PLANNING TO ENHANCE COMMUNICATION LINE RELIABILITY IN RURAL AREA OF CHEVRON PACIFIC INDONESIA

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Abstract

System modeling has been made in Chevron Pacific Indonesia by considering of existing network technology and transmission line. Availability of the existing network is 99.9964304%. Using Markov model, a planning analysis of reliability enhancement can be obtained in rural area of Chevron Pacific Indonesia between Kotabatak and Petapahan. Input parameters that are used are failure and repair rates from network devices, while output parameters of network reliability are system downtime and availability. Enhancement planning is divided into Plan 1 and Plan 2. Availability that is obtained in Plan 1 is 99.9966112%, while in Plan 2 is 99.9999998%. From calculations, it can be obtained that the availability increases 0.0001808% from the existing network to Plan 1, from Plan 1 to Plan 2 increases 0.0033886%, therefore from the existing network to Plan 2 increases 0.0035694%.

Keywords: reliability engineering; availability; Markov model; system downtime

1. INTRODUCTION

Chevron Pacific Indonesia (CPI) is the largest producer of Indonesia's crude oil. The company was searching for new crude oil and natural gas reserves from central Sumatra to offshore East Kalimantan. The company owns and operates the Rokan and Siak Production-Sharing Contracts (PSC) in central Sumatra. The majority of company's production came from fields in the Rokan PSC. Those are Duri, Minas, Kulin, Bekasap (Chevron Pacific Indonesia, April 2012), Kotabatak (M. H. Hoehn, et al., 2005), and Petapahan fields (Indonesian Petroleum Association, 1994).

Kotabatak field located in latitude 0°46'46.5594" north and longitude 101°10'44.4" east (M. H. Hoehn, et al., 2005), while Petapahan field located in latitude 0°37'3" north and longitude 101°0'8" east (Indonesian Petroleum Association, 1994). There are two stations between the fields; those are Kotabatak Gathering Station (KBGS) (A. Ridwan, 2006), and Kotabatak Substation (KBSS) (J. R. N. Sinulingga & I. Haumahu, 1988). KBGS was producing 27,000 barrels of oil per day and 310,000 barrels of water per day (A. Ridwan, 2006). KBSS has been in service for 18 years, supplying power for wells and gathering station in Kotabatak field (J. R. N. Sinulingga & I. Haumahu, 1988).

To communicate with the fields, the company has built fiber-optic communication network as shown in Fig. 1. In the figure, boxes represent switch. Today's network condition has one communication line connected between Kotabatak-Petapahan, with KBGS and KBSS routes. Availability and system downtime for the network are 99.9964304% and 18.87 minute/year, respectively.

This suggests that the network condition still has probability of system downtime is big enough, according to the network does not have alternative lines as network backup. Furthermore, Kotabatak field has only one device, where the field as a source of local area network connected to Minas and Duri. It is needed a planning of communication network to enhance reliability with bigger availability and smaller system downtime.

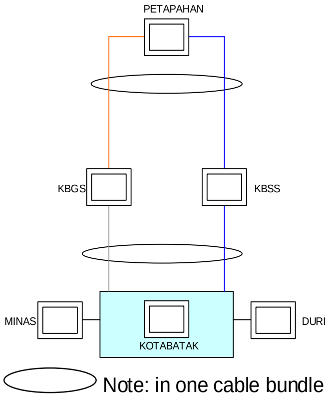

Fig. 1. Existing fiber-optic communication network

To plan a reliable communication network, many things must be considered e.g. network technology, transmission lines, and network topology that are used. Considering the network condition, if the network just use one communication line, then the probability of break line will big enough, with the result that information from Kotabatak to Petapahan could not be accessed. To solve it, adding different communication lines are needed as alternative lines when the line is break. Therefore, increasing of availability and decreasing of system downtime could be observed from the new planning to enhance the communication line.

In reliability engineering, availability investigates "the readiness of the system to perform its function at a given instance of time" (S. Sharvia, S. Kabir, M. Walker, & Y. Papadopoulos, 2016). One of the most important aspects of reliability analysis is to assess the reliability of a system from its basic elements. To model system reliability, it is used the physical configuration of an item that belongs to a system. Eventually, for reliability analysis, there are some schemes to model a system reliability.

