IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

MODELING UNDER MATLAB OF THE FUNCTIONAL AVAILABILITY OF A MEDICAL DEVICE BY A PROCESS OF MARKOV

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ABSTRACT
The reliability diagram of the parallel series type is used to look further into the study of the functional availability of a medical device. When one is interested at the binary state of operation of each component, the diagram of the parallel-series type, combined with a process of Markov in three states, can be useful like a tool to study the three situations of operation of a medical device. Adopted methodology allowed the establishment of a generating square matrix of the probabilities of the situations according to the component count or of characteristics.

KEYWORDS: Diagram, components, functions, matrix, probability, situation.

INTRODUCTION
Each device admits a reliability diagram of the type parallel-series (TSP), *which* makes to look further into the study of the functional availability. Diagram TSP also supposes that the device admits subsystems only formed as of his components ensuring the specific functions. Actually, a parallel-series system consists of M independent subsystems series-connected and in each $subsystem_i$ (i from 1, 2, 3 to. M), there is N_i components connected in parallel [1] Contrary to the assumptions made by [1] on which the authors supposed that each component can be in several states, we suppose to apply the binary state (0 or 1) of operation, **proposed by** [2][3][4][5][6][7], to the medical devices. Indeed, each component/characteristic can have a binary state (0 or 1): for 1 accepted and for 0 not-accepted. It is about a specificity of the medical devices under cover of the tests of quality control indispensably included in a protocol of major and minor maintenance. Really, we seek the availability of one $subfunction_i$ which is ensured by N_i component (characteristic) having to function simultaneously. Each component (characteristic) has its share of contribution to $subfunction_i$ and none component (characteristic) can only ensure $subfunction_i$. Moreover, in the event of failure of component (characteristic), the $subfunction_i$ is not completely failing and can be ensured in degraded mode. The objective of this work is to estimate the probabilities which describe the availability of one $subfunction_i$ knowing which must be ensured by N_i component/characteristic. We can observe three different situations S_1, S_2, S_3.

- S_1: $subfunction_i$ is ensured 100 %.
- S_2: $subfunction_i$ is partially assured (operation in degraded mode).

- S_3 : $subfunction_i$ is ensured 0 % (it is not at all assured).

This problem can be solved by the Markov method who stipulates here that, to seek the availability of $subfunction_i$, it is to find the probabilities P_{S1} , P_{S2} , P_{S3} , leading to the $subfunction_i$ in each situation S_1 , S_2 , S_3

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- Page type will be A4 with normal margin, word spacing should be 1.
- No space will be added before or after paragraph.
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MATERIALS AND METHODS

Material

The material is made up mainly of the model parallel series of a device suggested by [1], graphs of Markov and MATLAB2010a software.

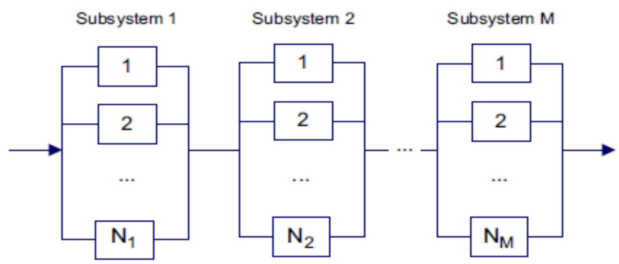

Figure 1: ***Illustration of the model of system parallel series proposed by [1]***

Methodology and formulation

The method is based on the configuration parallel-series of a system of [1] (see figure 1), process of Markov in three states and generating matrix of state probabilities. Then, we wrote a program under MATLAB2010a which takes the failure rates and the maintainability rates of N_i the component/characteristic, to generate the probabilities P_{S1} , P_{S2} , P_{S3} . With ($N_i + 1$) different numbers of P_{S3} .

- Under the method of the Markov graphs, as $subfunction_i$ is made up of N_i component/characteristic it can have ($N_i + 1$) possible situations.
- Let us specify here that the situations S_1 and S_3 are most extreme, respectively desired and no desired. S_1 and S_3 are stable and can always exist independently.
- The number of times we can hope for the situation S_1 is one (1) time.
- The number of times we can hope for the situation S_3 is one (1) times.
- When $N_i = 1$ the situation S_2 does not exist and we can hope for only the two situations S_1 and S_3 .
- For all $N_i >= 2$, the situation S_2 can exist and we can hope for the situation S_2 time.
- For all $N_i >= 2$, the total number of various situations which should be hoped for this is [$(1)\ S_1 + (N_i - 1)\ S_2 + (1)\ S_3$]. From where, $(N_i + 1)$ situations and consequently, $(N_i + 1)$ probabilities should be sought.
- The generating matrix equation of probabilities can be written gradually according to N_i .

