On demand printing with Additive Manufacturing (AM) for spare parts: scenarios for the insourcing of a 3D Printer

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Abstract: Additive Manufacturing (AM) has become a promising technique for spare parts management. The reduced lead time of AM compared to Classical Manufacturing (CM) has attracted the interest of researchers and many applications of AM to spare parts management have been introduced in the literature. However, the high production and equipment costs obscure the advantages of AM to spare parts management to practitioners and academics. The recent literature on spare parts management with AM have two main limitations which we address in this work. The first is that AM spare parts are mistakenly assumed to be less reliable than CM ones, which has been refuted by the recent literature on the mechanical characteristics of AM parts. Secondly, the external supply of AM parts that excludes the investment cost of the equipment. Our model overcomes these limitations by taking into account a spare part installed on a fleet of systems which failures are based on failure data from recent literature. In addition, we consider an insourced 3D printer, and account for the purchasing cost. We propose several scenarios for the insourcing of a 3D printing, considering a future cost reduction and constrained stock systems, individuating constrained stock system with high lead times for the CM part, ideal for in-house printing. The work has been supported by the project SUPERCRAFT, funded by the Emilia-Romagna Region (Italy) with European funds (POR FESR).

Keywords: Spare Parts, Additive Manufacturing, Decision Support System

I. INTRODUCTION

The efficient management of spare parts is essential for ensuring the high availability of production systems [1]. Especially for mass production systems, this is due to the unavailability of machinery, which then results in high financial losses [2]. The correct management of spare parts is hindered by their demand that is usually intermittent [3] and thus require ad hoc methods for its forecasting [4] . The other main limitation to the correct management of spare parts is the high and often uncertain procurement lead time of classical manufacturing (CM) parts [5]. In this context AM is an optimal alternative that overcomes these two main limitations. Spare parts management using an AM approach is effective thanks to its two main features:

1. The lower lead times compared to CM [6].
2. The ability of a 3D printer to produce many different parts using metal powders [7].

These two characteristics enable on demand printing for spare parts. On demand printing can ideally substitute the high stock levels that usually characterize the CM management of spare parts aimed at reducing downtimes that cause high backorder costs [8]. AM is based on Computer Aided Design (CAD) since it creates an object directly from a CAD model [9] [10]. Initially, AM was used above all as a prototyping technology given the small (even null) set up time required for the production [11]. However in the medical sector, for example, AM is used for everyday production [12]. This mass production with AM was also possible due to the two-characteristics previously cited and also due to the variety of materials that can be used and the various post processes applicable. Post processes are increase the mechanical properties of those parts with higher production costs [13]. In addition, post processes can be associated with specific operational conditions [14]. However, the diffusion of AM to produce spare parts has been delayed for several reasons. The first is related to an operational perspective, since companies have experience with CM spare parts but lack knowledge on AM parts and their sourcing. This knowledge gap is justified in terms of the mechanical properties of AM parts since there is a gap in real failure data under different conditions [15]. Given the continuous improvements in AM technologies, the only viable ways to predict the mechanical properties are failure criteria [16] [17] and accelerated tests. The second reason for the limited diffusion of AM technologies is the high production and purchasing costs of the printer. At the same time the cost of both the machinery and the production of AM parts are expected to decrease in the next few years [18], which we have taken into account on the basis that the technology will certainly keeping improving. In fact, the aim of this paper is to understand which scenarios would be preferable for the management of spare parts with the production on demand using an insourced 3D printer. Among the scenarios investigated, we analysed constrained stock systems and future improvements in AM technologies.

We considered a spare part installed on a fleet of systems (e.g. aircraft, production systems) that can be produced by CM or by AM. The spare parts data for both CM and AM characteristics came from a recent paper [8] of which our work can be seen as a natural extension. Sgarbossa et al. only accounted for an individual spare part and not a set of identical spare parts. However including the insourcing of a printer, which is a new aspect in the literature as we demonstrate in our literature review, it is essential to account for more than one part.

