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ASSESSMENT OF AVAILABILITY OF STREET LIGHT SYSTEM: A STUDY OF WARRI, DELTA STATE, NIGERIA

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ABSTRACT
The study computes the availability of street lighting system in Warri. This system under study consists of subsystems that are known as workstations. A generator and sets of street light make up a workstation. The power source and the street lighting were modeled into series and parallel combinations. Reliability Block Diagrams and Path Tracing Method were employed assuming independent failure of the components. The availability of the set of street lightings, workstations and hence the availability of the system were determined. Results of the study show that users in Cemetery road had the least availability of 62.19% for the period. The implication is that users travelling along this road experienced wide variation of light that could lead to accidents.

Keywords: *Availability, Street Lighting and Reliability block diagram*

NOMENCLATURE

A	Availability
A_G	Availability of generator
A_{PLws},	Availability of street lights in P_{Lws}
A_{PRws}	Availability of street lights in P_{Rws}
A_S	Availability of the system
A_{WS}	Availability of workstation
G	Generator or power source
n	Number of trials or generators or workstations
N	Total number of lamps
P_{Lws}, P_{Rws}	Sets of street lighting attached to a generator or power source to the left and right respectively
P_L, P_R	Street light (lamps) attached to a generator or power source to the left and right respectively
WS	workstation

1. INTRODUCTION

A well designed, fixed street and roadway lighting is a valuable infrastructure investment because it can provide social and economic benefits to the community [1]. Lighting installation must create an environment that ensures clear visibility and a precise perception of people and objects within the lit areas. Like other repairable systems, their reliability and availability depend on how well the individual components perform because each item contributes its own quarter.

Studies show that performance of Street lighting systems can be determined by measuring the luminance and illuminance of the light falling on the task plane [2]-[5]; The metric, luminaire system application efficacy (LSAE), builds upon the concept of application efficacy, which was devised to evaluate the delivery of light to where it is needed in the most energy efficient manner. Application efficacy was defined as the average luminous flux within a specific solid angle per unit power, [6, 7]. The situation is different when the quality of the light on the task plane

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is modeled into full light, partial and complete darkness, [7].

The availability importance measure of a component/subsystem of the Street lighting system is indexes that show how far the individual component contributes to the overall system availability, [8]. A good maintenance implementation and control policy will put the system in a good state. As part of ways of ensuring availability, control of public lighting and reducing energy consumption, research shows that street lighting can be stopped automatically after night, [9] and when there is no human movement in the street at night using a wireless Zig-Bee [10], [11]. Integration of sensors and Zig-Bee-based wireless sensor modules can furnish an optimal platform for an innovative LED streetlight application [12].

More so, the integration of street lighting monitoring and control data with the building management system can reduce energy by 45% in comparison to conventional street lighting system, especially without the use of monitoring and control, [13]. In [14] the combination of the concept of Internet of Things (IoT) and LED streetlight during harsh weather (fog, rain, snow, etc.), accident can be prevented on our roads. Monitoring with good maintenance will ensure sustainability of street lighting system. Various maintenance models that deal with problem of finding optimal inspection policies for systems which are subject to failures have been proposed, [15-22].

The objectives of this study are to: model the streetlights as they are installed and powered into workstations; determine the availability of the street lights in the workstations; determine the availability of the workstations and hence determine the availability of the system using path tracing method of reliability block diagram.

In order to keep this study within reasonable limits, the system was monitored between the hours of 6pm and 6am for a period of four months (January, February, March and April 2010) along Delta Steel Company (DSC) road, Okere, Odion and Cemetery roads. The street light is powered by 6 generating plants along the DSC (WS_1, WS_2 and WS_3 – Army gate installed 2007), Cemetery, Odion and Okere roads (WS_4, WS_5 and WS_6 installed 2008). This excludes the solar powered ones in the city.

2. MATERIALS AND METHOD

The data collected for the uptime and downtime of the generators powering the street lights in the streets are tabulated in Table 1. While values of the number of street lights working in the different streets are tabulated in Table 2.

