Availability Analysis of Oil Production Systems

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Abstract

System effectiveness in crude oil processing industries can be constrained by operational efficiency of the constitutive units. Thus ascertaining availability status of all system units can provide decision makers with an effective means of improving the technical performance of complex processing systems. Most of the works found in literatures focused on either models specifically for estimation of interval, instantaneous or stationary availability with specific repair distributions or models with mathematical complexities whose underlying assumptions impose ample application constraints to industries. This paper proposes a proof of concept compact generalized model for determination of availability of complex processing industries. The approach is clearly presented as an off-shoot of earlier but independent availability models (Lie et al. 1977, Ebeling, 2010). The applicability of the models has been illustrated using data obtained from a typical oil company, which will be called X-Company for the sake of confidentiality. The unit availability for the studied period as well as mean annual availability of the system can all be computed with the models. The lowest and highest availability values recorded for the units were 0.083 and 0.692 respectively. The mean system availability during the period stood at 0.451. The result shows that the proposed model is a good means of computing system availability. The results have also updated decision makers support tools for system performance improvement.

Keywords: System effectiveness, operational efficiency, availability, Oil Company, performance improvement

1. Introduction

Availability provides an alternative system performance measure which plays a key role in manufacturing systems, power plants and processing concerns among others. Most industrial systems often place towering availability as priority for sustaining product through-put and meeting set targets. On a practical note, two methods of increasing system availability can be outlined. The first one is by provision of standby replica systems that can immediately do the work of the in-process system marked for repair upon failure. The alternative is to use a system that can be reconfigured, typical of increasing the availability of a router compartment, which normally comprises other independent replica switches, such that; while one is in operation, the other is in suspended animation (Dhillon, 2007). There have been different efforts made towards estimating availability of systems in the past. Lie et al 1977 broadly define different categories of availability which were later elaborated elsewhere (Ebeling, 2010). Huang and Mi (2018) propose a non-parametric method for obtaining the instantaneous availability of a system, citing deficiencies in research in the area due to the computational complexities. A generalized framework that can recover and make the visualization of system availability possible has been suggested (Hassine et al., 2017). A technique for tackling the early fluctuation of instantaneous availability exists in literature (Rena, 2017).

Significant researchers labored on the use of statistical inferences in evaluating availability (Biswasa and Sarkarb, 2000, Cui and Xie, 2003, Qui *et al*, 2017). The presentation adopt availability modeling methodology geared at reducing maintainable units stoppages, or increasing the length of time to failure of systems going through many failures and imperfect repairs, before eventual replacement is made. Though the results propose useful availability models in tandem with the objectives, application in many practical situations will be difficult, given the assumptions that are rarely so in practice. Another setback to the use of the models in practical situations is that the distributions of choice whose parameters must be determined may not accommodate what really obtains in industrial situations. Carpitella et al (2018) describe stationary availability as an important driver of maintenance for industrial plants whose components are repairable. The work proposes a model for the computation of stationary availability of systems derived from the basic principles of Markov chains. Mathematical programming approaches and its affiliates were explored for decision on optimal system and K-out-of-n configurations with numerical examples. Stochastic availability modeling approaches have recently received attention (Borba and Tavares, 2017). Reliability block diagrams and stochastic Petrinets were employed to propose new models for evaluating availability and performance of systems. The original work was applied to hybrid storage systems, future plans to extend the methodology to energy consumption was stated.

