Improving the Mean Time to Failure of the System with the New Architecture of the Main Node with the Replacement Node of Industrial Wireless Sensor Networks for Monitoring and Control using Markov Model

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ABSTRACT:
Industrial and physical site information is sent to the monitoring center by sensors in wireless sensor networks so that they can easily control the process of a company in order to improve the optimal performance of the system until the failure occurs to monitor and control in wireless sensor networks. Sensors are exposed to a wide range of failures, possible hardware and software problems in normal conditions, extreme weather conditions or other conditions caused by harsh physical environment in the field of sensors. Therefore, there is a possibility of unpredictable failure for all types of sensors and with Industrial process monitoring, preventive status monitoring, prevented error and fault and failures. The focus of this article is to present a new architecture in improving the correct performance of the system, the replacement rate of more damaged nodes and timely replacement, at the time of the starting point of the failure, the main sensor with spare ones or healthy sensors with faulty ones. The proposed network structure is such that the spare node is placed in parallel with the main node; this method makes it possible for the spare node to be replaced in case of failure of the main node, and the failed node can be quickly repaired and put in a standby mode. Our proposed model is analyzed in terms of the average time of correct system operation until failure known as mean time to failure. In this article is presented and studied and evaluated, a new architecture to improve network performance against failure using Markov model and state probability, and mean failure rate for node fault tolerance, before failure with timely replacement in wireless sensor network. In the proposed architecture, the results show a better improvement of the system's correct performance in order to reduce the adverse effects of errors and failures and improve fault tolerance. The simulation results show that the advantage of using this method reduces the adverse effects of errors and failures and improves the optimal performance of the system in the industrial site.

KEYWORDS: Backup Node, Redundancy, Fault Tolerance, Failure Rate, Spare Sensor, Mean Time To Failure, Markov Model, Industrial Sensor Networks.

1. INTRODUCTION

One of the most important parameters in any system is Mean Time To Failure (MTTF)of the system until correct operation, which indicates the activeness of each system when needed and correct operation and avoiding error and failure system[1]. The mean time to failure of the system is obtained from the failure density function[2]. In this article is presented, a new architectural structure for calculating the mean time to equipment failure[3]. The sensor network can remain stable without interruption despite the failure of the sensor node[4]. The main goal of access from the

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control room and remote to the industrial site database equipment with high reliability [5]in order to improve mean time to failure (MTTF) for a better life of equipment and timely reconstruction and repairs and evaluation and management of failures; The increase of nodes and the replacement rate r and the failure rate β with the passing of the life of the equipment in the applied model in this project can be investigated in improving the mean time to failure of the system of different telecommunication layers[6].

Monitoring the industrial process is monitoring the preventive situation and preventing errors and faults. The difference between sensor failure and system failure is very important. Sensors are designed to monitor the system and their difference relationship is hierarchical, and system equipment validation is achieved by sensors and data measurement. In order to identify defective sensors and diagnose sensor malfunctions, the information of a sensor is used separately, the information of sensors is monitored and reviewed as characteristics and group characteristics of sensors and process history[7]. They are under supervision and investigation, so in order to protect and avoid malfunctions, it is necessary to improve the mean time to failure of the system [1].

The limitations of the WSN information system network can arise due to collisions, blocking, interference, collision, breakdown and attack in hostile environment or attackers' intrusion into information systems through the Internet network which leads to operational damage and is not legally allowed and they intend to access important information and other organizational resources [8] Also, in this regard, today the Cyber Physical Systems (self-adaptive) CPS [6] has been extensively researched of complex applications. Reliability is to achieve security and mean time to failure of the system. According to Figure 1, threats include three concepts of errors, mistakes, and failures that are being integrated[3]. Features and branches of reliability and the attributes include sensor information reliability–R(t),availability–A(t), safety–S(t), confidentiality, integrity, and maintainability–M(t); the means to achieve the dependability[9]: security, and the concept of reliability includes error prevention, error tolerance, error elimination, error prediction so that in order to contain fault prevention, fault tolerance, fault remove, fault forecasting. The well-known reliability tree for failure avoidance is shown and analyzed in Figure 1. Dependability is an integrating property and has been researched for a long time[10].

A fault tree is a visual representation of a combination of events that can cause an adverse event to occur. For different densities of nodes, consider multiple types of spares and draw the network graph for them, and then consider the nodes from the state without spares to those with spares using the Markov model and the Markov model for the nodes is drawn. Next, by solving the Markov equations, the availability and reliability function is obtained, and as a result, the mean time to failure or the average failure rate is obtained, and then the MTTF of the entire network is calculated. The results of the simulation, as we will see, show that in high densities, the use of shared spare nodes improves the MTTF, and also a limit is found from which the number of spare nodes can be increased It has no effect on improving MTTF [1, 11].

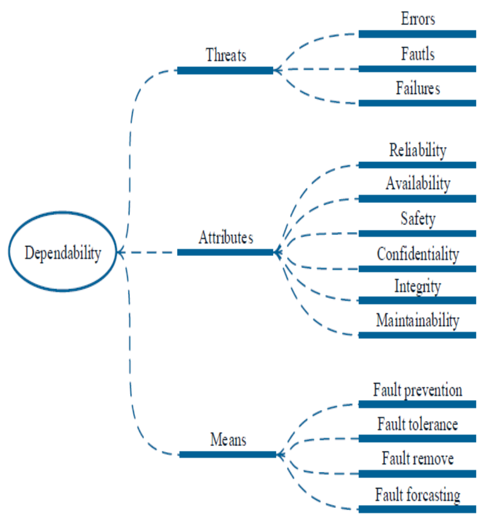


Fig. 1. Reliability credit dependability tree analysis designed for system monitoring [10].

A significant amount of the presented methods is to improve the reliability and quality of the network, in the field of information and challenges related to this issue, such as reliability in data density, intelligent traffic control, and the control arrival of information to the receiver. In the sensor network, the information collected in the cluster requires the minimum amount of data received from different sensor nodes.