2.1 Availabilities of the Sets of Street Lighting

The street light *as they are installed in each of the road* is shown in Figure 1. We let each lamp to the left of the power source, G to be P_{L1}, P_{L2}, P_{L3}, . . . , P_{Ln} and those to the right be P_{R1}, P_{R2}, P_{R3}, . . . , P_{Rn}. Because the failure of a lamp does not affect any other, a reliability block diagram is drawn as shown in Figure 2a. The reliability block diagram of Figure 2a is equivalent to that shown in Figure 2b

Availabilities in sample space P_{PLws} and P_{RLws} in each of the road in the city are the probabilities – $A(P_{Lws}) = \frac{P_{Lws}}{N}$ and $A(P_{Rws}) = \frac{P_{Rws}}{N}$ respectively – of having complete lighting from the sample space. Using data obtained for the period (from Table 2), all values of $A(P_{Lws})$ and $A(P_{Rws})$ for n = 17 trials in the different streets/roads were evaluated and tabulated in table 3. The availabilities of street light in P_{Lws} and P_{Rws} for the period is the mean of $A_1(P_{Lws})$, $A_2(P_{Lws})$, . . . , $A_{17}(P_{Lws})$ and $A_1(\mathbf{P}_{Rws})$, $A_2(\mathbf{P}_{Rws})$, . . . , $A_{17}(\mathbf{P}_{Rws})$ respectively, based on the assumption that the components are identical and independent. Therefore the availabilities of set of light P_{Lws} and P_{Rws} in WS_1, are $A_{PLws1} = 0.5294$ and $A_{PRws1} = 0.4983$.

Table 1. Uptime/downtime of generators (Jan.-April, 2010)

	G1		G2		G3		G4		G5		G6	
	Upt (hr)	Dnt (hr)	Upt (hr)	Dnt (hr)	Upt (hr)	Dnt (hr)	Upt (hr)	Dnt (hr)	Upt (hr)	Dnt (hr)	Upt (hr)	Dnt (hr)
Jan	351	21	345	27	354	18	295	77	321	51	333	39
Feb	331	5	326	10	334	2	256	80	323	13	327	9
Mar	366	6	360	12	366	6	336	36	349	23	354	18
April	360	-	360	-	360	-	346	14	353	7	355	5
Total	1408	32	1391	49	1414	26	1233	207	1346	94	1369	71

Table 2. Number of lamps with complete lighting in each sets of street light (Jan – April 2010)

	WS1		WS2		WS3		WS4		WS5		WS6	
	P_{Lws}	P_{Rws}	P_{Lws}	P_{Rws}	P_{Lws}	P_{Rws}	P_{Lws}	P_{Rws}	P_{Lws}	P_{Rws}	P_{Lws}	P_{Rws}
n	N=19	N=17	N=19	N=31	N=17	N=35	N=20	N=20	N=19	N=21	N=24	N=35
1	7	5	11	14	15	29	0	0	16	15	18	19
2	7	5	12	14	14	17	0	0	16	14	16	20
3	6	5	12	13	7	10	14	16	16	14	15	28
4	15	7	12	13	5	8	13	12	12	13	18	19
5	13	8	8	20	14	28	13	12	14	17	18	17
6	13	12	8	21	13	22	0	0	14	17	19	18
7	12	12	12	17	12	21	0	0	12	13	14	28
8	11	12	15	23	12	20	13	10	14	17	12	20
9	12	12	15	23	12	20	9	10	10	16	12	21
10	10	7	15	23	7	15	9	10	10	16	18	20
11	7	7	15	23	12	22	17	17	10	16	17	17
12	7	7	15	23	7	15	17	15	11	20	15	18
13	7	7	15	20	12	21	17	15	11	20	11	18
14	7	7	14	19	14	21	13	12	9	17	12	21
15	7	7	14	19	14	22	11	9	9	17	18	32
16	15	12	14	19	14	21	12	10	13	17	15	32
17	15	12	15	23	15	17	10	8	13	17	17	30

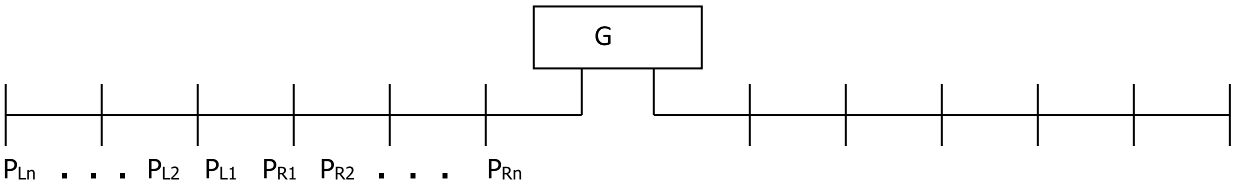

Figure 1: Schematic diagram of Street light and a power source as installed in each road