The paper is structured as follows: Section 2 reviews the literature; Section 3 introduces our model and Section 4 our experimental analysis. Our conclusions are given in Section 5

II. LITERATURE REVIEW

The intermittent demand for spare parts [3] makes it difficult to forecast and how to manage them. However, correct forecasting is essential and, in the literature, there are two main ways for this to be done. The first considers the standalone time series which was initiated by the seminar paper by Croston [3] which was extended by [19]. Non parametric approaches such as bootstrapping [20] and machine learning [21] have also recently been introduced in the literature. For a review on the theme we suggest [22]. The second approach links forecasting with the maintenance approach and optimizes both. The study by Kabir and Al-Olayan [23] was one of the first in this stream which has recently gained a lot of attention [24] and is well reviewed in [25]. Our work focuses on the impact of AM on spare part management thus forecasting is not central and not considered. Although AM is a valuable option for parts management and in particular for spare parts [26], few works have evaluated its application. Liu et al. (2014) investigated the reduction in safety stock derived from the introduction of AM technology for spare parts for aircrafts in both centralized and decentralized AM production. However they did not consider the purchasing cost of the printer in the centralized scenario and nor did they account for the lower reliability of AM compared to CM. However, due to the evolution of the technology and post processing, AM parts can now be more reliable than CM parts [28]. Song and Zhang [11] considered an overseas equipment manufacturer and on demand printing. They modelled the problem as a multi-class priority queue with Poisson demand, where they divided different spare parts into two clusters (make-to-stock and printed on demand) and then found the optimal continuous review policy. They considered the dynamics at the insourced 3D Printer (i.e. the waiting time in queue) although they did not consider an application with real failure data. Nor did they consider the cost of the 3D printer in their insourcing option, and in their analysis, they considered the same failure rate between AM and CM. Knofius et al. [29] modelled the dual sourcing problem as a continuous Markov decision process with a single-item perspective. In fact, they accounted for a single item installed on a base of an identical system, as is the case in this work. However, they considered only the outsourcing of AM with replenishment lead time exponentially distributed. Westerweel et al. [30] extended the dual sourcing problem with fixed order cycles considering two supply sources. Their results showed that on site on demand printing leads to savings by reducing the inventory and increasing the availability. In their work AM parts have lower reliability, which has already been highlighted as an out-of-date assumption. Similarly, through dynamic programming, Knofius et al. [26] [31] optimized the switching period from regular components to AM by considering the cost reduction for AM over time. This was a neat solution since one of the main drawbacks of AM is the still high cost. Lastly, Sgarbossa et al. [8] modified the classic reorder model outlined in [32] and applied it to a periodic multi-technology reorder model. The innovation of their work is the conjunction of spare parts management with different AM technologies to evaluate their impact with different materials and post-processing, finding the best match between them. An approach followed in a recent paper by our research group on preventive maintenance using on demand printing [33] investigated different AM technologies and post processing by constructing a decision support system (DSS) to help practitioners in choosing their best combination. In this work we exploited the data presented in [8] focusing on small spare parts since they have been found to be the most promising for AM. In fact, our work can be seen as a natural extension of [8]. Sgarbossa et al. only accounted for outsourced AM parts without including the purchasing cost of the printer. Purchasing cost that we included and that can be sustained only if a considerable number of parts are printed, for this reason we accounted for a spare part that is installed on a fleet of systems. Another difference in our study lies in the backorder cost which in the original paper of Sgarbossa et al. (2021) was considered as a unitary cost per part in the backorder, which in our model is considered as a unitary cost per part per unit time. Lastly, Sgarbossa *et al. (2021)* considered AM under the classical reorder model of Babai [32] where an AM part can be kept in stock. On the other hand in our model, AM parts are exclusively made on demand. The reason for this is the pressing demand in spare parts logistics to eliminate the inventory [34]. In addition it is a natural choice for example in the automobile industry for old parts due to discontinued manufacturing [11] or in constrained remote systems such as offshore platforms where stocks are not allowed or are highly constrained [30]. Thus, insourcing a printer is the most efficient approach to demand printing, which we have benchmarked with a make to stock system based on CM.