Reliability block diagrams are a model for showing "the effect of item failures on system performance" (M. Modarres, M. P. Kaminskiy, & V. Krivtsov, 2016). This model corresponds to arrange the physical items in the system; therefore, it is able to show success paths between input and output. It is able to solve combinatorial problems which are effect of sub-components on the failure of the whole system, and can be applied into large and complex systems. However, this model cannot show failure paths between input and output, and cannot solve non-combinatorial problems, for instance, system is either inactive or failure state. Therefore, this model is suitable for static systems.

Another model is fault tree method. This approach is “a deductive analysis technique which utilizes graphical representation based on Boolean logic to show logical connections between different failures and their causes” (S. Sharvia, S. Kabir, M. Walker, & Y. Papadopoulos, 2016). Therefore, this model is able to show failure paths between input and output, but cannot show the success ones. Like reliability block diagram, this model can solve combinatorial problems, and can be applied into large and complex systems, particularly static systems.

In this work, we use Markov chain to model an autonomous and fully observable system. This model is able to show both of success and failure paths, and can solve both of combinatorial and non-combinatorial problems.

2. RESEARCH DESIGN

The network used between Kotabatak and Petapahan has two lines. First line connects Kotabatak to Petapahan through KBGS route, the other line through KBSS route.

A. Existing Network

At this time, the network has only one line as shown in Fig. 1. Kotabatak field has only one device, with specification of the device can be seen in Table I where MTTR is mean-time-to-repair and FIT is Failures in Time.

Tabel 1. Validitas Instrumen

Component	Failure Rate (λ)		Repair Rate (μ)	
	FIT	λhour (per hour)	MTTR (hour)	Per-hour
3750-24PS Cisco Catalyst	209.170	$2.0917\text{x}10^{-7}$	12 - 24	4.167×10^{-2} – 8.333×10^{-2}
Cisco Gigabit SFP Module	75.064	$0.75064\text{x}10^{-7}$	12 – 24	4.167×10^{-2} – 8.333×10^{-2}
Optical Fiber	3.000024/km fiber	$3.000024\text{x}10^{-9}$	24 – 48	2.083×10^{-2} – 4.167×10^{-2}
Connector	1.7	$1.7\text{x}10^{-9}$	6	0.1667
Splice	1.7	$1.7\text{x}10^{-9}$	6	0.1667

B. Plan 1

On Plan 1, adding switching device is done in Kotabatak field as an additional device. The plan is shown in Fig. 2.

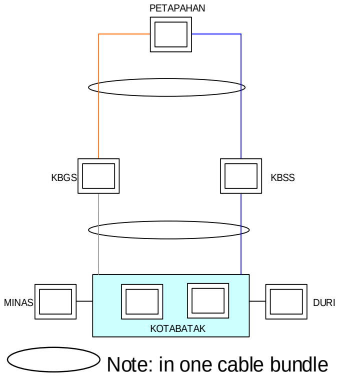

Fig. 2. Planning to enhance reliability in Plan 1

The Plan 1 is similar to the model and concept of system using two identical network components that can be repaired (Ramakumar, 1996). Failure rate and repair rate for system with two identical components are λ1 = λ2 = λ and μ1 = μ2 = μ, respectively.

The model of system for Plan 1 is shown in Fig. 3.

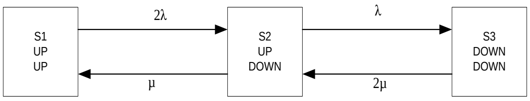

Fig. 3. State of the network using one network component

In the model above, transition from State 1 to State 2 is 2λ. It means there are two networks that have the probability of failure, but only one network will fail. Meanwhile, transition from State 3 to the State 2 is 2μ. There are two network failures and have probability to be repaired, although only one network will be fixed. The matrix for the model is

$$\begin{array}{c|ccc} & S1 & S2 & S3 \\ \hline S1 & 0 & 2\lambda & 0 \\ S2 & \mu & 0 & \lambda \\ S3 & 0 & 2\mu & 0 \end{array} \qquad (1)$$