The structure of the article is as follows: In the second part, accessibility and the mean time to failures of system are checked and then various types of replacement system models are presented, then in the third part, a review of the past works is given, and the two-element physical system with the function of repairing one failure and the possibility of replacing one mode or not repairing two failures due to the nature of the hot state of the system, and in the fourth part of work innovation, the complete and summarized model of reliability with two sensors similar to the original and standby and the possibility of replacing or repairing two failures due to the nature of the cold state has been investigated and analysis and mathematical relationships have been investigated and presented in order to improve reliability. In the fifth part simulation and evaluation, in the sixth part simulation results and finally in the seventh part the conclusion has been done.

2- Checking the accessibility and the mean time to failures of system

According to the real graph of the model in Figure 2, the relationship between system accessibility during the time and lifetime of the equipment and timely reconstruction and repairs has been evaluated to manage failures, and the accessibility can be repaired under any failure, but due to the wear and tear of the equipment, it is less than the previous value. Now, if we assume that the capability of full and timely repairs is covered, it can be returned to the first state according to Figure 3, and it can be used to calculate the mean time between two network failures according to (1) to (3) [12].

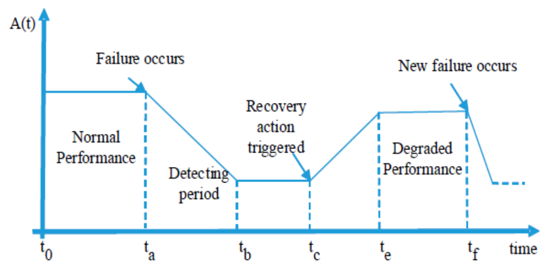


Fig. 2. real graph of system availability relationship during time and failure processing flow [3]

The mean time between two network failures[13] is equal to the sum of the average time required for repair plus the mean time to failure occurs [1].

$$MTBF = MTTF + MTTR \quad (1)$$

$$A(t) = \frac{MTTF}{MTTF + MTTR} = \frac{MTTF}{MTBF} \quad (2)$$

$$U(t) = 1 - A(t) = 1 - \frac{MTTF}{MTTF + MTTR} = \frac{MTTR}{MTTF + MTTR} = \frac{MTTR}{MTBF} \quad (3)$$

According to the model graph in Figure 2 [3], to calculate the average time between two failures according to relation (1) and the relation of system reliability or accessibility in relation (2) and the relation of system inaccessibility in relation (3) in the simplest case[6], two parameters are needed Main (MTBF) mean time between failures and MTTF is mean time to failure of a component or the time of failure[11] and also we need the parameter MTTR mean time to repair [4].

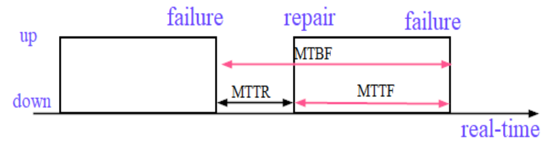


Fig. 3. The graph of the average time of network failure[6].

The current research is focused on a mechanism to provide an alternative work network that ensures the correct operation of the system to achieve accessibility according to the relation (2) by timely replacing spare sensor parts with faulty and disabled sensors [4]. And it is also important to discuss the sources of error. By solving the Markov equations and knowing the average failure rate, the MTTF of the total network is calculated [4, 12].

To check the error according to figure (4), it shows the sequence of occurrence of the error in the industrial site (physical layer) which leads to the error in the data layer [4] and then the possibility of failure and loss of the control system[2], It includes three concepts: the threats consist of errors, faults and failures;. A fault is a physical defect or partial changes in the phenomenon of the physical world, and an error is the cause of the fault, and in general, it happens in any system, and in a special, it leads to a deviation from the correctness of the world of information and communication, which is a the type of confusion is from the correct functioning of the system and finally[4], errors and deviations leads to failure. So failure is an event that occurs over time from error, and in fact, it is a special state of error and error is tolerable to some extent, and if it exceeds that limit, it leads to failure [2].

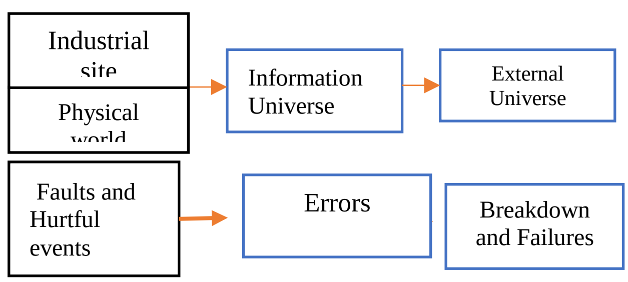


Fig. 4. The proposed model of the presence of an error until the occurrence of a failure and the sequence of occurrence of an error on the site (physical layer) [6].

The mean time to failure is calculated for two types and three types of sensors, and MTTF values for different λ or β are compared in both cases. Redundancy using the backup node [10] is used to increase fault tolerance in these networks. Using the Markov model, the probability of states and the average rate of failure are obtained[9]. The results show that increasing the number of spare parts increases fault tolerance [1].

2.1 TYPES OF DESIGN MODELS OF APPLIED REPLACEMENT SYSTEM IN FAULT TOLERANCE WITH REDUNDANT MEMBER AS SUPPORT AND SERIES, PARALLEL SYSTEM STRUCTURE

In order to tolerate errors and failures in the use of replacement systems, there are various models, and considering that replacement spare parts are divided into single-type and multi-type categories, single-type spare parts in case of type failure Certain sensors can be replaced; But multi-type spare parts can be replaced in case of failure of several types of sensors. It is possible to use all kinds of systems with redundant supporting or redundant members in the form of series, parallel and combined structures and the structure of the spare system. To investigate the impact of redundancy on the average downtime, usually different areas are considered, such as hardware redundancy, data redundancy and time redundancy. Systems with redundant members act as backups. The effect of path redundancy on the mean time to failure (MTTF) is investigated. Node redundancy is used to increase the reliability of the sensor network by using spare nodes[9].

If a system is designed with n sensors and suppose one of them, for example A_1 is the main sensor and the rest of the system sensors $(A_2, \ldots A_n)$ are spare. It can be used as a series or parallel structure as shown in figure (5). Since the system of serial structure with the interruption or failure of one leads to the interruption and failure of the whole system, in fact, in certain cases to improve the reliability function, MTTF of the whole network[3]. Also, the parallel structure of the system has a better efficiency in improving the reliability and MTTF of the whole network [7].