III. MODEL

In this section our mathematical model, its notation and underlying hypothesis will be explained.

A. *Notation*

- N: total number of spare parts installed
- n_{AM}: number of spare parts produced on demand via AM, variable to be optimized
- $N - n_{AM}$: number of spare parts produced with CM managed with stocks
- i: production mode (options are CM or AM)
- $MTTF_i$: mean time to failure of the spare part made with production mode-i $[weeks]$
- λ_i: failure rate of the spare part made with production mode-i $[\frac{part}{weeks}]$
- c_a: purchasing cost of the CM option $[\frac{€}{part}]$
- c_p: production cost of the AM option $[\frac{€}{part}]$
- c_b: unitary backorder cost per time unit $[\frac{€}{part*week}]$
- h: weekly holding rate $[\frac{1}{week}]$
- f: fixed weekly costs for the purchasing of a 3D printer, considered as depreciation
- t_{prod}: production time of the AM option
- LT: replenishment lead time of the CM option
- m: number of insourced 3D printers, variable to be optimized
- T: review period
- S: order up to level for CM option, variable to be optimized
- S_{max} : máximum order up to level for CM option in stocks constrained systems
- y: auxiliary variable representing the number of failures of the part in $T + LT$
- CA: purchasing cost for CM parts $[\frac{€}{week}]$
- CP: production cost for AM parts $[\frac{€}{week}]$
- CB_{AM}: backorder cost for AM parts $[\frac{€}{week}]$
- CB_{AM}: backorder cost for AM parts $[\frac{€}{week}]$
- CH: inventory cost $[\frac{€}{week}]$
- CS: weekly cost for the purchasing of a 3D printer

B. *Hypothesis*

1. For both the production options (CM and AM) failures follow a Poisson distribution. This is a reasonable assumption for spare parts [8]
2. The model considers a spare part that is installed on a fleet of N-systems (e.g. aircraft) where the spare part is subjected to the same failure rates i.e., the failures depends only on the production mode adopted
3. For the parts produced with AM a strictly on demand approach is followed.
4. For the parts produced with CM a period policy with order up to level is proposed inspired by [32] and [8] who recently modified it.
5. Each system in the case of production with CM has its own inventory.
6. For the parts produced with CM the review period is not optimized but tested with two different levels.
7. For the parts produced with AM only one printer can be purchased. This assumption is in line with the adoption of a new technology in a company.

C. *Mathematical Model*

Below is our model for the management of N spare parts choosing between classical management with CM under a periodic review policy or printing on demand with AM.

$$min\ Ctot = Ca + Cp + Cb_{CM} + Cb_{AM} + Ch + Cs \qquad 1)$$

s.t.

$$P_{\lambda_{CM},T+LT,y} = \frac{(\lambda_{CM}(T+LT))^{y} \cdot e^{-\lambda_{CM}(T+LT)}}{y!} \qquad 2)$$

$$t_{FM,n_{AM}} = \frac{1}{\mu} + \frac{\rho}{2\mu(1-\rho)} \qquad 3)$$

$$n_{AM} \leq M \cdot m \qquad 4)$$

$$0 \leq n_{AM} \leq N \qquad 5)$$

$$0 \leq m \leq 1 \qquad 6)$$

$$0 \leq S \leq S_{max} \qquad 7)$$

$$n_{AM}, M, S \in N \qquad 8)$$

Where the terms in 1) can be written as:

$$Ca = (N - n_{AM}) \cdot c_a \cdot \lambda_{CM} \qquad 9)$$

$$Cp = n_{AM} \cdot c_p \cdot \lambda_{AM} \qquad 10)$$

$$Cb_{AM} = n_{AM} \cdot c_b \cdot t_{FM,n_{AM},m} \cdot \lambda_{AM} \qquad 11)$$