<u>Case 1:</u> $N_i = 1$

Table 1. Parameters of the model for $N_i = 1$

p_s	$p_{s1}; p_{s2}$
λ	λ_1
μ	μ_1

The matrix expression based on the parameters of the table 1 is given to the equation (1).

$$\begin{bmatrix} -\lambda_1 & \mu_1 \\ \lambda_1 & -\mu_1 \end{bmatrix} \times \begin{bmatrix} p_{S1} \\ p_{S2} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad (1)$$

The resolution of the equation (1) gives p_{s1} and p_{s2} checking the condition of the equation (2).

$$p_{s1} + p_{s2} = 1 \quad (2)$$

Case 2 : $N_i = 2$

Table 2 : Parameters of the model for $N_i = 2$

p_s	$p_{s1}; p_{s2}; p_{s3}$
λ	$\lambda_1; \lambda_2$
μ	$\mu_1; \mu_2$

The matrix expression based on the parameters of the table 2 is given to the equation (3).

$$\begin{bmatrix} -(\lambda_1+\lambda_2) & \mu_2 & 0 \\ (\lambda_1+\lambda_2) & -(\lambda_2+\mu_2) & (\mu_1+\mu_2) \\ 0 & \lambda_2 & -(\mu_1+\mu_2) \end{bmatrix} \times \begin{bmatrix} p_{s1} \\ p_{s2} \\ p_{s3} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad (3)$$

The resolution of the equation-3 gives p_{s1}, p_{s2} and p_{s3} checking the condition of the equation (4).

$$p_{s1} + p_{s2} + p_{s3} = 1 \quad (4)$$

Case 3: $N_i = 3$

Table 3 : Parameters of the model for $N_i = 3$

p_s	$p_{s1}; p_{s2}; p_{s3}; p_{s4}$
λ	$\lambda_1; \lambda_2; \lambda_3$
μ	$\mu_1; \mu_2; \mu_3$

The matrix expression based on the parameters of the table-3 is given to the equation (5).

$$\begin{bmatrix} -(\lambda_1+\lambda_2+\lambda_3) & (\mu_3) & 0 & 0 \\ (\lambda_1+\lambda_2+\lambda_3) & -(\mu_3+\lambda_2+\lambda_3) & (\mu_2+\mu_3) & 0 \\ 0 & (\lambda_2+\lambda_3) & -(\mu_2+\mu_3+\lambda_3) & (\mu_1+\mu_2+\mu_3) \\ 0 & 0 & (\lambda_3) & -(\mu_1+\mu_2+\mu_3) \end{bmatrix} \times \begin{bmatrix} p_{s1} \\ p_{s2} \\ p_{s3} \\ p_{s4} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (5)$$

The resolution of the equation (5) gives p_{s1}, p_{s2}, p_{s3} and p_{s4} checking the condition of the equation (6).

$$p_{s1} + p_{s2} + p_{s3} + p_{s4} = 1 \quad (6)$$

RESULT AND NUMERICAL APPLICATION

For $N_i = n$ and if we note G the generating matrix of probabilities for $(n+1)$ situations, G is a square matrix of $(n+1)\,\mathrm{x}\,(n+1)$ whose general expression, by deduction of equations 1, 2 and 3, is given according to the equation-7 with the condition of the equation (8).

ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

$$G=\begin{bmatrix} -(\sum_{i=1}^{N_i=n}\lambda_i) & (\sum_{i=n}^{N_i=n}\mu_i) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ (\sum_{i=1}^{N_i=n}\lambda_i) & \updownarrow & (\sum_{i=n-1}^{N_i=n}\mu_i) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & (\sum_{i=2}^{N_i=n}\lambda_i) & \updownarrow & (\sum_{i=n-2}^{N_i=n}\mu_i) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & (\sum_{i=3}^{N_i=n}\lambda_i) & \updownarrow & .. & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & .. & .. & .. & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & .. & .. & .. & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & .. & \updownarrow & (\sum_{i=3}^{N_i=n}\mu_i) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & (\sum_{i=n-2}^{N_i=n}\lambda_i) & \updownarrow & (\sum_{i=2}^{N_i=n}\mu_i) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & (\sum_{i=n-1}^{N_i=n}\lambda_i) & \updownarrow & (\sum_{i=1}^{N_i=n}\mu_i) \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & (\sum_{i=n}^{N_i=n}\lambda_i) & -(\sum_{i=1}^{N_i=n}\mu_i) \end{bmatrix} \quad (7)$$

With $G(i,i) = -[G(i-1,i) + G(i+1,i)] \equiv \updownarrow$ (8)

Consequently, the general matrix expression to determine $(n+1)$ the probabilities of each $(n+1)$ possible situation is given by the equation (9).