Most of the works found in literatures (those above inclusive) focused on either proposition of models specifically for estimation of interval, instantaneous or stationary availability with specific repair distributions or models with mathematical complexities whose underlying assumptions impose ample application constraints to industries. Past researchers present statistical inference based availability models whose repair times does not depend on direct estimates of distribution parameters (Ke, et al. 2018). The modeling approach is still not devoid of assumptions without practical application replicas. There subsists obvious drought of availability models for specific industrial concerns rooting from realities of processes and activities performed by its system. In particular, there was none available for oil processing where very high availability is recommended for consistent optimal performance. This was the motivation that drove the authors to explore system availability with general applicability to industrial systems, but with model validation data taken from a characteristic oil company plant, which will be referred to as Company X for confidentiality in this presentation. An attempt was made in this paper to propose compact generalized system availability. The Lie *et al*–Ebeling models were relied upon to propose compact generalized model that can cater for most availability parameters encountered in practice. The paper use on-site information and historical failure and repair evidence observed on specific systems to provide availability estimations. In the approach, the time between performances of preventive maintenance is used in representing expected prior knowledge, which include judgment about the repair time and expected number of failures in a given interval. The ready time, system design life and operational availability combines with other characteristics in yielding the model that represents required availability. The approach can estimate availability from component to system level for any given period.

2 Availability Model Formulations

Let the generalized operational availability A_G, and Operational availability A_o, be represented as in equation (1) and (2) respectively (Ebeling, 2010):

$$A_G = \frac{MTBM + ready\ time}{MTBM + ready\ time + M'} \quad (1)$$

$$A_o = \frac{MTBM}{MTBM + M'} \quad (2)$$

Where:

$MTBM$ = Mean time between maintenance

M' = Mean maintenance downtime resulting from both corrective and preventive maintenance actions

$$M' = MTBM\left[\frac{1}{Ao} - 1\right] \quad (3)$$

Substituting (3) into (1),

$$A_G = \frac{MTBM + rt}{MTBM + rt + MTBM(\frac{1}{Ao} - 1)} \quad (4)$$

Where:

$rt =$ ready time

$$A_G = \frac{Ao\{MTBM + rt\}}{MTBM/Ao + Ao(rt)} \quad (5)$$

The mean time between maintenance (MTBM) defined by equation (6) includes both unscheduled and preventive maintenance

$$MTBM = \frac{t_d}{m(t_d) + t_d/T_{pm}} \quad (6)$$

Where:

T_{pm} = mean time between performances of preventive maintenance

t_d = system design or economic life

$m(t_d)$ = expected number of failures in the interval (0, t_d)

Substituting for MTBM in model (6) into equation (5)

$$A_G = \frac{Ao\ t_d\ Tpm + Ao\ rt\ [\ Tpm.m(t_d) + t_d]}{t_d Tpm + rt\ [Tpm.m(t_d) + t_d} \quad (7)$$

$$A_G = Ao\,[t_d T_{pm} + rt\,[T_{pm}\, m(t_d) + t_d]]\,.\,\{t_d T_{pm} + rt\,[\,T_{pm}.m(t_d) + t_d]\}^{-1} \quad (8)$$

$$A_G = A_o\, K.K^{-1} \quad (9)$$

Where:

$k \; = t_d T_{pm} + rt \, [T_{pm} \, m(t_d) + t_d$

The availability at a given period j for any year, say i is given by:

$$A_{Gij} = A_{o_{i,j}} \, [\, t_{di,j} T_{pmi,j} + rt_{i,j} \, [\, T_{pm_{i,j}} \; m(t_d)_{i,j} + t_{d_{i,j}}]] \; . \; \{\, t_{di,j} T_{pmi,j} + rt_{i,j} \, [\, T_{pm_{i,j}} \; m(t_d)_{i,j} + t_{d_{i,j}}]\}^{-1} \qquad (10)$$

An average availability can be calculated for any number of n years as:

$$A_{G_{av}} \; = \frac{1}{n} \sum_{i=1}^{n} Ao_{i,j} K_{i,j} . {K_{i,j}}^{-1} \qquad (11)$$

While:

$$A_{Gi} = \mathrm{A_o i} \; K_i {K_i}^{-1} \qquad (12)$$

is the availability for year i,

$$A_{Gij} = \sum_{i=1}^{n} Ao_{i,j} K_{i,j} . {K_{i,j}}^{-1} \qquad (13)$$

is the availability for year i during a specified period, j

Hence, equations (11) through (13) makes it possible to easily determine the computation of the availability for any number of years, a particular year or a particular component within a given year. The intervals can be taken to be from the time the system was first installed and commissioned or from the time of last maintenance, whichever is applicable.