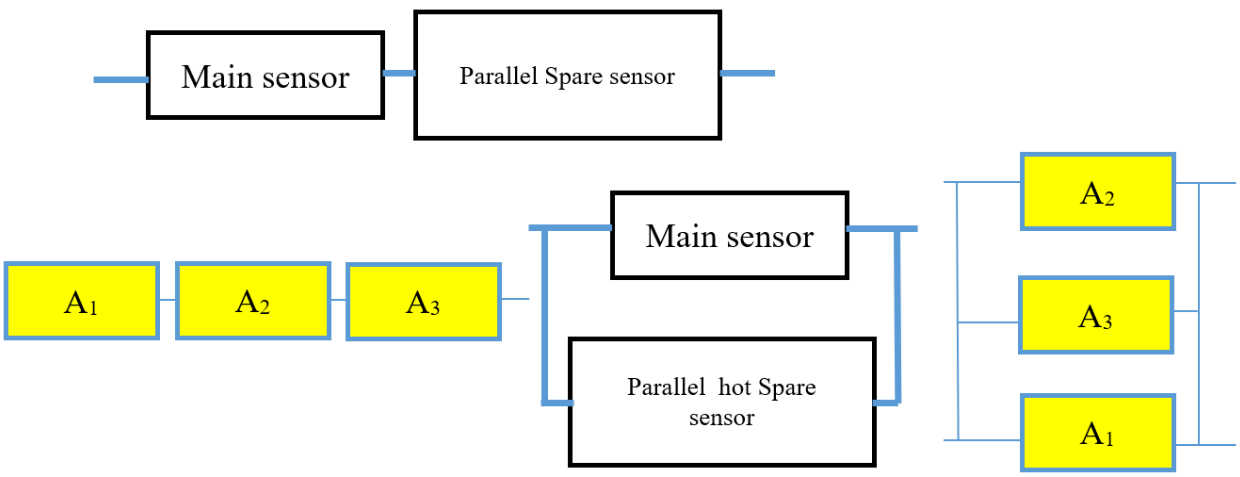


Fig. 5. Structure of series, parallel system[12].

3. A REVIEW PREVIOUS WORK RECORDS AND A REVIEW OF THE MODEL OF TWO PARALLEL SENSORS WITH THE ADDITION OF A STANDBY SENSOR AND THE POSSIBILITY OF REPLACING ONE MODE.

Failure tolerance is a type of system ability that allows the system to continue its operation after an error occurs in any of its parts. Reliability R(t) is the probability that a component of the system will continue to operate until time t and the useful life of the equipment can be increased to improve performance. MTTF can be obtained by finding the overall density function F(t)[3]. In this model, according to figure (8), the state space has three members S = [1], where state 2 is the desired state and the probability of the desired state functioning is equal to unity or P(2) = 1[9], in other words, the state is always desirable occurs and remains 2 state and state 1 is a healthy sensor and its spare is damaged or vice versa and zero state both main and standby sensors are damaged and the probability of operation of both states 1 and zero is equal to zero or P(1) = P(0)=0 and it is not desirable that these situations occur, so the probability of both of them is assumed to be close to zero[14]. In the system architecture, it is assumed that there is a main sensor and a spare in each node. If both fail with a very small probability with a failure rate of 2β, it is necessary to replace r or repair the failed node, and if one of the main or backup or spare nodes fail with a failure rate of β, it is does not have necessary to replace r or repair the failed node; But repairs can be prioritized. In fact, two sensors or equipment support each other, if both sensors have a good performance, they will be displayed with mode 2, and if one of them is out of service due to an error or malfunction, it will be displayed with a probability 2β of 2 state can be reached 1 state; That is, with this probability, one sensor is desirable and one spare sensor is damaged, and again if one of the healthy sensors is out of service due to an error or damage, it will go from state 1 to state 0 with probability β, in which case no sensor is present. It does not perform well and is broken, and both sensors do not function well, in this case, repairing and replacing the two malfunctions in this model will not work, and it is not possible to return to state 1. With the probability r of one of the sensors, repair or replacement has gone from state 1 to state 2, in which a repair or replacement sensor has optimal performance [9] and is out of trouble and does not need to be repaired or replaced; It means that both sensors are healthy[15].

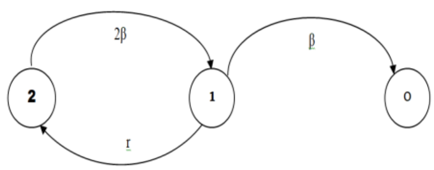


Fig. 6. two-element physical system with the function of repairing one failure and the possibility of replacing or not repairing two failures due to the essence of the hot state [9].

The state space diagram is used to understand the two-element physical system without replacing or repairing two failures (two damaged sensors) and there is repair the possibility of replacing one of the damaged sensors and repairing it to the desired state.

$$\frac{dp_2}{dt} = -2\beta p_2 + r\ p_1 \tag{4}$$

$$\frac{dp_1}{dt} = 2\ \beta p_2 - (\beta + r)\ p_1 \tag{5}$$

$$\frac{dp_0}{dt} = \beta\ p_1 \tag{6}$$

$$\text{MTTF} = \frac{3}{2\ \beta} + \frac{r}{2\ \beta^2} \tag{7}$$

After taking the Laplace transform from the sides of equations (4), (5) and (6) and applying the initial conditions according to Appendix (1), we arrive at the relation of accessibility or the equivalent of the time average of the correct operation of the system until the time of failure (7) which where r is the replacement rate of the spare part instead of the sensor and β is the sensor failure rate [9]. Also, by matrix method $A * P = A$ according to figure (6) in relation (8) we have:

$$(P(2)\quad P(1)\quad P(0))*\begin{bmatrix} 1-2\boldsymbol{\beta} & 2\beta & 0 \\ r & 1-(\beta+r) & \beta \\ 0 & 0 & 0 \end{bmatrix} = (P(2)\quad P(1)\quad P(0)) \tag{8}$$