$$\begin{bmatrix} -(\sum_{i=1}^{N_i=n}\lambda_i) & (\sum_{i=n}^{N_i=n}\mu_i) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ (\sum_{i=1}^{N_i=n}\lambda_i) & \updownarrow & (\sum_{i=n-1}^{N_i=n}\mu_i) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & (\sum_{i=2}^{N_i=n}\lambda_i) & \updownarrow & (\sum_{i=n-2}^{N_i=n}\mu_i) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & (\sum_{i=3}^{N_i=n}\lambda_i) & \updownarrow & .. & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & .. & .. & .. & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & .. & .. & .. & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & .. & \updownarrow & (\sum_{i=3}^{N_i=n}\mu_i) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & (\sum_{i=n-2}^{N_i=n}\lambda_i) & \updownarrow & (\sum_{i=2}^{N_i=n}\mu_i) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & (\sum_{i=n-1}^{N_i=n}\lambda_i) & \updownarrow & (\sum_{i=1}^{N_i=n}\mu_i) \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & (\sum_{i=n}^{N_i=n}\lambda_i) & -(\sum_{i=1}^{N_i=n}\mu_i) \end{bmatrix} \times \begin{bmatrix} p_{s1} \\ p_{s2} \\ p_{s3} \\ .. \\ .. \\ .. \\ .. \\ p_{s(n-1)} \\ p_{s(n)} \\ p_{s(n+1)} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (9)$$

The resolution of the equation-9 gives $p_{s(n+1)}$ probabilities checking the condition of the equation (10).

$$p_{s1} + p_{s2} + p_{s3} + ... + p_{s(n-1)} + p_{s(n)} + p_{s(n+1)} = 1 \quad (10)$$

Tableau 4. Simulated probabilities of the possible situations for N_i from 1 to 10

N_i	p_{si}											$\sum p_{si}$
	p_{s1}	p_{s2}	p_{s3}	p_{s4}	p_{s5}	p_{s6}	p_{s7}	p_{s8}	p_{s9}	p_{s10}	p_{s11}	
1	0,8889	0,1111	-	-	-	-	-	-	-	-	-	**1,0000**
2	0,6538	0,3270	0,0192	-	-	-	-	-	-	-	-	**1,0000**
3	0,6398	0,3119	0,0468	0,0015	-	-	-	-	-	-	-	**1,0000**
4	0,4946	0,3915	0,1005	0,0128	0,0006	-	-	-	-	-	-	**1,0000**
5	0,6454	0,2816	0,0638	0,0084	0,0008	0,0000	-	-	-	-	-	**1,0000**
6	0,4619	0,4057	0,1101	0,0196	0,0024	0,0003	0,0000	-	-	-	-	**1,0000**
7	0,6389	0,2789	0,0706	0,0104	0,0011	0,0001	0,0000	0,0000	-	-	-	**1,0000**
8	0,3398	0,4831	0,1445	0,0286	0,0036	0,0004	0,0000	0,0000	0,0000	-	-	**1,0000**
9	0,4176	0,3647	0,1754	0,0362	0,0055	0,0005	0,0001	0,0000	0,0000	0,0000	-	**1,0000**
10	0,1786	0,4278	0,2637	0,1056	0,0211	0,0029	0,0003	0,0000	0,0000	0,0000	0,0000	**1,0000**

DISCUSSION

For each N_i (from 1 to 10), the table 4 presents the results of the numerical application. For each line of p_{si}, the first column is the probability of the first situation: i.e. probability so that all the components are functional. The last column is the probability of the last situation: i.e. probability so that none the components is functional. The other columns represent the probabilities of the intermediate situations. When the diagram parallel series of the device is well established, we can seek to purely bring back the functional model of the device in the shape of a diagram series. In this case, the principal concern is how to control or predict at any device moment useful, each of the three situations S_1, S_2, S_3 for a subsystem made up of Ni component/characteristic functioning in parallel. It is about a strategy to predict the operation level of a subsystem or a functional group given in equipment. The model is appropriate for the context of exploitation of a medical device. Indeed, the awaited functional availability is a function of the episodes of the patient health care. The binary state operation of a medical device is in fact broken up into extreme situations and intermediate situations. That it is the principal scientific contribution of this work compared to work of [2][3][4][5][6][7] on the binary states. An analysis of the results in table-4 reveals that, when the component number increases, the probabilities of the intermediate situations tend towards zero. Moreover, there is a difficulty to allot the intermediate probabilities to a corresponding component. They are the principal limits of the method suggested in this work. The method adopted for each $subfunction_i$ can be extended to all subfunctions of the equipment thus to the whole equipment especially, of the equipment equipped with a diagnostic software computer-assisted

CONCLUSION

The diagram of reliability of the parallel-series type is used to look further into the study of the functional availability of a medical device. When one is interested at the binary state of operation of each component, the diagram of the parallel series type combined with a process of Markov. This one in three states can service of a tool effective and innovating. To do that, the medical device is considered only by its subsystems formed by these components ensuring of the specific functions. The deployed method allows to estimate the various operation situations of the functional groups of a medical device. Consequently, one can deduce the risks and the levels from dysfunction of the device.

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ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

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