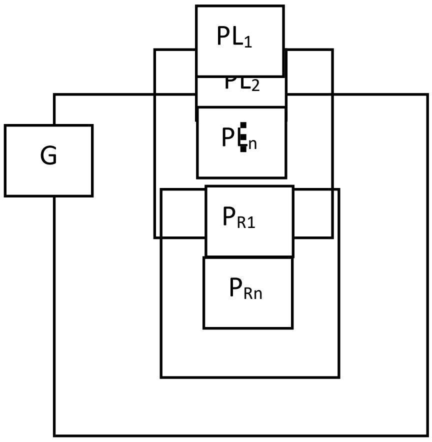

Figure 2a: RBD of a Street light in each road

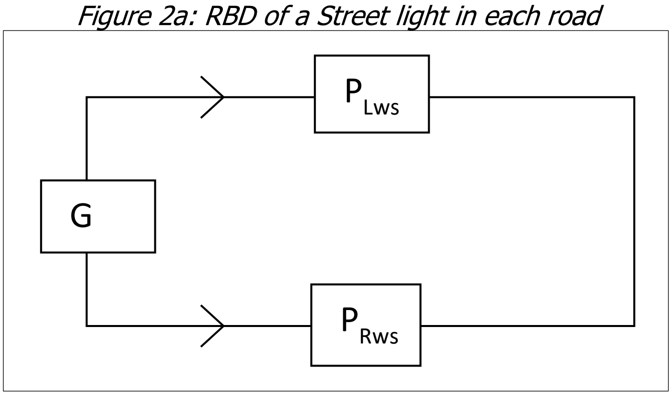

Figure 2b: RBD of a Street light in each road

Table 3. Availabilities of sets of streetlight P_{Rws} and P_{Lws} (Jan-April 2010)

DSC₁ (WS1)		DSC₂(WS2)		Army Gate(WS3)		Cemetery Road(WS4)		Odion Road(WS5)		Okere Road(WS6)	
$A(P_{Lws})$	$A(P_{Rws})$	$A(P_{Lws})$	$A(P_{Rws})$	$A(P_{Lws})$	$A(P_{Rws})$	$A(P_{Lws})$	$A(P_{Rws})$	$A(P_{Lws})$	$A(P_{Rws})$	$A(P_{Lws})$	$A(P_{Rws})$
0.3684	0.2941	0.5789	0.4516	0.8824	0.8286	0.0000	0.0000	0.8421	0.7143	0.7500	0.5429
0.3684	0.2941	0.6316	0.4516	0.8235	0.4857	0.0000	0.0000	0.8421	0.6667	0.6667	0.5714
0.3158	0.2941	0.6316	0.4194	0.4118	0.2857	0.7000	0.8000	0.8421	0.6667	0.6250	0.8000
0.7895	0.4118	0.6316	0.4194	0.2941	0.2286	0.6500	0.6000	0.6316	0.6190	0.7500	0.5429
0.6842	0.4706	0.4211	0.6452	0.8235	0.8000	0.6500	0.6000	0.7368	0.8095	0.7500	0.4857
0.6842	0.7059	0.4211	0.6774	0.7647	0.6286	0.0000	0.0000	0.7368	0.8095	0.7917	0.5143
0.6316	0.7059	0.6316	0.5484	0.7059	0.6000	0.0000	0.0000	0.6316	0.6190	0.5833	0.8000
0.5789	0.7059	0.7895	0.7419	0.7059	0.5714	0.6500	0.5000	0.7368	0.8095	0.5000	0.5714
0.6316	0.7059	0.7895	0.7419	0.7059	0.5714	0.4500	0.5000	0.5263	0.7619	0.5000	0.6000
0.5263	0.4118	0.7895	0.7419	0.4118	0.4286	0.4500	0.5000	0.5263	0.7619	0.7500	0.5714
0.3684	0.4118	0.7895	0.7419	0.7059	0.6286	0.8500	0.8500	0.5263	0.7619	0.7083	0.4857
0.3684	0.4118	0.7895	0.7419	0.4118	0.4286	0.8500	0.7500	0.5789	0.9524	0.6250	0.5143
0.3684	0.4118	0.7895	0.6452	0.7059	0.6000	0.8500	0.7500	0.5789	0.9524	0.4583	0.5143
0.3684	0.4118	0.7368	0.6129	0.8235	0.6000	0.6500	0.6000	0.4737	0.8095	0.5000	0.6000
0.3684	0.4118	0.7368	0.6129	0.8235	0.6286	0.5500	0.4500	0.4737	0.8095	0.7500	0.9143
0.7895	0.7059	0.7368	0.6129	0.8235	0.6000	0.6000	0.5000	0.6842	0.8095	0.6250	0.9143
0.7895	0.7059	0.7895	0.7419	0.8824	0.4857	0.5000	0.4000	0.6842	0.8095	0.7083	0.8571

