Function Integration Impact on Failure Rates in Additive Manufactured Parts

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This paper investigates impacts of merging components and reduction of sub-assemblies on failure rate while keeping functionality by exploiting additive manufacturing (AM) capabilities. The analysis is performed by considering a base structure for part composition providing set of functions, and then comparing this with a list of alternatives that consist of merged components realized through AM. The comparative analysis focuses on failure rates and failure counts with optimum maintenance strategies applied. The analysis assumes respective failure mode elimination and failure rate reduction due to geometry improvement and additive manufactured material strength capabilities.

Twelve parts group build base structure providing set of functions. Some of the functions are required for assembling purposes only and with that will create an opportunity for component merging. Table 1.a present part dependencies indicating direction how failure modes are transferred. Table 1.b presents explored merging scenarios realized through AM

Table 1. The functional part dependency of a) base structure b) alternatives that consist of merged components realized through AM

a)

Input \ Output	Part_01	Part_02	Part_03	Part_04	Part_05	Part_06	Part_07	Part_08	Part_09	Part_10	Part_11	Part_12
Part_01	X	0	0	0	1	0	0	0	0	0	0	0
Part_02	0	X	0	0	0	0	1	0	0	0	0	0
Part_03	0	0	X	1	0	0	0	0	0	0	0	0
Part_04	0	1	1	X	0	0	0	0	0	0	0	0
Part_05	1	0	0	1	X	1	0	1	0	0	0	0
Part_06	0	0	0	0	0	X	0	1	0	0	0	0
Part_07	0	1	0	1	0	0	X	0	0	0	0	0
Part_08	1	0	0	0	0	0	0	X	0	0	0	0
Part_09	0	0	1	0	0	0	0	0	X	0	0	1
Part_10	0	0	0	1	0	0	0	1	0	X	1	1
Part_11	0	0	0	0	0	0	0	0	1	0	X	0
Part_12	0	0	0	0	0	0	0	0	0	0	0	X

b)

Input \ Output	Part_01	Part_05	Part_08	Part_06	Part_10	Part_12	Part_09	Part_11	Part_03	Part_04	Part_07	Part_02
Part_01	X	1	0	0	0	0	0	0	0	0	0	0
Part_05	1	X	1	1	0	0	0	0	0	1	0	0
Part_08	1	0	X	0	0	0	0	0	0	0	0	0
Part_06	0	0	1	X	0	0	0	0	0	0	0	0
Part_10	0	0	1	0	X	1	0	1	0	1	0	0
Part_12	0	0	0	0	0	X	0	0	0	0	0	0
Part_09	0	0	0	0	0	1	X	0	1	0	0	0
Part_11	0	0	0	0	0	0	1	X	0	0	0	0
Part_03	0	0	0	0	0	0	0	0	X	1	0	0
Part_04	0	0	0	0	0	0	0	0	1	X	0	1
Part_07	0	0	0	0	0	0	0	0	0	1	X	1
Part_02	0	0	0	0	0	0	0	0	0	0	1	X

For the purpose of the reliability analysis failure modes affecting component functions were simplified down to two failure rate contributors. First as an Exponential distribution with a constant failure rate and second, increasing failure rate, described by Weibull distribution.

In performed analysis merged components realized through AM have improved failure rates due to geometry improvement (modeled as Effectiveness Factor for constant failure rate reduction) and additive manufactured material strength capabilities (modeled as Effectiveness Factor for Eta parameter in Weibull distribution). Additionally, due to function reduction of sub-assemblies respective failure modes were eliminated.

Figure 1.a and Figure 1.b present partial Reliability results for base structure and one of the merger alternatives. Proposed analysis method allows recognize how reliability targets for additive manufactured parts can be reached by optimizing function merger. Part maintainability and predictive maintenance activities are also discussed from the perspective of applicability to optimize maintenance strategies.

a)

Name	Reliability (Analytical)
Ass01	0.0077
Part01	0.7144
Function 1	0.7144
Failure 1	0.8939
C01	0.9648
W01	0.9266
Failure 5	0.8523
C05	0.9700
W05	0.8786
Failure 8	0.9376
C08	0.9696
W08	0.9671
Part02	0.5978
Function 2	0.5978
Failure 2	0.8739
C02	0.9631
W02	0.9074
Failure 4	0.8818
C04	0.9550
W04	0.9234
Failure 7	0.7758
C07	0.9689
W07	0.8007
Part03	0.6826
Function 3	0.6826
Failure 3	0.8959
C03	0.9680
W03	0.9255
Failure 4	0.8818
C04	0.9550
W04	0.9234
Failure 9	0.8641
C09	0.9666
W09	0.8940

b)

Name	Reliability (Analytical)
Ass01	0.7214
Part01_3D1	0.9164
Function 1	0.9904
Failure 1	0.9904
C01	0.9968
W01	0.9936
Function 5	0.9823
Failure 5	0.9823
C05	0.9948
W05	0.9874
Function 6	0.9645
Failure 6	0.9645
C06	0.9911
W06	0.9732
Function 8	0.9766
Failure 8	0.9904
C08	0.9929
W08	0.9975
Failure 10	0.9860
C10	0.9945
W10	0.9915
Part02_3D1	0.9342
Function 9	0.9843
Failure 9	0.9843
C09	0.9990
W09	0.9853
Function 10	0.9860
Failure 10	0.9860
C10	0.9945
W10	0.9915
Function 11	0.9770
Failure 11	0.9770
C11	0.9895
W11	0.9873

Figure 1. Example of reliability results (partial) for a) base structure b) one of the alternatives that consist of merged components realized through AM

Keywords: Additive manufacturing; Reliability; Failure Rate; Parametric analysis; Components merger