Reliability and availability analysis for robot subsystem in automotive assembly plant: a case study

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Abstract. The automotive assembly plant is a manufacturing environment consisting of conveying systems and robots. Robots with high reliability will ensure no interruption during production. This study is to analyze the individual robot reliability compared to reliability of robots subsystem in series configuration. Availability was computed based on individual robots breakdown data. Failures due to robots breakdown often occurred during the operations. Actual maintenance data for a period of seven years were used for the analysis. Incorporation of failures rate and mean time between failures yield the reliability computation with the assumption of constant failure rate. Result from the analysis based on 5000 operating hours indicated reliability of series configuration of robots in a subsystem decreased to 2.8% in comparison to 38% reliability of the individual robot with the lowest reliability. The calculated lowest availability of the robots is 99.41%. The robot with the lowest reliability and availability should be considered for replacement.

1. Introduction

Sequences of robotic system in production line increase the automation level of the industry, hence helps the industry to achieve high production volume. The automation in the automotive industry in fact helps the industry to improve in term of safety, quality, and standardization as well as to achieve production efficiency. However, failures and breakdown of robotic system is inevitable and give high impact to the production throughput.

The usage of robotic systems is to achieve high production throughput in all production lines such as stamping shop, body assembly shop, painting shop and assembly shop. Each production line is equipped with several robots, equipment, conveyors, manipulators and material handling equipment. In general, the stamping parts will transfer to body shop and flow from one process to another process via automatic conveyer systems and welded together by spot welder robotic systems. The body in white (BIW) then fed to painting shop for painting process and sprayed by a cluster of robotic systems. Finally, the painted bodies are fed to assembly shop for assembly processes via automatic conveyor system as shown in figure 1. There are 156 units of robots operated in this particular automotive plant. The robot failures data were kept as maintenance data which was well documented for a tracebility purposes.

Robots failures often occurred in industry which contributed to the downtime and production shut off. In the automotive industries with high level of automation, the failures are recorded as maintenance data. The robot failures data in many literatures are acquired from laboratory experiments, not from actual maintenance data. As stated by Vineyard, Amoako-Gyampah [1], most
research studies on machine failures and maintenance decisions have assumed some failures distribution such as exponential or Weibull and most of the data were provided by the suppliers of the equipment. Relationship between the failures data and production data during warranty periods could be used for quality improvements for manufacturing industry. This approach was adopted by Jeon and Sohn [2] who used warranty data to activate an early warning for the design errors and highlight faults in manufacturing process.

Based on the current literature, most of the study analyzed the robots reliability as a unit which data was collected in the laboratory environment. However, this study was carried out for robots in the actual manufacturing environment in the automotive assembly plant. Simon, Javad [3] used maintenance data and daily reports data of conveyor systems in mining industry for a case study of reliability and maintainability. From the data the reliability and availability of the conveyors were computed.

A robot which performs without failure for a specified period of time under specified operating conditions is considered having high reliability. The discipline of reliability engineering basically is a study of the causes, distribution and prediction of failures [4]. Robotic systems are commonly used in automotive assembly line. It is important robot should have high reliability in order for production continuity. The lineups of robots exist in both series configuration and parallel configuration.

Study done by Tsarouhas, Varzakas [5] on the mobile robot reliability and a serial configuration of components in the mobile robots showed that the robot reliabilities are low as well as the entire system reliability. Sun, Xi [6] analyzed the reliability of machine-level reliability and system-level reliability for a manufacturing system in a series-parallel configuration of equipment for manufacturing plant. Result from the case study indicates the system reliability for serial-parallel hybrid system showed the highest reliability.

Reliability and availability co-exist in the sense of reporting for equipment maintainability issue. Availability of an equipment or a robot is measured as a factor of its reliability. Availability is defined as the probability that a system is operating satisfactorily at any random point in time t, when subject to a sequence of up and down cycles which constitute an alternating renewal process [7].

Performance of robot in a subsystem will affect the availability. Therefore, the performance of each individual robot in subsystem should be analyzed in order to determine how each robot affect the reliability and availability performance for the whole production line in automotive assembly plant.

The objective of the present study is to apply the reliability model to evaluate the reliability and availability of an automotive robotic system. The failure rate, $\lambda$, mean time to repair and mean time between failures were used in the analysis. The case study is on automotive assembly plant’s robots at top coat line of painting shop. The case study used for comparison of individual robot and for the entire robots in the subsystem consists of 8 robots in the top coat system. The processes involved in top coat line are base coat and clear coat. The 8 robots in top coat line are arranged in the configuration 4 robots in left hand side and 4 robots in a right hand side as shown in figure 2. All robots must be fully operational and in the case of one of the robots fail to perform to function the whole top coat system will be shut off.