$$Cb_{CM} = (N - n_{AM}) \cdot \sum_{y=S}^{\infty}(y - S) \cdot P_{\lambda_{CM},T+LT,y} \cdot c_b \cdot \left(\int_0^{T+LT} \frac{\lambda_{CM}^{y} \cdot t^{y-1} \cdot e^{-\lambda_{CM} t}}{(y-1)!} \cdot (T + LT - t)\, dt\right) \qquad 12)$$

$$Ch = \sum_{y=0}^{S-1}(S - y) \cdot P_{\lambda_{CM},T+LT,y} \cdot h \cdot c_a \cdot \frac{y}{\lambda_{CM}} \cdot \frac{1}{(T+LT)} \qquad 13)$$

$$Cs = m \cdot f \qquad 14)$$

The goal of our model is to minimize the total cost for the management of the parts (1) which is composed of different sub costs. In particular, there is a purchasing cost for the fraction of parts that we decide to outsource with CM (9) which became a production cost for the parts internally produced with AM (10). Similarly, there is a backorder cost for the fraction produced with AM (11) which is proportional to the waiting time at the printer (3). The expression for the waiting time was obtained by modelling the queue as an M/D/1 system [35] since we accounted for only one printer that can be insourced. In the total cost there is also the backorder cost for the CM parts (12) for which the expression is new and differs from the backorder cost considered in [8]. In fact, we accounted for a backorder cost that is proportional to the unavailability time calculated as the average waiting time in $T + LT$ when the number of failed parts overcame the order up to level. Lastly, the total cost includes the holding cost (13) and purchasing cost of the printer (14).

IV. EXPERIMENTAL ANALYSIS

Here we describe our experimental analysis based on real data from [8]. They leveraged accelerated tests available in the literature to obtain the ratio between the Mean Time To Failure (MTTF) of the parts. Specifically, we accounted for a small part that Sgarbossa et al. found was best suited to AM management for which the data are reported in Table 1.

TABLE I
INPUT DATA

Data	Value	Data	Value
N	90	c_p	$150\ [\frac{€}{part}]$
$MTTF_{CM}$	$26\ [week]$	c_b	$2000[\frac{€}{part * week}]$
λ_{CM}	$0.0385\ [\frac{part}{weeks}]$	h	$0.0058\ [\frac{1}{week}]$
λ_{AM}	$0.0055\ [\frac{part}{weeks}]$	f	$769.88\ [\frac{€}{week}]$
c_a	$30\ [\frac{€}{part}]$	t_{prod}	$0.1\ [week]$

All the data come from Sgarbossa et al. (2021) except for the fixed weekly cost of the purchasing of the printer which was obtained considering a cost of € 200,000 amortized over five years. We tested this data considering two levels of lead time and reorder time, the first where both are equal to 12 weeks and the second 24 weeks. The results of these base scenarios are listed in Table 2.

TABLE II
BASE SCENARIO RESULTS

	n_{AM}	m	S	$Ctot$
$T = 12\ LT = 12$ $S_{max} = \infty$.	0	0	4	143.60
$T = 24\ \ LT = 24$ $S_{max} = \infty$.	0	0	6	160
$T = 12\ LT = 12$ and $T = 24\ \ LT = 24$	90	1	-	947.41

As shown in Table 2 in the base scenario with both the levels for T and LT it is economically viable to use the classical CM management of parts with an order up to level of 4 parts in the lower level and of 6 in the higher. In fact, in these situations management with AM is almost six times more expensive than with CM. We thus decided to carry out a further analysis considering future improvements in AM technology, shown in Table 3, together with various constraints on the stock levels.

TABLE III
DATA CONSIDERING IMPROVEMENTS OVER TIME FOR AM

Year	f	t_{prod}	c_p	**Reduction**
1	€ 730.77	0.095	€ 142.50	**5%**
2	€ 692.31	0.09	€ 135.00	**10%**
3	€ 653.85	0.085	€ 127.50	**15%**
4	€ 615.38	0.08	€ 120.00	**20%**

We also considered constraints on the order up to level, by setting S_{max}, which is a reasonable assumption for remote locations, where the application of AM has already been tested but considering that AM parts to be less reliable than CM ones [30]. The results for the lower level of T and LT are shown in Figure 1.