3 Data Collection:

The data required for the validation of the proposed availability models is categorized into two types: quantitative and qualitative. Quantitative data refer to down times experienced in X-Company units irrespective of cause. Qualitative data are the types obtained through observed information such as interviews and opinion surveys. The data of down time and its affiliates considered in the research are collected based on maintenance records. In particular, the data were obtained from the Planning and Budget Monitoring Department of the PHRC and by personal interview with the management team and key operating personnel of the PHRC who had worked for a period of fifteen years and beyond. Table 1 presents the average Power plant and utilities down time in hours for five years (2000-2004). Frequency of process units, power plant and utilities down time for five years (2000-2004) are cumulated in Table 2. The Turbo-generators in the company has a design or economic life is 20years. The whole plant is self-sufficient in power and utilities generated from the power plant and utilities (PPU). There are four (4) turbo-generators (TG1-4) each with a capacity of 14 MW of electricity per hour and four (4) boilers (BO1-4), capable of generating 120 tons of steam per hour each. The section also generates cooling/service water, plant/instrument air and nitrogen.

Table 1: Average Downtime of Process Units and Power Plant Utilities in Hours

Unit	2001	2002	2003	2004	2005	Average
CDU1	3715.86	187.61	1165.36	1111.47	1630.47	1562.15
VDU	8235.00	4423.00	3470.40	5751.09	4368.00	5249.50
KHU	8784.00	8760.00	8760.00	8760.00	4368.00	7886.40
CRU	4775.48	2349.42	1854.07	5208.58	3299.27	3497.36
NHU	5113.76	1768.87	2528.75	5562.31	3481.00	3690.94
FCCU	8297.01	4204.54	2757.86	6352.25	4368.00	5195.93
CDU2	6198.58	4250.66	3131.11	8126.50	4368.00	5214.97
PLAT FORMER	7237.00	4844.03	3908.78	8760.00	4368.00	5823.56
TGO1	6091.94	103.77	1807.90	3446.58	2830.33	2856.10
TGO2	4035.60	8016.00	8760.00	8760.00	4368.00	6787.92
TGO3	3005.75	1509.00	6135.65	1575.21	556.53	2556.43
TGO4	3743.31	730.92	856.43	1314.17	1867.37	1702.44
BO1	1193.79	467.70	1331.93	746.09	4368.00	1621.50
BO2	7353.41	2881.45	1835.66	1990.34	1751.30	3162.43
BO3	8784.00	8016.00	4344.00	8398.00	1157.32	6139.86
BO4	478.00	609.69	1076.09	4324.37	1386.28	1574.89

Crude Distillation Unit (CDU) Vacuum Distillation Unit (VDU), Naphtha Hydro-treating Unit (NHU), Catalytic Reforming Unit (CRU), Kero Hydro-treating Unit (KHU) Continuous catalyst Regeneration Unit (CCRU), Fluid catalytic cracking unit (FCCU)

Table 2. Cumulative frequency of downtime for production units

UNIT	2000	2001	2002	2003	2004	Average
CDU1	9	4	9	20	8	10.0
VDU	10	12	10	9	DOWN	10.25
CRU	11	10	12	7	9	9.80
NHU	4	9	15	12	10	10.0
FCCU	6	6	12	24	DOWN	12.0
PLATFORMER	14	15	8	N/A	DOWN	12.33
CDU2	12	18	12	4	DOWN	11.50
BO 1-4	32	23	27	31	31	28.80
TG 1-4	52	28	31	45	25	36.20