To calculate the Q matrix according to equation (9) and the (I-Q) matrix according to equation (10), we have[2]:

$$Q = \begin{bmatrix} 1-2\boldsymbol{\beta} & 2\beta \\ r & 1-(\beta+r) \end{bmatrix} \tag{9}$$

$$[I-Q] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 1-2\boldsymbol{\beta} & 2\beta \\ r & 1-(\beta+r) \end{bmatrix} = \begin{bmatrix} 2\boldsymbol{\beta} & -2\beta \\ -r & (\beta+r) \end{bmatrix} \tag{10}$$

Calculating the determinant of I-Q matrix according to equation (11) and calculating $(I-Q)^{-1}$, we reach the same equation (7) of reliability or MTTF according to equation (12) [2].

$$\begin{vmatrix} 2\boldsymbol{\beta} & -2\beta \\ -r & (\beta+r) \end{vmatrix} = 2\beta^2 \tag{11}$$

$$(I-Q)^{-1} = \frac{1}{2\beta^2}\begin{bmatrix} (\beta+r) & 2\beta \\ r & 2\boldsymbol{\beta} \end{bmatrix} = \begin{cases} m_{11}+m_{12} = \dfrac{3\beta+r}{2\ \beta^2} = \dfrac{3}{2\ \beta} + \dfrac{r}{2\ \beta^2} \\ m_{21}+m_{22} = \dfrac{2\ \beta+r}{2\ \beta^2} \end{cases} \tag{12}$$

And the result of the addition of the first row [2] is similar to the proof of the relationship in Appendix (1) in improving the reliability performance using the Markov model for different types of sensors and spare parts in hot mode.. In cases where the instantaneousness of the emergency conditions in the disconnection and failure of two sensors does not interrupt the production process [16] and the failure can be replaced within a few minutes, the hot mode has no meaning and the cold mode models of the system can be used. only in the moment of emergency conditions, the equipment trips and runs or the start-up Estimation is time-consuming and costly, the hot state model is used [12].

4. THE INNOVATION OF THE ARTICLE PRESENTS A NEW MODEL

A model with two parallel sensors with an additional standby sensor and the possibility of multi-mode replacement

Using, analyzing and investigating the reliability model of two sensors as one main sensor and one spare sensor, investigating the overall possibilities of different states for repair and replacement have been done. According to Figure 7, the complete model of reliability with two similar main and standby sensors or the system model for two parallel sensors and both standbys is drawn and checked for different situations[12].

4.1. System model and investigation of different situations

In the system architecture, it is assumed that there is a main sensor and a spare sensor in each node, where:

μ or r: replacement rate of the spare sensor instead of the main sensor, which is shown by r.

λ or β: the rate of failure or damage of the sensor shown by β [14].

Therefore, as a new work, it can be stated on the model that if both the main and spare sensors are damaged with a very small probability with a failure rate of 2β, it is necessary to replace or repair the damaged node, and if one of the main nodes or back-up or the spare with a failure rate of β is damaged again, it is necessary to replace 2r or repair both nodes or the main and back-up sensor or the damaged spare, and this depends on the application of this model in the assumptions of the physical system conditions in which state and whether with quick replacement or repair in a short time there is a possibility to return without interruption in the operation of the system and these conditions determine the use of the system in hot and cold mode. According to Figure 7, the structure of two elements or sensors, parallel mode model or spare system is more practical, and as seen, the standby and inactive mode system (cold system) which is parallel and always active system mode (hot system)is very different and has more reliability than the parallel mode, both are ready; But a main sensor with a redundant sensor, the main sensor is always in service and the back-up sensor wakes up and comes in service in case of failure of the main sensor; It should also be kept in mind that a sensor that is serviced most of the time reduces the useful life of the equipment and has less reliability, and a sensor sometimes that is serviced and is more on standby has more reliability[9]. The state space has three members S=[14], where state 2 is the desired state and the probability of the desired state functioning is equal to one or P(2)=1, in other words, it is desirable that state 2 always occurs and remains, and state 1 is a sensor healthy and its spare is broken or vice versa and the zero state both the main sensor and the standby are broken and the probability of operation of both the 1 and 0 states is equal to zero or P(1)=P(0)=0, in other words It is not possible for these situations to occur, and therefore the probability of both of them is assumed to be close to zero[14].

In fact, two sensors or equipment support each other and both sensors should perform well., we show it with state 2, and with the probability of occurrence of $(1-\beta)^2$, state 2 returns to itself. And with probability B2, both sensors will be damaged and will reach zero state, and if one of them is out of service due to error or failure, with probability 2 β(1-β), it will go from state 2 to state 1 and with The probability of occurrence rβ+(1-β) (1-r) state 1 returns to itself; That is, with this probability, one sensor is desirable and one spare sensor is damaged, and again if one of the healthy sensors is out of service due to an error or failure, it will go from state 1 to state 0 with probability β(1-r) which in In that state, none of the sensors have optimal performance and are damaged and need to be repaired or replaced, which will remain in the same state without repair or replacement or damaged with a probability of $(1-r)^2$, and with a probability of 2 r(1-r) one of the sensors is repaired or replaced and with the probability of r(1-β) it has gone from state 1 to state 2, in which case both sensors are repaired or replaced and have optimal performance and are not damaged. and there is no need for repair or replacement, and it goes from state 0 to state 2 with probability r2; It means that both sensors have been repaired or replaced[9].

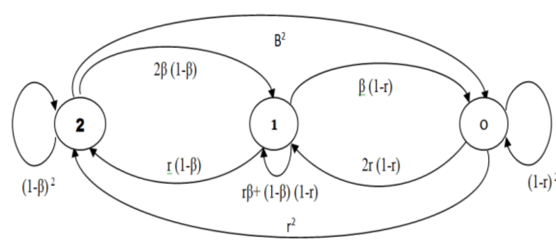


Fig. 7. complete model of reliability with two similar sensors, main and standby, and the possibility of replacing or repairing two failures due to the nature of the cold state.

4.2. Mathematical relations for calculating reliability and failure rate and repair and replacement rate

At first, to check the MTTF and be compare the complete idea of the model in figure (7) for two sensors as one main sensor and one spare sensor in the direction of repair and replacement (r) of damaged nodes (β) with the previous idea model in figure (6) .