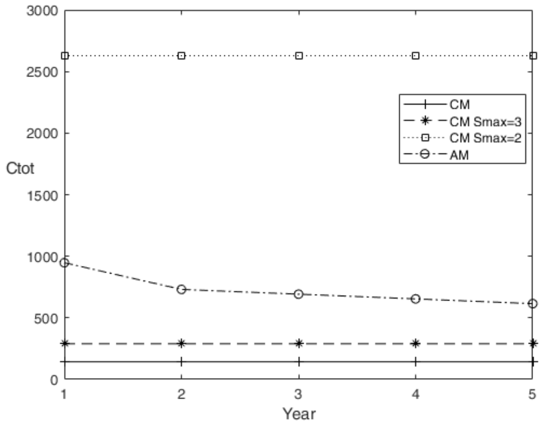

Fig. 1. Results for T=12 and LT=12

As shown in Figure 1 with the cost for CM considered and future improvements for AM as reported in Table 3 the management on demand of the parts is economically viable only with a strict constraint on the stock levels. In fact, it is only with $S_{max} = 2$ that AM becomes more convenient being almost three times less expensive in the first year and up to four times less expensive in the year 5. This is an interesting result that clearly shows the profitability of AM under a stock constrained system. It is also confirmed by imposing an $S_{max} = 1$ (not reported since not in scale) where a management with CM will cost 20.6670 € that is up to 21 times the cost for AM in the first year and up to 33 times year five. This again confirms how stock constrained scenarios favour AM while obviously a cost reduction over time increases this advantage. On the other hand, for non-constrained stock systems with this lower level of lead time and reorder time AM is still not preferable. We also tested the effect of a cost reduction over time of AM and CM constrained stock systems for the higher level of T and LT, the results of which are shown in Figure 2. As shown in the figure with a higher level for the revision period and lead time AM is less expensive but only under stocks constraints. In fact, here AM is favoured with less constraints on the stock's levels being up to four time lower in the first-year respect to a management with CM with $S_{max} = 3$ and up to seven times lower in five years. While management with AM is slightly higher than with CM and $S_{max} = 4$ in the first year (€ 947.41 vs € 789.17) while from the second year AM becomes advantageous since it is 22% less expensive in year five.

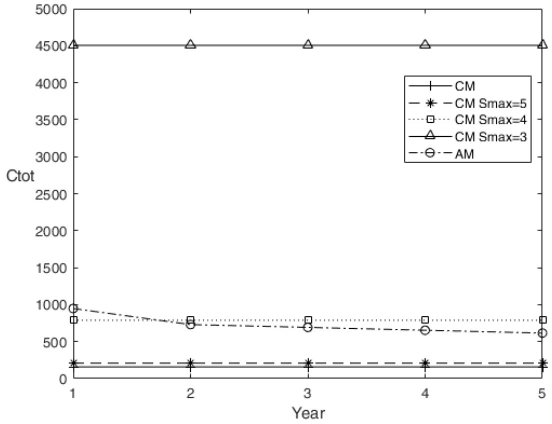

Fig. 2. Results for T=24 and LT=24.

At the same time even with the higher level of T and LT and with no constraints on the stocks or with soft constraints i.e., $S_{max} = 5$, a classical management using CM parts and order up to level policy is preferrable than printing on demand.