4. Application of data to developed availability model

The data of table 1 and 2 as well as on-site estimates of relevant parameters agreed after critical brainstorming sessions with maintenance practitioners of the case study system were applied to the proposed models. The result is the evolution of availability values for specific units of the system in the first instance, followed by cumulative annual availabilities per annum for each of the years in the study stretch. Using the system data and applying equations (12), (17) and (19), the estimation of the extent of availability of the oil production system can be determined. The average availability for the entire period can be calculated with the above models, for a particular case where k is unity. Similarly, the average availability for all the system for each year can be calculated just as the average overall availability for all the units for the entire period can also be determined. The overall availability for the entire period for each unit is displayed in figure 2, while figure 3 presents the annual availability for the entire oil production system.

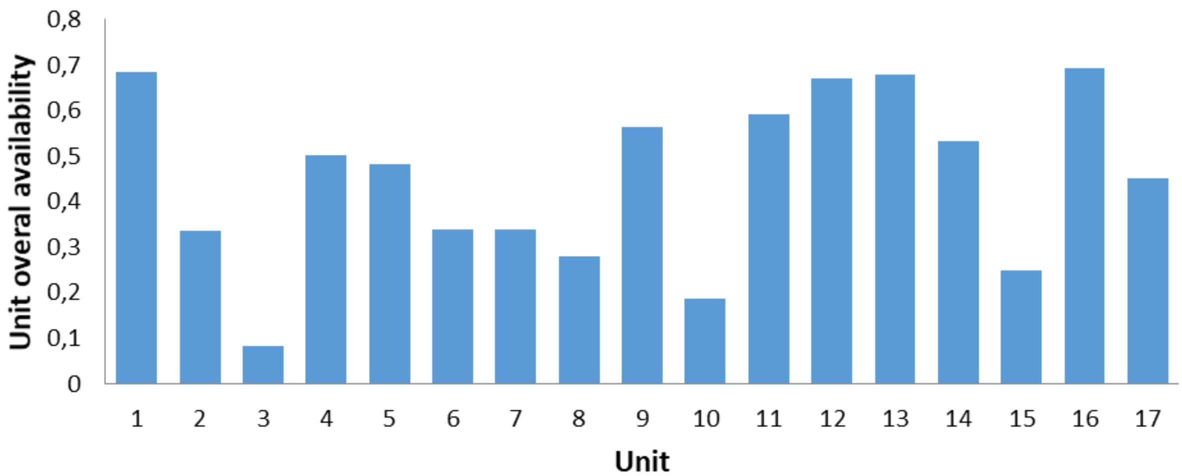

Figure 1: Mean availability for each unit

Key: 1 = CDU1; 2 = VDU; 3 = KHU; 4 = CRU; 5 = NHU; 6 = FCCU; 7 = CDU2; 8 = PLAT FORMER; 9 = TG01; 10 = TG02; 11 = TG03; 12 = TG04; 13 = B01; 14 = B02; 15 = B03; 16 = B04; 17 = Annual average