Markov differential equation can be written as

$$\begin{bmatrix} P_1'(t) \\ P_2'(t) \\ P_3'(t) \end{bmatrix} = \begin{bmatrix} -2\lambda & \mu & 0 \\ 2\lambda & -(\lambda+\mu) & 2\mu \\ 0 & \lambda & -2\mu \end{bmatrix} \begin{bmatrix} P_1(t) \\ P_2(t) \\ P_3(t) \end{bmatrix} \qquad (2)$$

If Δt → 0 then matrix P is stochastic transition probability where

$$P = \begin{bmatrix} 1-2\lambda & 2\lambda & 0 \\ \mu & 1-\lambda-\mu & \lambda \\ 0 & 2\mu & 1-2\mu \end{bmatrix} \qquad (3)$$

From the matrix above then

$$\begin{aligned} &(1-2\lambda)P_1 + \mu P_2 = P_1 \\ &2\lambda P_1 + (1-\lambda-\mu)P_2 + 2\mu P_3 = P_2 \\ &\lambda P_2 + (1-2\mu)P_3 = P_3 \end{aligned} \qquad (4)$$

If $\sum_{i=1}^{n} P_i$ =1 or $P_1+P_2+P_3=1$ then

$$P_1 = \left(\frac{\mu}{\lambda+\mu}\right)^2$$

$$P_2 = \frac{2\lambda}{\mu}\left(\frac{\mu}{\lambda+\mu}\right)^2 \qquad (5)$$

$$P_3 = \left(\frac{\lambda}{\lambda+\mu}\right)^2$$

If two components are needed to be successful (series connection) then availability and unavailability systems are, respectively:

$$A = P_1 = \left(\frac{\mu}{\lambda + \mu}\right)^2 \tag{6}$$

$$U = P_2 + P_3 = \frac{2\lambda\mu + \lambda^2}{(\lambda + \mu)^2} \tag{7}$$

To find mean-time-to-failure (MTTF), assume S3 is absorption condition. Hence,

$$\begin{array}{c|ccc} & S1 & S2 & S3 \\ \hline S1 & 1 & 0 & 0 \\ S2 & 0 & (1-2\lambda) & 2\lambda \\ S3 & \lambda & \mu & (1-\lambda-\mu) \end{array} \tag{8}$$

Based on the above matrix, the matrix Q is

$$Q = \begin{bmatrix} (1-2\lambda) & 2\lambda \\ \mu & (1-\lambda-\mu) \end{bmatrix} \tag{9}$$

Therefore, the fundamental matrix is

$$[I - Q]^{-1} = \frac{1}{2\lambda^2}\begin{bmatrix} \lambda + \mu & 2\lambda \\ -\mu & 2\lambda \end{bmatrix} \tag{10}$$

Based on the fundamental matrix, MTTF is

$$MTTF = \frac{(\lambda + \mu) + 2\lambda}{2\lambda^2} = \frac{3\lambda + \mu}{2\lambda^2} \tag{11}$$

C. Plan 2

Using ring topology, Plan 2 uses two different lines. Thus, if a line is broken then communication will be moved to the other line, as shown in Fig. 4.

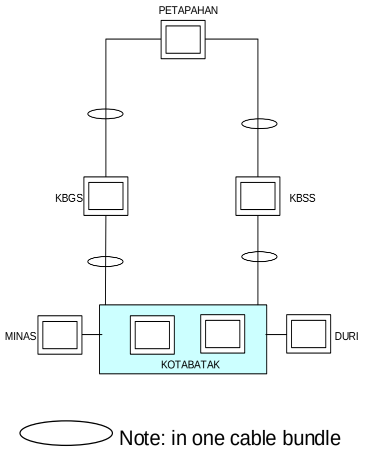

Fig. 4. Planning to enhance reliability in Plan 2

The Plan 2 is similar with model and concept of system with two different network components that can be repaired (Ramakumar, 1996). Failure rate and repair rate for such system are λ_1, λ_2 and μ_1, μ_2 respectively.

The system model for Plan 2 is shown in Fig. 5.