The failures data of robots, generally recorded maintenance data in top coat production line were acquired for the period of seven years. Result of the failures analysis is expected to assist painting production line decision maker to justify the decisions on the robot life cycle.
2. Mathematical Formulation

All 8 robots are configured as a series which represents reliability model in series configuration for the top coat line [7]. In the case of one robot fails to perform its function it will result to failure to the whole system. The individual reliability of robot was calculated as shown in equation (1).

\[ R(t) = e^{-\lambda t} \]  \hspace{1cm} (1)

Thus, the reliability of robot in top coat line is expressed in series configuration as shown in equation (2).

\[ R_s(t) = R_1(t) \cdot R_2(t) \cdot R_3(t) \cdot \ldots \cdot R_n(t) = \prod_{i=1}^{n} R_i(t) \]  \hspace{1cm} (2)

where, \( R_1(t), R_2(t), \ldots, R_n(t) \) are reliabilities of each individual robot respectively. As the assumption is constant failure rate, \( \lambda \) for all robots, which means that the exponential distribution for the reliability functions, then, is as shown in equation (3).

\[ R_s(t) = e^{-\lambda_1 t} \cdot e^{-\lambda_2 t} \cdot \ldots \cdot e^{-\lambda_n t} = \exp \left[ - \sum_{i=1}^{n} \lambda_i t \right] = \exp[-\lambda t] \]  \hspace{1cm} (3)

As for the MTTR and MTBF calculations, the equations are shown in equation (4) and equation (5) respectively.
\[ MTBF = \frac{T(t)}{r} \]  

(4)

where, \(T(t)\) is the total operating time, and \(r\) is the number of failures.

\[ MTTR = \frac{Production\ Time\ (\text{min})}{Number\ of\ Failures} \]  

(5)

Hence, the availability equation is shown in equation (6).

\[ Availability = \frac{MTBF}{MTBF + MTTR} \times 100\% \]  

(6)

3. Results and Discussion

Analysis on reliability of each robot and reliability of robots in a subsystem were computed in top coat line. The actual failures maintenance data were utilized which was acquired for a period of seven years as a case study and as a basis of computation of individual robot reliability and series robot reliability.

There are two groups of robots involved in the analysis; there are B1, B2, B3 and B4 are the base coat robots and C1, C2, C3 and C4 are clear coat robots. Four robots in each side left and right are configured in series as a modeling which illustrated in figure 3. In the case of failures occurred in one of the robot either left or right robot in top coat line, the whole production in top coat line will shut off.

The formulations of reliability for each individual robot were calculated. Table 1 shows the result after computation based on equation (1) and (2). The robot B3 is having the reliability 0.38; Robot B2, C1, C3 and C4 having the reliability 0.62; while robot B1, B4 and C2 having the reliability 0.79. It is clearly shown, robot B3 having the lowest reliability in comparison with others robots.

| Robots | B1 | B2 | B3 | B4 | C1 | C2 | C3 | C4 |
|--------|----|----|----|----|----|----|----|----|
| Reliability, R(t) | 0.79 | 0.62 | 0.38 | 0.79 | 0.62 | 0.79 | 0.62 | 0.62 |
| Reliability, Rs(t) | | | | | | | | 0.028 |

The graph in figure 4(a) to 4(h) shows the results of reliability analysis for each individual robot, B1, B2, B3, B4, C1, C2, C3 and C4 respectively. The plot shows, the individual robots are having a decreasing reliability over the longer operating hours.
3.1. Analysis on Subsystem Robots Reliability

As for the subsystem reliability, Rs(t), the reliability is 0.028 at the 5000 operating hours. Based on the results of reliability analysis as drawn in figure 5, the behaviour of robot subsystem reliability, Rs(t) is decreasing compared to individual robot reliability, R(t) in series configuration.

3.2. Analysis on Robots Availability

Evaluation of availability analysis for each robot station is shown in figure 6. The availability were calculated using equation (4), equation (5) and equation (6). The availability of the robots ranging from 99.9993% to 99.4069%. Robot B3 has the lowest availability in comparison with others robots with the availability value is 99.4069%.
4. Conclusion
Based on 5000 operating hours, the reliability of the robots B1, B4 and C2 are 79% respectively, while robots B2, C1, C3 and C4 are 62% respectively. The robot B3 having the lowest reliability is 38%. Further analyses were carried out in series configuration of robots in a system reliability decreased to 2.8% at the same operating hours. It is proven that the system reliability decreased further compared to reliability of the individual robot of the system. The availability analysis was carried out for all individual robots. The range of availability value is 99.9993% to 99.4069%. Robot B3 which is the third robot in the subsystem has the lowest availability value of 99.4069%.

It is recommended, immediate attention to the third robot is required. The plant management is recommended to consider immediate attention to the third robot on the replacement strategy. Proper maintenance schedule must be established for the second, fifth, seventh and eight robots.

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