POLITECNICO DI TORINO
Repository ISTITUZIONALE

A production scheduling case study solved for Electron Beam Powder Bed Fusion

Original
A production scheduling case study solved for Electron Beam Powder Bed Fusion / Pastore, E., Galati, M., Alfieri, A., Iuliano, L.. - ELETTRONICO. - 58:(2024), pp. 982-987. (18th IFAC Symposium on Information Control Problems in Manufacturing (INCOM 2024) Vienna 28/08/2024) [10.1016/j.ifacol.2024.09.148].

Availability:
This version is available at: 11583/2996180 since: 2025-01-03T14:52:00Z

Publisher:
Elsevier

Published
DOI:10.1016/j.ifacol.2024.09.148

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

25 November 2026

Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnline CONFERENCE PAPER ARCHIVE

IFAC PapersOnLine 58-19 (2024) 982–987

A production scheduling case study solved for Electron Beam Powder Bed Fusion

Erica Pastore*, Manuela Galati, Arianna Alfieri, Luca Iuliano

**Department of Management and Production Engineering, Politecnico di Torino, Torino, Italy (e-mail: erica.pastore@polito.it, manuela.galati@polito.it, arianna.alfieri@polito.it, luca.iuliano@polito.it).*

Abstract: Additive Manufacturing (AM) represents a pillar of the modern industrial revolution. Its peculiar characteristics make AM largely differ from conventional manufacturing; thus, the approach to the production planning and control must change and be adapted to such technology. While for conventional manufacturing nesting and scheduling decisions are taken at different planning stages, they are both made in daily operations when AM technology is considered. This paper proposes a case study applied to the powder bed fusion process with electron beam (PBF-EB) and involving the problem of scheduling parts in a distributed production system composed of many parallel identical facilities. According to the typical PBF-EB production stages, each facility also has a second stage for cleaning and support removal operations, and only a subset of facilities has a third stage for surface finishing and post-heat treatments. In the case study, the scheduling problem is solved by a proposed genetic algorithm to minimize the makespan.

Copyright © 2024 The Authors. This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

Keywords: Additive Manufacturing, Electron Beam-Based Powder Bed Fusion for Metals, Scheduling, Post-processing, Distributed Flexible Flow Shop, Case Study

1. INTRODUCTION

Additive manufacturing (AM) technologies refer to a group of manufacturing systems in which the production is performed by adding subsequent layers of materials. This approach contrasts with the conventional one because it allows the production of geometries with high complexity and superior performance.

Thanks to the absence of tools or additional equipment to produce parts, AM technologies were rapidly adopted for prototyping applications. However, today, AM is a manufacturing reality for many industrial sectors, such as aerospace and medical (Careri et al., 2023). Also, owing to the ease of production, the use of AM is growing for manufacturing spare parts or for part repair (Kulshrestha et al., 2024). Because of all these advantages, AM represents a pillar of the modern industrial revolution, mainly for the possibility of realizing distributed production.

According to ISO/ASTM 52900:2021, many different AM processes exist today and can work with different materials and shapes, such as metallic powders or thermoplastic filaments. In the industry, AM processes based on metallic powders are central. A successful case is the production of the turbine blades of GE9X, the world most powerful and biggest commercial aircraft engine. The blades are produced by powder bed fusion with an electron beam of high-performance material, intermetallic titanium, which significantly reduced the engine weight compared to its predecessor, in which Inconel was used (Wartbichler et al, 2021).

Most of the literature on AM today focuses on making the process more efficient, sustainable, and enlarging the materials portfolio. As AM processes and products largely differ from conventional manufacturing, the literature on production planning and control for AM technologies has also been growing lately (De Antón et al., 2023, Pastore et a., 2023). New methods have been studied to handle decisions about the placement and orientation of multiple parts in the same build platform (i.e., nesting decisions) and the scheduling of such parts (Oh et al., 2020). Indeed, different from conventional manufacturing (in which nesting and scheduling decisions are made at different planning stages), production systems with AM technology call for such decisions to be taken in daily operations, i.e., at the same planning stage.

The literature on nesting and scheduling for AM is vast, and the reader can refer to De Antón et al. (2023), Oh et al. (2020) for exhaustive reviews. Owing to its complexity, the joint scheduling and nesting problem has been studied in single-stage systems with one or more parallel AM machines (e.g. Lee et al., 2023). Some authors only focus on one of the two decision processes by assuming that the output of the other is given. The AM scheduling problem (without nesting considerations) has been addressed in single-stage systems with single or parallel AM machines (Liu et al., 2023), and in assembly systems (Ying et al., 2023). A limited number of studies have also considered distributed systems with many AM facilities to produce parts (e.g. Kucukkoc, 2024). Also, only a few papers on scheduling for AM specifically consider peculiar AM processes. For instance, Aloui et al. (2021) and Rohaninejad et al. (2022) considered selective laser melting technology.