Also we have, by matrix method A*P=A according to figure (7) and equation (13)

$$(P(2)\quad P(1)\quad P(0))*\begin{bmatrix}(1-\beta)^2 & 2\beta(1-\beta) & \beta^2\\ r(1-\beta) & \beta r+(1-\beta)(1-r) & \beta(1-r)\\ r^2 & 2r(1-r) & (1-r)^2\end{bmatrix}=(P(2)\quad P(1)\quad P(0)) \tag{13}$$

to calculate the Q matrix according to equation (14) and the (I-Q) matrix according to equation (15) [2], We have[17]:

$$Q=\begin{bmatrix}1+\beta^2-2\boldsymbol{\beta} & 2\beta(1-\beta)\\ r(1-\beta) & r\beta+(1-\beta)(1-r)\end{bmatrix}= \tag{14}$$

$$\begin{bmatrix}1+\beta^2-2\boldsymbol{\beta} & 2\beta-2\beta^2\\ r-\beta r & 2\beta r+1-(r+\beta)\end{bmatrix}$$

$$\left([I-Q]=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}-\begin{bmatrix}1+\beta^2-2\boldsymbol{\beta} & 2\beta-2\beta^2\\ r-\beta r & 2\beta r+1-(r+\beta)\end{bmatrix}=15\right)$$

$$\begin{bmatrix}2\boldsymbol{\beta}-\beta^2 & 2\beta^2-2\beta\\ \beta r-r & (\beta+r)-2\beta r\end{bmatrix}$$

according to equation (16), with Calculating the determinant of I-Q matrix we arrive at the reliability relation or MTTF according to equation (17) and calculating $(I-Q)^{-1}$, which is compared to the previous state in the simulation section[2, 17].

$$\begin{vmatrix}2\beta & -2\beta\\ -r & (\beta+r)\end{vmatrix}=2\beta^2-\beta^3-\beta^2 r=\beta^2(2-(r+\beta)) \tag{16}$$

$$MTTF=(I-Q)^{-1}=\frac{1}{\beta^2(2-(r+\beta))}\begin{bmatrix}(\beta+r)-2\beta r & 2\beta-2\beta^2\\ r-\beta r & 2\boldsymbol{\beta}-\beta^2\end{bmatrix} \tag{17}$$

$$=\begin{cases} m_{11}+m_{12}=\dfrac{3\beta+r-2\beta r-2\beta^2}{\beta^2(2-(r+\beta))}=\dfrac{3\beta+r-2\beta(r+\beta)}{\beta^2(2-(r+\beta))}\\ m_{21}+m_{22}=\dfrac{2\beta+r-\beta r-\beta^2}{\beta^2(2-(r+\beta))}\end{cases}$$

5. SIMULATION AND EVALUATION

The results of the simulation have been obtained using MATLAB software and a computer system with the following specifications

5.1 COMPARING THE RESULTS OF THE CURRENT WORK WITH THE PAST

At first, the sum of the first line of the equation (15) is simulated and it is found that the MTTF according to figure (8a) to compare the current work with the past (previous idea with the new idea) in low failure rate and low replacement rate r = 0.001: 0.009 have no difference and according to figure (8b) in similar failure rate and slightly higher replacement rate r = 0.01:0.09 the improvement of MTTF becomes more obvious and according to figure (8c) in similar failure rate and slightly higher replacement rate r = 0.1:0.3 improvement MTTF gets better and according to figure (8d) in similar failure rate and slightly higher replacement rate r = 0.4:0.8, the improvement of MTTF becomes much better and according to figure (8e) in similar failure rate and slightly higher replacement rate r = 0.9:1 also, the improvement of MTTF shows that if this replacement rate is achieved, the MTTF will be very excellent.

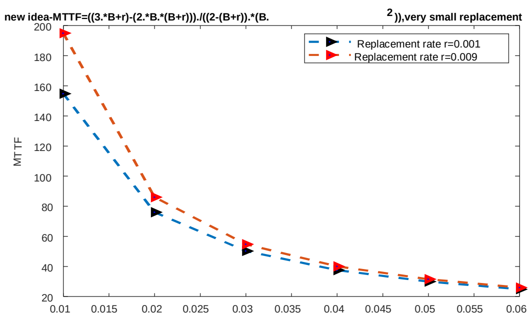
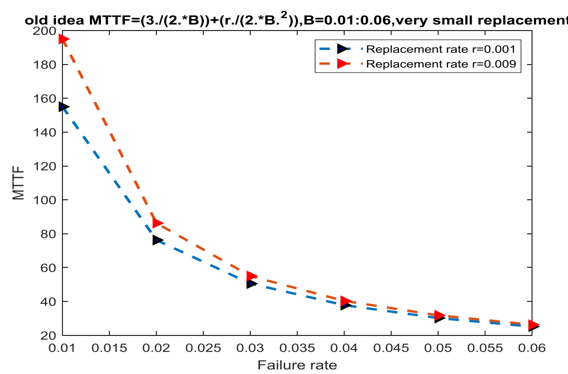


Fig.(a)