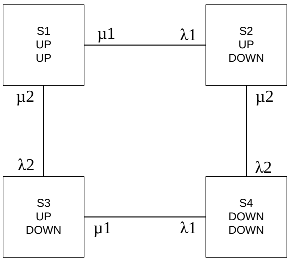

Fig. 5. The network state using two network components

The matrix for the model above is

$$\begin{array}{c|cccc} & S1 & S2 & S3 & S4 \\ \hline S1 & 0 & \lambda 1 & \lambda 2 & 0 \\ S2 & \mu 1 & 0 & 0 & \lambda 2 \\ S3 & \mu 2 & 0 & 0 & \lambda 1 \\ S4 & 0 & \mu 2 & \mu 1 & 0 \end{array} \tag{12}$$

Markov differential equation can be written as

$$P = \begin{bmatrix} P_1' \\ P_2' \\ P_3' \\ P_4' \end{bmatrix} = \begin{bmatrix} -(\lambda_1 + \lambda_2) & \lambda_1 & \lambda_2 & 0 \\ \mu_1 & -(\lambda_2 + \mu_1) & 0 & \lambda_2 \\ \mu_2 & 0 & -(\lambda_1 + \mu_2) & \lambda_1 \\ 0 & \mu_2 & \mu_1 & -(\mu_1 + \mu_2) \end{bmatrix} \begin{bmatrix} P_1(t) \\ P_2(t) \\ P_3(t) \\ P_4(t) \end{bmatrix} \tag{13}$$

If Δt → 0 then stochastic transition probability P is

$$P = \begin{bmatrix} 1 - (\lambda_1 + \lambda_2) & \lambda_1 & \lambda_2 & 0 \\ \mu_1 & 1 - (\lambda_2 + \mu_1) & 0 & \lambda_2 \\ \mu_2 & 0 & 1 - (\lambda_1 + \mu_2) & \lambda_1 \\ 0 & \mu_2 & \mu_1 & 1 - (\mu_1 + \mu_2) \end{bmatrix} \tag{14}$$

Approximation for getting the steady state probability is solving the algebra equation below

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} -(\lambda_1 + \lambda_2) & \lambda_1 & \lambda_2 & 0 \\ \mu_1 & -(\lambda_2 + \mu_1) & 0 & \lambda_2 \\ \mu_2 & 0 & -(\lambda_1 + \mu_2) & \lambda_1 \\ 0 & \mu_2 & \mu_1 & -(\mu_1 + \mu_2) \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \end{bmatrix} \tag{15}$$

And the solutions are

$$P_1 = \frac{\mu_1 \mu_2}{(\lambda_1 + \mu_1)(\lambda_2 + \mu_2)}$$

$$P_2 = \frac{\lambda_1 \mu_2}{(\lambda_1 + \mu_1)(\lambda_2 + \mu_2)}$$

$$P_3 = \frac{\mu_1 \lambda_2}{(\lambda_1 + \mu_1)(\lambda_2 + \mu_2)}$$

$$P_4 = \frac{\lambda_1 \lambda_2}{(\lambda_1 + \mu_1)(\lambda_2 + \mu_2)} \tag{16}$$

In Plan 2, the components are arranged in parallel connection, thus the availability and unavailability systems are, respectively:

$$A = P_1 + P_2 + P_3 = \frac{\mu_1\mu_2 + \lambda_1\mu_2 + \mu_1\lambda_2}{(\lambda_1 + \mu_1)(\lambda_2 + \mu_2)} \tag{17}$$

$$U = P_4 = \frac{\lambda_1\lambda_2}{(\lambda_1 + \mu_1)(\lambda_2 + \mu_2)} \tag{18}$$

To find MTTF, assume S3 and S4 are absorbing conditions, thus

$$\begin{array}{c|cccc} & S4 & S3 & S1 & S2 \\ \hline S4 & 1 & 0 & 0 & 0 \\ S3 & 0 & 1 & 0 & 0 \\ S1 & 0 & \lambda 2 & -(\lambda 1 + \lambda 2) & \lambda 1 \\ S2 & \lambda 2 & 0 & \mu 1 & -(\lambda 2 + \mu 1) \end{array} \tag{19}$$