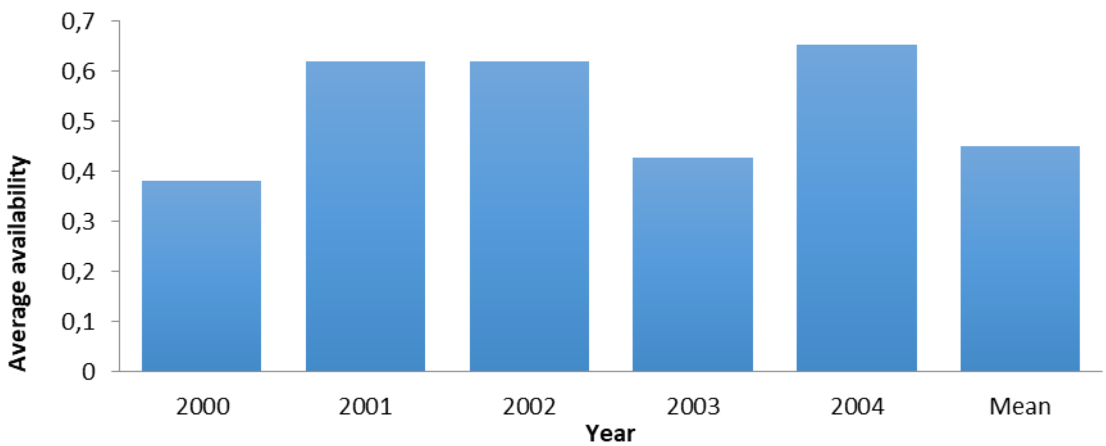

Figure 2: Annual plant availability

5 Discussion of Results

The proposed models were applied successfully to the data obtained from the case study system. The approach is a proof of concept technique for estimating various availability parameters of a given process industry. The methodology of this work can assist in eliciting many forms of availability quantities from unit to system level, and from interval to cumulative status. Taking figure 1 for instance, CDU1 and CDU2, each have unit availability of 0.685 and 0.338 respectively. The availability of VDU is very low at 0.335, but much better than that of KHU and TG02 with 0.083 and 0.188 availability values respectively. The highest availability recorded for the system units occurred in B02 having 0.692. The exercise can be extended to annual availability of the combined system units or annual system availability. The result of the computed annual system availability for the studied case system is displayed in figure 2. System availability started with 0.381 in 2000 and almost doubled in the subsequent two years to 0.62 before decelerating to 0.429 in the following year. The highest value was recorded in 2004 when the system experienced availability of 0.655. The mean availability of the plant throughout the studied period was 0.451. It will be very difficult for the company to achieve its performance expectations with this level of system availability. Therefore, the maintenance department should as a matter of urgency indulge in qualitative availability and maintenance improvement program to reverse the trend. This presentation has exposed the availabilities of each unit which can guide managers and practitioners more properly on the hierarchy of attention to be accorded to specific units for improved system performance. It has also presented a useful model that can track availability status of components up to system levels.

The future direction of the research will involve investigation of root cause of the low mean availability level and its analysis to further provide availability improvement policies that can be used alongside the results of this research work.

6 Conclusion

A general approach for the determination of availability status of processing plants and allied industries has been proposed in this paper. The method of models formulation is clearly presented as an off-shoot of earlier but independent availability models (Lie et al. 1977, Ebeling, 2010). The applicability of the models has been illustrated on relevant data obtained from a typical X-company. The results were graphically displayed and the significance properly explained. The unit availability for the entire period as well as mean annual availability of the system can all be computed with the models. The lowest and highest availability values recorded were 0.083 and 0.692 respectively at the Kero Hydro-treating unit and second boiler unit. The mean system availability during the study stretch is about 0.451. The result shows that managers and practitioners should embark on urgent availability improvement strategies to improve the functionality and effectiveness of the company.

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Biographies

Dr Paul A. Ozor obtained a bachelor's degree (B.Engr) in Mechanical/Production Engineering at Enugu State University of Science and Technology, Nigeria. He worked as project manager with some Engineering Companies before proceeding to Department of Mechanical Engineering, University of Nigeria Nsukka (UNN) for higher studies, and specialized in Industrial Engineering and Operations Management. He obtained both Masters and PhD degrees in 2008 and 2015 respectively from UNN. He has been a teaching and research staff of UNN for over a decade. He is a Professional Member of Nigeria Society of Engineers. Dr Ozor is currently a TWAS-NRF research fellow to University of Johannesburg, South Africa, and had been awarded the Association of Common Wealth Universities' (ACU) early career scholarship in 2014. His research interests include Industrial Operations modelling, Quality management, Systems Analysis, Reliability Engineering, with special emphasis on System Sustainability, Failure mode effects and criticality analysis (FMECA), Safety and Risk assessment (SRA) as well as Environmental influence modelling, including Waste Management, Water and Energy nexus.

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