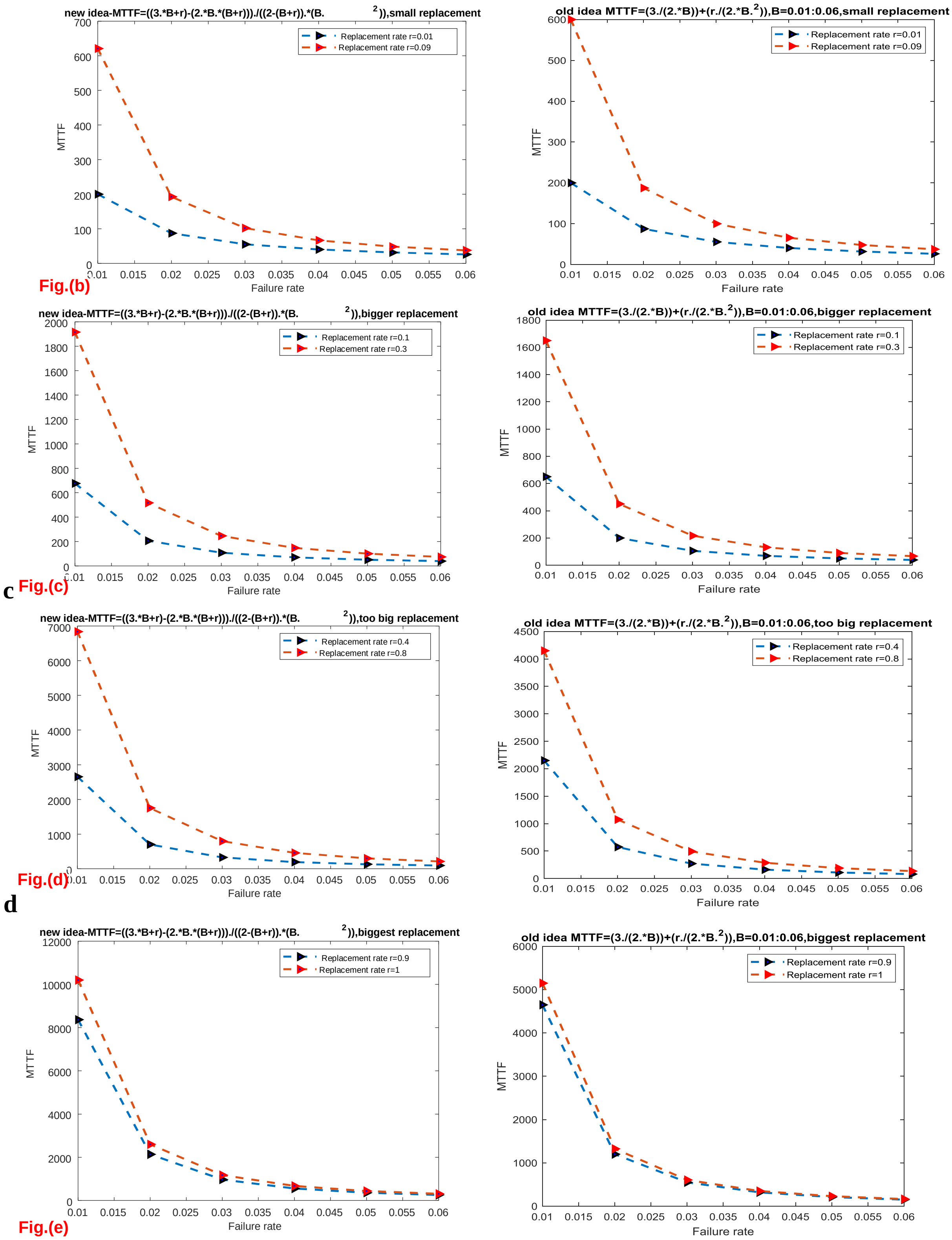


Fig. 8. Comparison of the current work with the past in the study of MTTF improvement in low failure rate and gradually higher replacement rate

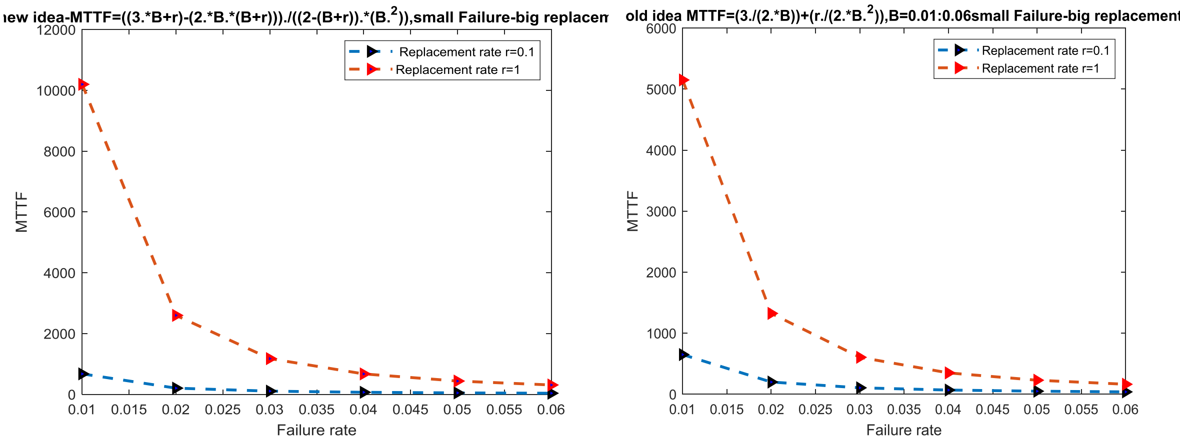


Fig. 9. Comparison of the current work with the past in examining the improvement of MTTF in low failure rate and two low and high replacement rates

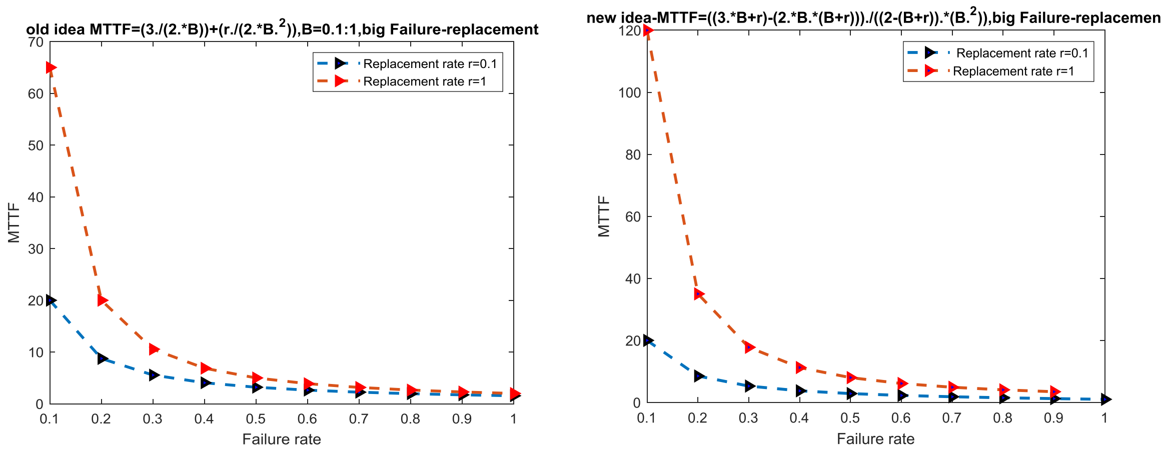


Fig. 10. Comparison of the current work with the past in examining the improvement of MTTF in low failure rate to very high failure rate and two low and high replacement rates.