Similarly, the availabilities in WS_2, WS_3, WS_4, WS_5, and WS_6 are evaluated $A_{PLws2} = 0.6873$ and $A_{PRws2} = 0.6205$, $A_{PLws3} = 0.6886$ and $A_{PRws3} = 0.5529$, $A_{PLws4} = 0.4941$ and $A_{PRws4} = 0.4588$, $A_{PLws5} = 0.6502$ and $A_{PRws5} = 0.7731$, $A_{PLws6} = 0.6495$ and $A_{PRws6} = 0.6353$ respectively.

2.2 Availabilities of the Workstation

A workstation is made up of a power source and a set of street lighting in each road as shown in a schematic diagram of Figure 2b. The failure modes in this system are the power source and any components in the luminaires. Assuming independent failure and using Path tracing method, the paths for the RBD in Figure 2b are:

$$X_1 = G, P_{Lws} \quad \text{and} \quad X_2 = G, P_{Rws} \qquad (1)$$

But the probability of success [23] of the workstation is given by

$$P(X_1 \cup X_2) = P(X_1) + P(X_2) - P(X_1 \cap X_2) \qquad (2)$$

This implies that

$$P(G, P_{Lws} \cup G, P_{Rws}) = P(G, P_{Lws}) + P(G, P_{Rws}) - P(P_{Lws}, G, P_{Rws}) \qquad (3)$$

But

$$P(G, P_{Lws}) = A_G A_{PLws} \qquad (4)$$

That is, product of availabilities of G and P_{Lsw} since their path is in series (Figure 2b). Also,

$$P(G, P_{Rws}) = A_G A_{PRws} \qquad (5)$$

And $P(P_{Lws}, G, P_{Rws}) = A_{PRws} A_{PLws} A_G = A_{WS}$ (6)

Substituting equations 4, 5 and 6 into 3, the availability of the workstation is:

$$A_{WS} = A_G A_{PLWS} + A_G A_{PRWS} - A_{PRWS} A_{PLWS} A_G$$
$$= A_G (A_{PLWS} + A_{PRWS} - A_{PRWS} A_{PLWS})$$
$$= A_G [A_{PLWS} + A_{PRWS}(1 - A_{PLWS})]$$
$$= A_G [1 - 1 + A_{PLWS} + A_{PRWS}(1 - A_{PLWS})]$$
$$A_{WS} = A_G [1 - (1 - A_{PLWS}) + A_{PRWS}(1 - A_{PLWS})]$$
$$= A_G [1 + A_{PRWS}(1 - A_{PLWS}) - (1 - A_{PLWS})]$$
$$= A_G [1 + (A_{PRWS} - 1)(1 - A_{PLWS})]$$
$$\therefore A_{WS} = A_G [1 - (1 - A_{PRWS})(1 - A_{PLWS})] \qquad (7)$$

The availabilities of each generator (power source) were evaluated using

$$A_G = \frac{\text{uptime}}{\text{uptime} + \text{downtime}} \qquad (8)$$

And the availabilities of the different workstations are then evaluated using equations 4 to 7 and are presented in Figure 3.

2.3 Availability of the System

There are a number of workstations in each of the road of the city that make up the system of street lighting. The availability/reliability block diagram of the system can be drawn as shown in Figure 4.

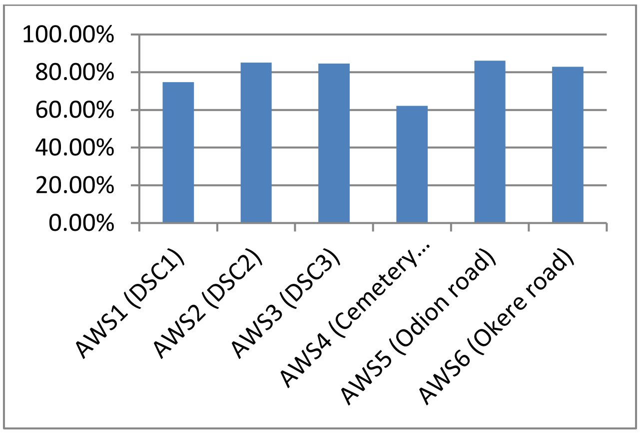

Figure 3: Workstation's availability (Jan-April 2010)