V. CONCLUSIONS

In this work we have presented a management model for a set of identical spare parts that optimizes the choice between management with a classical order up to level policy using CM parts and printing on demand with AM. The model for the management of CM parts is very similar to the one by Sgarbossa et al. (2021) and Babai et al (2011) but modified to account for a backorder cost proportional to the waiting time. This modification was essential to equally compare CM with AM since for AM we accounted for an insourced 3D printer and modelled the queue at the printer to derive the wating time for AM parts. On the other hand, accounting for a 3D printer forced us to also account for a set of identical spare parts installed in a fleet of systems (e.g. production system, aircraft) to justify the purchasing of a printer. This is in contrast with Sgarbossa et al. (2021) who considered AM parts to be outsourced. We applied our model to real data on CM and AM parts from Sgarbossa et al. (2021) in contrast with current literature where failures data are often only estimated. In our analysis we have included both stocks constrained scenarios and an improvement over future for AM technologies while considering two levels for the revision period and procurement lead time. Our results clearly show how under unconstrained stock system is still not convenient to insource a 3D printer for the production on demand of spare parts with both the levels for the revision period and lead time. However, while constraining the stock levels AM become more convenient as well as by considering its improvement over time. Specifically, for the lower level of T and LT a management with AM is convenient only with an order up to level constrained to two parts being three times less expensive than CM. An advantage that became higher, up to four times less expensive than CM, if we consider the improvements over five years. While with softer constraint on the stock CM is still preferable. Results change with the higher level of the reorder time and procurement lead time where less constraints on the stock are required to favour AM. In fact, in this case AM is preferable with an order up to level constrained to be equal or less than three from the first year being up to seven times lower than CM. In addition, in this situation AM became preferable also with the order up to level of CM constrained to four from the second year. Thus, we can conclude that:

- Print on demand with AM respect to a classical management of spare parts with CM is preferable when the system is constrained from a stock point of view. That is a situation arising in many operative settings i.e., offshore platforms.
- Print on demand with AM is more useful under system with high revision period and procurement lead time.
- The improvement of AM over years makes it convenient even for soft stocks constrained systems.

At the same time our study can be extended in order to overcame some of its limitations. Specifically:

- In this study we compared a classical management of spare parts with CM with a print on demand approach with AM. However, AM should be tested also for print to stock policies.
- We considered only a set of identical spare parts. Should be useful to consider a set of different parts with their own characteristics and evaluate the insourcing of a printer.

REFERENCES

[1] S. Dellagi, W. Trabelsi, Z. Hajej, and N. Rezg, "Integrated maintenance/spare parts management for manufacturing system according to variable production rate impacting the system degradation:," *https://doi.org/10.1177/1063293X19898734*, vol. 28, no. 1, pp. 72–84, Jan. 2020, doi: 10.1177/1063293X19898734.

[2] L. R. Muniz, S. V. Conceição, L. F. Rodrigues, J. F. de Freitas Almeida, and T. B. Affonso, "Spare parts inventory management: a new hybrid approach," *Int. J. Logist. Manag.*, vol. 32, no. 1, pp. 40–67, Jan. 2021, doi: 10.1108/IJLM-12-2019-0361/FULL/PDF.

[3] J. D. Croston, "Forecasting and Stock Control for Intermittent Demands," *J. Oper. Res. Soc.*, vol. 23, pp. 289–

303, 1972, doi: https://doi.org/10.1057/jors.1972.50.

[4] A. A. Syntetos and J. E. Boylan, "On the bias of intermittent demand estimates," *Int. J. Prod. Econ.*, vol. 71, no. 1–3, pp. 457–466, May 2001, doi: 10.1016/S0925-5273(00)00143-2.

[5] A. Spalanzani and K. E. Samuel, "Absorbing uncertainty within supply chains," *Int. J. Product. Qual. Manag.*, vol. 2, no. 4, pp. 441–458, 2007, doi: 10.1504/IJPQM.2007.013337.

[6] A. Yadollahi and N. Shamsaei, "Additive manufacturing of fatigue resistant materials: Challenges and opportunities," *Int. J. Fatigue*, vol. 98, pp. 14–31, May 2017, doi: 10.1016/J.IJFATIGUE.2017.01.001.

[7] M. Galati, P. Minetola, and G. Rizza, "Surface Roughness Characterisation and Analysis of the Electron Beam Melting (EBM) Process," *Materials (Basel).*, vol. 12, no. 13, Jul. 2019, doi: 10.3390/MA12132211.

[8] F. Sgarbossa, M. Peron, F. Lolli, and E. Balugani, "Conventional or additive manufacturing for spare parts management: An extensive comparison for Poisson demand," *Int. J. Prod. Econ.*, vol. 233, no. June 2020, p. 107993, 2021, doi: 10.1016/j.ijpe.2020.107993.