As a result, we saw that as the replacement rate gradually increases, the drastic difference in the improvement of MTTF becomes more obvious ; So that in the similar failure rate β=0.01:0.06, as the replacement rate gets closer to improvement and one, the MTTF will gradually improve compared to the previous opinion, and according to figure (9), the comparison of the current work with In the past (the previous idea with the new idea), the MTTF improvement in the low failure rate β = 0.01:0.06 and the two low and high replacement rates r = 0.1, 1 have been examined and the MTTF improvement is 10,000 compared to the previous model of 5,000. ¬ and also according to figure (10) the failure rate is much higher β=0.1:1 (which in practice this failure rate is not acceptable and should always be a number close to zero and solutions such as replacement of parts and repair and replacement of quality parts And... it is used so that the failure rate tends to zero and the maintenance and repair of sensors and devices has an economic justification) and the replacement rate is checked at r = 0.1 and one and the improvement of MTTF is equal to 120 compared to the previous model 65 is obtained.

6. SIMULATION RESULTS IN THE APPLICATION OF THE ARTICLE IN INDUSTRIAL WIRELESS SMART SENSOR NETWORKS

As it is clear, the new architectural model has different repair and replacement rates and more paths from the side of damaged nodes in state 0 and 1 to the healthy node in state 2 compared to the previous work. Review a lower failure rate and higher replacement rate improved the MTTF of current work compared to the past, and also if the failure point of the sensors occurs, corrective action should be taken as soon as possible, otherwise the failure rate will be too high, which will reduce the MTTF, and solutions such as replacing parts and repairing and replacing parts with excellent quality in a shorter period of time... it is used so that the high failure rate tends to zero and the replacement rate at r = 0.1 and r = 1 was checked and observed that the current work compared to the past in improving the MTTF in a very high failure rate has solutions. It was observed that the more the number of spare parts is, it is not economical, but the reliability improves ; Up to two spare parts in service and low failure rate, reliability above 90% is guaranteed. In order to reduce the failure rate, we can do some things, such as: having a number of spare parts and sensors ready in advance so that they can be replaced as soon as they fail and need to be replaced, to increase the efficiency, effectiveness and useful life of the equipment, and are given importance In relation with reliability. and that The higher the failure rate, the lower the reliability, and they have an inverse relationship, It is obvious that the performance of the equipment and reliability decreases exponentially with time, and after a certain period of their useful life, for example, the interval passes in one to two years, we face a much greater intensity in the useful efficiency and performance and reliability of the equipment, It means that it degrades quickly in this period, and therefore, in this period, one should take measures such as more visits and repairs or replacing the sensor earlier than replacing the used parts, so that the efficiency does not drop.which. Change the used parts so that the efficiency does not decrease. If the lifetime of sensors and devices be halved with having a spare node or 2 sensors with assumed failure rates, the reliability is guaranteed above 90% and remains close to one; While if we want to save the life of the equipment and double the lifetime of the sensors and tools compared to the previous state, it means that they will use one piece of equipment more than the useful life, with 3 and 4 spare parts or 5 sensors (much more cost) with the same failure rate as before, the reliability is less than one, and therefore to compensate for more efficiency and reliability with a much larger number of spare parts, it must reach one, and this indicates that the performance of the equipment in the initial time until their optimal life time decreases exponentially; So that after a period of their useful life has passed, we face a much greater intensity in efficiency.

7. CONCLUSION

The results of the simulation showed that the use of ready spare nodes in the new architectural model with different repair and replacement rates and more routes improved the mean time to failure or MTTF. Based on the observed results, it is very effective to prepare backup replacement nodes (spare) in order to reduce the adverse effects of the error. Whatever the replacement rate more, the MTTF will be higher, and also with the increase in the failure rate of the equipment, the MTTF decreases exponentially, that is, at the beginning, the deterioration is fast and gradually the severity of the deterioration is reduced, and therefore, with the initial planning of repairs to timely repair and replacement of defective parts with healthy ones prevents the increase of failure rate, following a failure with a higher replacement rate, the spare part is repaired and the MTTF is improved. And in comparing the current work with the past, there is little difference in the improvement of MTTF in low failure rate and low replacement rate, but gradually with the passing of the sensor life with the increase of the failure rate, as the replacement rate increases, , the greater the difference in MTTF improvement; So that in the similar failure rate, as the replacement rate gets closer to improvement and one, the MTTF gradually improves very well compared to the previous opinion, and also, in action, a high failure rate is not acceptable and always practically by doing tricks such as replacement of parts and repair and replacement of quality parts, etc., we tend the failure rate to zero so that the maintenance and repair of sensors and instruments has economic justification, and increasing the replacement rate r and reducing the failure rate β has a direct effect on improving the mean time to failure on the equipment system works properly.

REFERENCES

[1] Munir, A., J. Antoon, and A. Gordon-Ross, *Modeling and analysis of fault detection and fault tolerance in wireless sensor networks.* ACM Transactions on Embedded Computing Systems (TECS), 2015. **14**(1): p. 1-43.

[2] Jiang, W., Z. Ma, and X. Deng, *An attack-defense game based reliability analysis approach for wireless sensor networks.* International Journal of Distributed Sensor Networks, 2019. **15**(4): p. 1550147719841293.

[3] Zhou, P., et al., *A comprehensive technological survey on dependable self-managing CPS: The decade of researches on correctness and dependability.* 2017.

[4] Vatinvises, T., *Monitoring Mechanism Design for a Distributed Reconfigurable Onboard Computer*. 2016, Georg-August-Universität Göttingen.

[5] Ghobaei-Arani, M., S. Jabbehdari, and M.A. Pourmina, *An autonomic resource provisioning approach for service-based cloud applications: A hybrid approach.* Future Generation Computer Systems, 2018. **78**: p. 191-210.

