is transferred to the plant for treatment, plant availability is predicted to increase by 2%. Secondly, the replacement of the existing DAF unit with an improved unit with a 20% increase in current availability, may lead to an improvement overall plant availability of 21%. Although the model is unable to give an accurate number of the availability, the magnitude of the improvement is a reflection on the effectiveness of the improvement. These are only two examples of a number of different evaluations that the model can be used for.

3.3.3 Effluent Prediction

The WWTP removes effluent from the wastewater before it is returned into the ocean. The major effluents are nitrogen, chemical oxygen demand (COD) and oil. Each equipment unit within the refinery contributes to removing a certain type of effluent. The WWTP is considered to have 100% process capability when the units within the plant are able to process the incoming feed and achieve the required effluent quality. To assess the WWTP process capability, the mechanical availability of the appropriate units, calculated in Avsim, are combined with their respective effluent model using an Excel simulator developed for this project. The effluent models use the effluent input levels and the plants removal rate, measured by the refinery's environmental department. These are used together with the mechanical availability to predict effluent output levels. If output levels are below the levels required for environmental compliance, the plant capability is meeting the required capability. During these time periods the WWTP is considered to be available from a process perspective.

The effluent model uses a simple simulator and the model was able to give a good indication of the mean and standard deviation of the outgoing effluent. However, due to the simplicity of the simulator it was not able to replicate the natural variation seen in the inflow. Future work could involve researching an improved effluent model to achieve a more accurate representation of the plant.

4.0 Conclusion

Availability simulation is a useful tool for assessing the efficiency of the WWTP. Firstly, the model increases the refinery personnel's understanding of the WWTP and aids in capturing knowledge. Secondly the model allows potential improvements to be analysed and their impact considered. Finally, the effluent model allows the process capability of the WWTP to be analysed and the effect of mechanical availability on effluent discharge to be assessed.

5.0 References

[01] R. Barlog, "Reliability Review and Reliability/Availability Model", BP Whiting Refinery, 2004
[02] H. Kortelainen, J. Salmikuukka, Jukka and S. Pursio, "Reliability simulation model for systems with multiple intermediate storages", in *Annual Reliability and Maintainability Symposium*, 2000, pp. 65-70.
[03] A. Harold, "A set of numbers is not a Data Set", *IEEE Transactions on Reliability*, vol. 48, June 1999, pp. 135-140
[04] P. Jager and B. Bertsche, "A new approach to gathering failure behaviour information about mechanical components based on expert knowledge", in *Annual Reliability and Maintainability Symposium*, 2004, pp. 90-95
[05] M.Drew, "Open Pit Mining Operation", ARMS Reliability Engineers, 2004
[06] T. Bendell, "An Overview of Collection, Analysis, and Application of Reliability Data in the Process Industries", *IEEE Transactions on Reliability*, vol. 37, June 1988, pp. 132-137.
[07] S. Kunttu and H. Kortelainen "Supporting Maintenance Decisions with Expert and Event Data," in *Annual Reliability and Maintainability Symposium*, 2004, pp. 593 – 599.
[08] T. Thomaidis and S. Pistikopoulos, "Criticality Analysis of Process Systems in *Annual Reliability and Maintainability Symposium*, 2004, pp. 451-458