[9] K. V. Wong and A. Hernandez, "A Review of Additive Manufacturing," *ISRN Mech. Eng.*, vol. 2012, pp. 1–10, Aug. 2012, doi: 10.5402/2012/208760.

[10] I. Gibson, D. Rosen, and B. Stucker, *Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing, second edition*. 2015.

[11] J. S. Song and Y. Zhang, "Stock or print? impact of 3-d printing on spare parts logistics," *Manage. Sci.*, vol. 66, no. 9, pp. 3860–3878, 2016, doi: 10.1287/mnsc.2019.3409.

[12] M. Regis, E. Marin, L. Fedrizzi, and M. Pressacco, "Additive manufacturing of Trabecular Titanium orthopedic implants," *undefined*, vol. 40, no. 2, pp. 137–144, Feb. 2015, doi: 10.1557/MRS.2015.1.

[13] S. Liu and Y. C. Shin, "Additive manufacturing of Ti6Al4V alloy: A review," *Mater. Des.*, vol. 164, p. 107552, Feb. 2019, doi: 10.1016/J.MATDES.2018.107552.

[14] N. N. Kumbhar and A. V. Mulay, "Post Processing Methods used to Improve Surface Finish of Products which are Manufactured by Additive Manufacturing Technologies: A Review," *J. Inst. Eng. Ser. C*, vol. 99, no. 4, pp. 481–487, Aug. 2018, doi: 10.1007/S40032-016-0340-Z/FIGURES/3.

[15] S. Mellor, L. Hao, D. Zhang, S. Mellor, L. Hao, and D. Zhang, "Additive manufacturing: A framework for implementation," *Int. J. Prod. Econ.*, vol. 149, no. C, pp. 194–201, Mar. 2014, doi: 10.1016/J.IJPE.2013.07.008.

[16] M. Peron, S. M. Javad Razavi, J. Torgersen, and F. Berto, "Fracture Assessment of PEEK under Static Loading by Means of the Local Strain Energy Density," *Mater. 2017, Vol. 10, Page 1423*, vol. 10, no. 12, p. 1423, Dec. 2017, doi: 10.3390/MA10121423.

[17] M. Peron, J. Torgersen, and F. Berto, "Rupture Predictions of Notched Ti-6Al-4V Using Local Approaches," *Mater. 2018, Vol. 11, Page 663*, vol. 11, no. 5, p. 663, Apr. 2018, doi: 10.3390/MA11050663.

[18] B. Westerweel, R. J. I. Basten, and G. J. van Houtum, "Traditional or Additive Manufacturing? Assessing Component Design Options through Lifecycle Cost Analysis," *Eur. J. Oper. Res.*, vol. 270, no. 2, pp. 570–585, Oct. 2018, doi: 10.1016/J.EJOR.2018.04.015.

[19] M. Z. Babai, A. Syntetos, and R. Teunter, "Intermittent demand forecasting: An empirical study on accuracy and the risk of obsolescence," *Int. J. Prod. Econ.*, vol. 157, no. 1, pp. 212–219, Nov. 2014, doi: 10.1016/J.IJPE.2014.08.019.

[20] M. Hasni, M. S. Aguir, M. Z. Babai, and Z. Jemai, "On the performance of adjusted bootstrapping methods for intermittent demand forecasting," *Int. J. Prod. Econ.*, vol. 216, pp. 145–153, Oct. 2019, doi: 10.1016/J.IJPE.2019.04.005.

[21] F. Lolli, R. Gamberini, A. Regattieri, E. Balugani, T. Gatos, and S. Gucci, "Single-hidden layer neural networks for forecasting intermittent demand," *Int. J. Prod. Econ.*, vol. 183, pp. 116–128, Jan. 2017, doi: 10.1016/J.IJPE.2016.10.021.

[22] J. E. Boylan and A. A. Syntetos, "Spare parts management: A review of forecasting research and extensions," *IMA J. Manag. Math.*, vol. 21, no. 3, pp. 227–237, 2010, doi: 10.1093/imaman/dpp016.