[6] Power, A., *A predictive fault-tolerance framework for IoT systems*. 2020: Lancaster University (United Kingdom).

[7] Venkatesan, L., S. Shanmugavel, and C. Subramaniam, *A survey on modeling and enhancing reliability of wireless sensor network.* Wireless Sensor Network, 2013. **5**(03): p. 41.

[8] Mosharmovahed, B., M.A. Pourmina, and S. Jabbehdari, *Clustering Methods Survey in VANET on Roads and Mountain Trails with High Reliability.* Majlesi Journal of Telecommunication Devices, 2021(1).

[9] Kumar, V., et al., *Reliability analysis in wireless sensor networks.* International Journal of Engineering and Technology, 2011. **3**(2): p. 74-79.

[10] Atif, M., et al., *Soft computing techniques for dependable cyber-physical systems.* IEEE Access, 2019. **7**: p. 72030-72049.

[11] Silva, I., et al., *Reliability and availability evaluation of wireless sensor networks for industrial applications.* Sensors, 2012. **12**(1): p. 806-838.

[12] Catelani, M., et al., *Reliability Analysis of Wireless Sensor Network for Smart Farming Applications.* Sensors, 2021. **21**(22): p. 7683.

[13] Soltanali, H., et al., *Sustainable production process: An application of reliability, availability, and maintainability methodologies in automotive manufacturing.* Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability, 2019. **233**(4): p. 682-697.

[14] Alsheikh, M.A., et al., *Markov decision processes with applications in wireless sensor networks: A survey.* IEEE Communications Surveys & Tutorials, 2015. **17**(3): p. 1239-1267.

[15] Munir, A. and A. Gordon-Ross. *Markov modeling of fault-tolerant wireless sensor networks*. in *2011 Proceedings of 20th International Conference on Computer Communications and Networks (ICCCN)*. 2011. IEEE.

[16] Bein, D., et al., *Reliability modeling in wireless sensor networks.* International Journal of Information Technology, 2005. **11**(2): p. 1-8.

[17] Kumar, V., et al., *Markov model for reliable packet delivery in Wireless Sensor Networks.* International Journal of Computer Science Issues (IJCSI), 2011. **8**(3): p. 429.

APPENDIX

Proving the relationship between reliability and the mean time to failure until the failure occurs

$$sp_{2(s)} - p_{2(0)} = -2\beta p_{2(s)} + r\ p_{1(s)}$$

$$sp_{1(s)} - p_{1(0)} = 2\ \beta p_{2(s)} - (\beta + r)\ p_{1(s)}$$

$$sp_{0(s)} - p_{0(0)} = \beta\ p_{1(s)}$$

$$p_{2(0)} = 1$$

$$p_{1(0)} = p_{0(0)} = 0$$

$$sp_{2(s)} - 1 = -2\ \beta p_{2(s)} + r\ p_{1(s)}$$

$$sp_{1(s)} = 2\beta p_{2(s)} - (\beta + r)\ p_{1(s)}$$

$$sp_{0(s)} = \beta\ p_{1(s)}$$

$$p_{2(s)} = \frac{(s + \beta + r)}{s^2 + (3\ \beta + r)s + 2\beta^2}$$

$$p_{1(s)} = \frac{2\beta}{s^2 + (3\ \beta + r)s + 2\beta^2}$$

$$p_{0(s)} = \frac{\beta p_{1(s)}}{s} = \frac{2\beta^2}{s(s^2 + (3\beta + r)s + 2\beta^2)}$$

and the relation of reliability $R(t) = 1 - P_0(t)$ *and taking the derivative of* $R(t)$

$$f_x(t) = \frac{-\ dR}{\mathbf{dt}} = \frac{dP0(t)}{dt}$$

$$L_x(S) = \quad f_x(S) = sp_{0(s)} - p_{0(0)} = \frac{2\ \beta^2}{(s^2 + (3\ \beta + r)s + 2\beta^2)}$$

$$f_x(t) = \frac{2\ \beta^2(e^{-\alpha_2 t} - e^{-\alpha_1 t})}{\alpha_{1-}\alpha_2}$$

and apply the Laplace transform

$$\alpha_1, \alpha_2 = \frac{(3\ \beta + r) \pm \sqrt{\beta^2 + 6\ \beta r + r^2}}{2}$$

and obtaining the roots of the denominator of the quadratic equation of adding and multiplying the roots is assumed and we have

$$\alpha_1 + \alpha_2 = 3\ \beta + r \quad \alpha_1.\alpha_2 = 2\ \beta^2$$

$$R(t) = \int_0^{\alpha} \frac{d}{dt} \frac{2\ \beta^2(e^{-\alpha_2 t} - e^{-\alpha_1 t})t}{(\alpha_{1-}\alpha_2)} d\alpha = \frac{2\ \beta^2}{(\alpha_{1-}\alpha_2)} \int_0^{\alpha} (e^{-\alpha_2 t} - e^{-\alpha_1 t} - \alpha_2 te^{-\alpha_2 t} + \alpha_1 te^{-\alpha_1 t}) d\alpha$$

and calculating the integral separately in the relation

$$\frac{-1}{t}(e^{-\alpha_1 2} - 1) + \frac{1}{t}(e^{-\alpha_2 2} - 1) - \frac{1}{t} + \frac{1}{t} = \frac{(e^{-\alpha_2 2} - e^{-\alpha_1 2})}{t}$$

And using the opposite equation in the integration relations, we reach the proven reliability relations.

$$\frac{1}{\alpha^2} = \int_0^{\alpha} te^{-\alpha t}$$

$$R(t) = \frac{2\ \beta^2(e^{-\alpha_2 2} - e^{-\alpha_1 2})}{(\alpha_{1-}\alpha_2)t}, MTTF = E(X) = \int R(t)dt = \frac{2\ \beta^2(\frac{1}{\alpha_2 2} - \frac{1}{\alpha_1 2})}{(\alpha_{1-}\alpha_2)}$$

$$\frac{2\beta^2(\alpha_{1+}\alpha_2)}{(\alpha_1\alpha_2)^2} = \frac{2\beta^2(3\ \beta + r)}{(2\beta^2)^2} = \frac{3}{2\ \beta} + \frac{r}{2\ \beta^2}$$