Based on the above matrix, the matrix Q is

$$Q = \begin{bmatrix} -(\lambda_1 + \lambda_2) & \lambda_1 \\ \mu_1 & -(\lambda_2 + \mu_1) \end{bmatrix} \tag{20}$$

And the fundamental matrix is

$$[I - Q]^{-1} = \frac{1}{\lambda_1\lambda_2 - 2\lambda_1\mu_1 - \lambda_2^2 + \lambda_2\mu_1} \begin{bmatrix} -(\lambda_2 + \mu_1) & \lambda_1 \\ \mu_1 & (\lambda_1 + \lambda_2) \end{bmatrix} \tag{21}$$

Based on the fundamental matrix, MTTF is

$$MTTF = \frac{-(\lambda_2 + \mu_1) + \lambda_1}{\lambda_1\lambda_2 - 2\lambda_1\mu_1 - \lambda_2^2 + \lambda_2\mu_1} = \frac{\lambda_1 - \lambda_2 + \mu_1}{\lambda_1\lambda_2 - 2\lambda_1\mu_1 - \lambda_2^2 + \lambda_2\mu_1} \tag{22}$$

3. RESULTS AND DISCUSSIONS

For facilitating calculation, physical configuration is shown in network blocks. In the existing network, based on observation in Kotabatak field, there is only one switching device for providing communication link to rural area. Detail of the link can be seen in table 2.

Table 2. Network Link In The Existing Network

No.	Link	Distance (km)	Equipment
1.	Kotabatak – KBGS	39	3750+spf+FC+FO+FC+splice+spf+3750
2.	KBGS – Petapahan	22	3750+spf+FC+FO+FC+splice+spf+3750
3.	Petapahan – KBSS	19	3750+spf+FC+FO+FC+splice+spf+3750
4.	KBSS – Kotabatak	36	3750+spf+FC+FO+FC+splice+spf+3750
	Total	116	

While modeling of the system blocks is shown in Fig. 6.

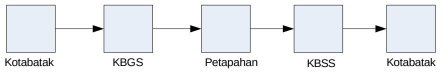

Fig. 6. Network blocks in the existing network

To gain availability and system downtime, it is necessary to calculate λ and μ in total,

$\lambda = \lambda_{\text{Kotabatak-KBGS}} + \lambda_{\text{KBGS-Petapahan}} + \lambda_{\text{Petapahan-KBSS}} + \lambda_{\text{KBSS-Kotabatak}}$
$= 2.667778888 \times 10^{-6}$ per-hour

$\mu=\mu_{\text{Kotabatak-KBGS}}+\mu_{\text{KBGS-Petapahan}}+\mu_{\text{Petapahan-KBSS}}+\mu_{\text{KBSS-Kotabatak}}$
$=0.14943312$ per-hour

Thus, using Eq. (6), the availability is
$A=\left(\frac{\mu}{\mu+\lambda}\right)2=0.999964304\times100\%=99.9964304\%$

If the unavailability

$$U=\frac{2\lambda\mu+\lambda^2}{(\lambda+\mu)^2}=3.59\ x\ 10^{-5}$$

Then the system downtime is 18.87 minute/year.

In Plan 1, physical configuration is still the same as the existing network. However, in Kotabatak, there is an additional device, which is a switch. Thus, Plan 1 has one additional link of five links with a distance of 119 km, compare to the existing network. Equipment details for Plan 1 can be seen in table 3.

Table 3. Network Link in Plan 1

No.	Link	Distance (km)	Equipment
1.	Kotabatak old – KBGS	39	3750+spf+FC+FO+FC+splice+spf+3750
2.	KBGS – Petapahan	22	3750+spf+FC+FO+FC+splice+spf+3750
3.	Petapahan – KBSS	19	3750+spf+FC+FO+FC+splice+spf+3750
4.	KBSS – Kotabatak new	36	3750+spf+FC+FO+FC+splice+spf+3750
5.	Kotabatak new – Kotabatak old	3	3750+spf+FC+FO+FC+spf+3750
	Total	119	

Modeling of the system blocks is similar to the existing network, except for additional device, shown in Fig. 7.