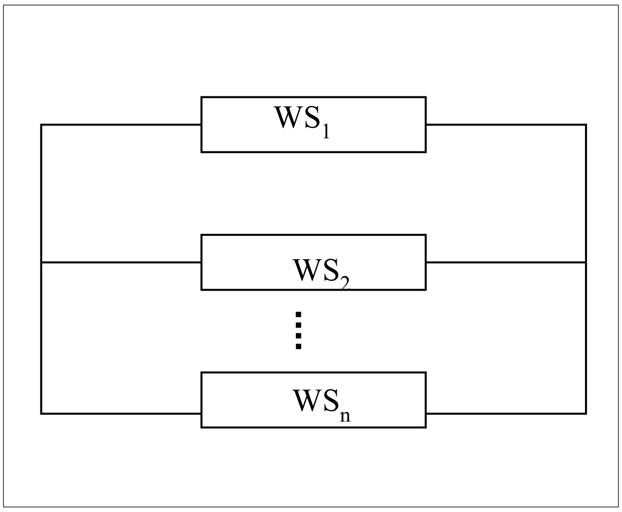

Figure 4. RBD of the system

The failure of a workstation does affect the system's availability but does not make the whole system to fail. The availability of the system is therefore:

$A_s = 1 - [(1 - A_{WS1})(1 - A_{WS2}) \;...\; (1 - A_{WSn})]$ or

$$A_s = 1 - \prod_{i=1}^{n}(1 - A_{wsi}) \qquad (9)$$

This can be expressed in terms of A_G, A_{PRws}, and A_{PLws} by substituting equation 7 into 8 to obtain:

$$A_s = 1 - \prod_{i=1}^{n}\{1 - A_{Gi}[1 - (1 - A_{PRwsi})(1 - A_{PLwsi})]\} \qquad (10)$$

The system availability with all workstations working is configured using equation 9,

A_s = 1-(1-0.7469)(1-0.8514)(1-0.8452)(1-0.6219)(1-0.8605)(1-0.8292)

Therefore, As = 0.999948 = 99.9948%

3. RESULTS AND DISCUSSION

The availabilities of each power source were evaluated and it was discovered that the availability of generator three in DCS3 has the highest availability. While generator number 4 is the lowest available for the period because it experienced more period between failures thereby posing greater challenge to maintenance crew.

Workstation availability depends on generator and a number of street-lights put together, though A_{G3} being 98.19% is the highest, that does not make subsystem WS3 (A_{WS3} = 84.52%) most available (See Figure 3). The study reveals that A_{WS5} (86.05%) is most available. While subsystem A_{WS4} =62.19% (A_{G4} = 0.8563, A_{PLws4} = 49.41% and A_{PRws4} = 45.88%) implies greatest challenge to the company in charge of maintenance of the system.

4. CONCLUSION

In conclusion, the availabilities of the various components of the street lights in Warri have been determined for the period between January and April 2010. First and foremost, the availability of each generator that powers the street lights has been determined: 97.78% for DSC_1, 96.60% for DSC_2, 98.19% for DSC_3, 85.63% for Cemetery road, 93.47% for Odion road and 95.07% for Okere road. Secondly, the availability of the street light sector by sector, (the availability of the street lights in the workstations) was determined. In DSC_1, 52.94% to the left and 49.83% to the right of the generator; in DSC_2, 68.73% to the left and 62.05% to the right; in DSC_3, 68.86% to the left and 55.29% to the right; in Cemetery road, 49.41% to the left and 45.88% to the right; in Odion road, 65.02% to the left and 77.31% to the right; in Okere road, 64.95% to the left and 63.53% to the right. The availability of the workstations was evaluated as: 74.69% for DSC_1, 85.14% for DSC_2, 84.52% for DSC_3, 62.19% for Cemetery road, 86.05% for Odion and 82.92% for Okere. From these results, it is clear that the availabilities of the street lights are relatively low. This implies that more components are failing in the street light than in the generators.

5. RECOMMENDATIONS

It is therefore recommended that street light faults should be reported immediately and authorities concerned should respond by solving the problem. Street light patrol should be on ground to check if there is any problem along the line. Apart from corrective maintenance, periodic maintenance should be practiced by authorities in charge and above all various maintenance models that deal with problem of finding optimal inspection policies for systems which are subject to failures should be employed.

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