[23] A. B. M. Z. Kabir and A. S. Al-Olayan, "A stocking policy for spare part provisioning under age based preventive replacement," *Eur. J. Oper. Res.*, vol. 90, no. 1, pp. 171–181, 1996, doi: 10.1016/0377-2217(94)00246-0.

[24] S. Zhu, W. van Jaarsveld, and R. Dekker, "Spare parts inventory control based on maintenance planning," *Reliab. Eng. Syst. Saf.*, vol. 193, no. July 2019, p. 106600, 2020, doi: 10.1016/j.ress.2019.106600.

[25] F. Zahedi-Hosseini, P. Scarf, and A. Syntetos, "Joint optimisation of inspection maintenance and spare parts provisioning: a comparative study of inventory policies using simulation and survey data," *Reliab. Eng. Syst. Saf.*, vol. 168, no. March, pp. 306–316, 2017, doi: 10.1016/j.ress.2017.03.007.

[26] N. Knofius, M. C. van der Heijden, and W. H. M. Zijm, "Consolidating spare parts for asset maintenance with additive manufacturing," *Int. J. Prod. Econ.*, vol. 208, pp. 269–280, Feb. 2019, doi: 10.1016/J.IJPE.2018.11.007.

[27] P. Liu, S. H. Huang, A. Mokasdar, H. Zhou, and L. Hou, "The impact of additive manufacturing in the aircraft spare parts supply chain: Supply chain operation reference (scor) model based analysis," *Prod. Plan. Control*, vol. 25, no. December 2017, pp. 1169–1181, 2014, doi: 10.1080/09537287.2013.808835.

[28] M. Peron, J. Torgersen, P. Ferro, and F. Berto, "Fracture behaviour of notched as-built EBM parts: Characterization and interplay between defects and notch strengthening behaviour," *Theor. Appl. Fract. Mech.*, vol. 98, pp. 178–185, Dec. 2018, doi: 10.1016/J.TAFMEC.2018.10.004.

[29] N. Knofius, M. Van Der Heijden, and A. Sleptchenko, "Improving effectiveness of spare part supply by additive manufacturing as dual sourcing option Improving effectiveness of spare part supply by additive manufacturing as dual sourcing option," no. June, 2017, doi: 10.13140/RG.2.2.31846.22082.

[30] B. Westerweel, R. Basten, J. den Boer, and G. van Houtum, "Printing Spare Parts at Remote Locations: Fulfilling the Promise of Additive Manufacturing," *Prod. Oper. Manag.*, no. April, 2021, doi: 10.1111/poms.13298.

[31] N. Knofius, M. C. van der Heijden, and W. H. M. Zijm, "Moving to additive manufacturing for spare parts supply," *Comput. Ind.*, vol. 113, p. 103134, 2019, doi: 10.1016/j.compind.2019.103134.

[32] M. Z. Babai, Z. Jemai, and Y. Dallery, "Analysis of order-up-to-level inventory systems with compound Poisson demand," *Eur. J. Oper. Res.*, vol. 210, no. 3, pp. 552–558, 2011, doi: 10.1016/j.ejor.2010.10.004.

[33] F. Lolli, A. M. Coruzzolo, M. Peron, and F. Sgarbossa, "Age-based preventive maintenance with multiple printing options," *Int. J. Prod. Econ.*, vol. 243, p. 108339, Jan. 2022, doi: 10.1016/j.ijpe.2021.108339.

[34] S. Ivan and Y. Yin, "Additive manufacturing impact for supply chain - Two cases," *IEEE Int. Conf. Ind. Eng. Eng. Manag.*, vol. 2017-December, pp. 450–454, Feb. 2018, doi: 10.1109/IEEM.2017.8289931.

[35] K. Furmans, C. Huber, and J. Wisser, "Queueing Models for manual order picking systems with blocking," *Logist. J. Ref. Veröffentlichungen*, no. November 2009, 2009, doi: 10.2195/lj_ref_furmans_2092_092009.