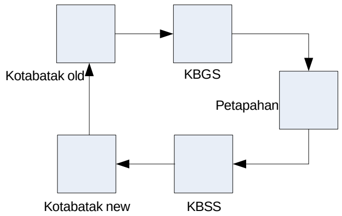

Fig. 7. Network blocks in Plan 1

From the modeling, it known as a system with two identical components, and has series connection. In this system, all of components must be work or, in the other words, must not fail. Because failure in one component in the series connection will cause system failure. Using the same technique in the existing network for calculating availability and system downtime, we get 99.9966112% and 17.81 minute/year, respectively.

In Plan 2, communication link is modified into two different paths, so there are failure and repair rates in both paths. There are two links in first path, and three links in the other path, seen in table 4.

Table 4. Network Link in Plan 2

No.	Path 1	Distance (km)	Equipment
1.	Kotabatak old – KBGS	39	3750+spf+FC+FO+FC+splice+spf+3750
2.	KBGS – Petapahan	22	3750+spf+FC+FO+FC+splice+spf+3750
	Total	61	
No.	**Path 2**	**Distance (km)**	**Equipment**
1.	Kotabatak old – Kotabatak new	3	3750+spf+FC+FO+FC+spf+3750
2.	Kotabatak new – KBSS	36	3750+spf+FC+FO+FC+splice+spf+3750
3.	KBSS – Petapahan	19	3750+spf+FC+FO+FC+splice+spf+3750
	Total	58	

System block modeling in Plan 2 is modified from Plan 1 as shown in Fig. 8.

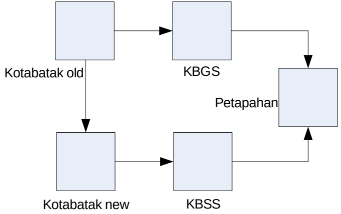

Fig. 8. Network blocks in Plan 2

Path 1 is from Kotabatak old to Petapahan via KBGS, while path 2 is via Kotabatak new – KBSS, with failure rates λ_1, λ_2 and repair rates μ_1, μ_2, respectively. Thus,

$$\lambda_1 = \lambda_{\text{Kotabatak old-KBGS}} + \lambda_{\text{KBGS-Petapahan}} = 1.343737464\times10^{-6} \text{ per-hour}$$

$$\mu_1 = \mu_{\text{Kotabatak old-KBGS}} + \mu_{\text{KBGS-Petapahan}} = 0.07435297 \text{ per-hour}$$

$$\lambda_2 = \lambda_{\text{Kotabatak old-Kotabatak new}} + \lambda_{\text{Kotabatak new-KBSS}} + \lambda_{\text{KBSS-Petapahan}} = 1.898509431\times10^{-6} \text{ per-hour}$$

$$\mu_2 = \mu_{\text{Kotabatak old-Kotabatak new}} + \mu_{\text{Kotabatak new-KBSS}} + \mu_{\text{KBSS-Petapahan}} = 0.116867172 \text{ per-hour}$$

Availability in this plan uses parallel connection which system is still running although one path is not working. Using Eq. (17) and (18), we get

$$A = \frac{\mu_1\mu_2 + \lambda_1\mu_2 + \mu_1\lambda_2}{(\lambda_1+\mu_1)(\lambda_2+\mu_2)} = 0.999999998 \times 100\% = 99.9999998\%$$

$$U = \frac{\lambda_1 \lambda_2}{(\lambda_1 + \mu_1)(\lambda_2 + \mu_2)} = 2.93 \times 10^{-10}$$

Therefore, the system downtime is 1.54×10-4 minute/year.

From calculation above, we get increasing in availability from the existing network to Plan 1 is 0.0001808%, while there is 0.0033886% increasing from plan 1 to plan 2. Thus, availability from the existing network to plan 2 in 0.0035694% is significantly increase. It can be concluded that using two different paths will provide better availability.

4. CONCLUSION

From calculation above, we get increasing in availability from the existing network to Plan 1 is 0.0001808%, while there is 0.0033886% increasing from plan 1 to plan 2. Thus, availability from the existing network to plan 2 in 0.0035694% is significantly increase. It can be concluded that using two different paths will provide better availability.

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