This paper addresses the scheduling problem for a distributed production system composed of many parallel facilities. Each facility has one AM machine characterized by the powder bed fusion with an electron beam for metals (PBF-EB/M)

2405-8963 Copyright © 2024 The Authors. This is an open access article under the CC BY-NC-ND license.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2024.09.148

technology. A second stage in the facility includes some post-processing operations typical of such technology, i.e., cleaning and support removal; also, only a subset of the facilities has a third stage of post-processing operations (surface finishing and post-heat treatments). The problem is to find the optimal schedule to minimize the makespan (i.e., the completion time of the last part in the system). A genetic algorithm is proposed to solve the problem, and it is applied to a case study. The case study includes the scheduling of real parts manufactured by PBF-EB/M machines, and various configurations of the distributed system.

The remainder of the paper follows. Section 2 describes the problem, and Section 3 the proposed solution method. The case study is presented and discussed in Section 4, while Section 5 concludes the paper.

2. PROBLEM DESCRIPTION

The addressed problem is a scheduling problem for a distributed system composed of PBF-EB/M and post-processing machines. In the following, the considered AM process is discussed in detail, then the system is described, and finally, assumptions on scheduling and nesting decisions are given.

2.1 The PBF-EB/M production process

The AM process considered for the analysis is a powder bed fusion with an electron beam for metals. With respect to other AM processes for metal, in a PBF-EB, it is possible to produce multiple parts stacked in the build platform and along the build direction. In this way, it is possible to realize a 3D nesting, guaranteeing the build volume full saturation. This is possible thanks to a preheating phase that precedes the melting and slightly sinters the powder. The formatted sintered powder supports the construction of parts on top of each other (Galati et al., 2022).

On the other hand, the sintering also produces rougher surfaces, and therefore, the parts produced by EB-PBF are usually near net shape and may need post-finishing operations. Also, depending on the processed material, post-heat treatment may be required for tuning the final component mechanical properties. This chain simplifies the complete PBF-EB/M process into three steps: production, the first post-processing phase (PP1), and the second post-processing (PP2).

The *production* process consists of nesting the parts in the build volume, assigning the process parameters and slicing, preparing the machine and loading the powder, creating a proper vacuum level, and printing. The printing process starts by preheating the build plate to a specific temperature. After this phase, layer-by-layer production starts by distributing a certain amount of powder over the start plate. The powder bed is then preheated and melted according to the 2D section. Then, the build platform is lowered by an amount corresponding to the layer thickness, and a new powder bed is distributed. The process is repeated until the entire build is completed. The preheating and melting phases are performed using an electron beam, in which electricity and speed are adjusted according to the targeted energy for each phase. After the process, the produced parts are surrounded by sintered powder particles that are softly agglomerated and keep the parts together. This agglomerate is called cake.

The *post-processing phase 1* (PP1) consists of the cleaning phase and support removal. The cleaning consists of a blasting process performed on the cake, which separates the parts and cleans them up from the sintered powder. The excess powder is recovered, sieved, and used for the next production. After the cleaning, the structures used to support the construction of overhang features, if present, are removed. PP1 procedures are necessary for all the produced parts.

A *post-processing phase 2* (PP2) might be necessary for improving the surface finishing or tuning the material properties via post-heat treatment. If required, these operations follow PP1. Examples of finishing processes are shoot peening, Laser Shock Peening (LSP), Laser Polishing (LP) and conventional machining processes such as turning and milling (Mahmood et al., 2022). The most common thermal treatments are solution heat treatment and hot isostatic pressing, which improve physical and mechanical properties (Guo et al., 2018).

2.2 The production system

The system used in the case study is schematized in Figure 1. In the pre-manufacturing stage, scheduling and nesting decisions are made according to the customer orders. Such decisions are related to the AM and post-processing machines and to the sequence of parts to be produced in each machine. The production and the PP1 phase are supposed to be performed in a set of distributed identical facilities. Each facility consists of one PBF-EB machine and one PP1 station, and parts are produced in batches (denoted as *job* in the paper) according to the nesting decisions previously made. The sequence is assumed to be the same for AM and PP1. Then, if the part needs a PP2 phase, it is transported to a dedicated PP2 station, where each part is processed individually. PP2 stations are in a subset of production facilities, and parts produced in a specific facility can be transported to another one to complete PP2, if necessary. In the end, parts leave the system, and the related customers are satisfied.

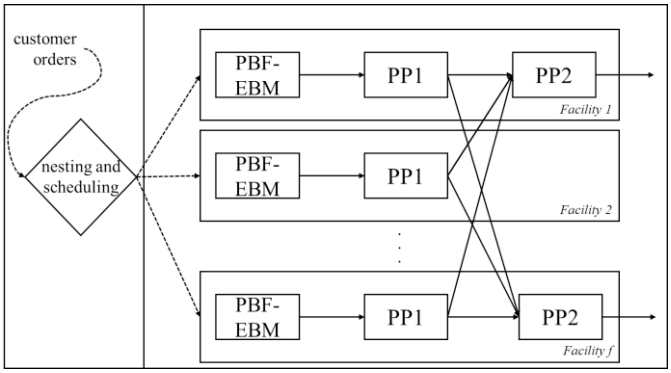

Figure 1. Addressed production system.

2.3 The scheduling and nesting decisions

This paper assumes that the *nesting decisions* have been previously defined according to the best manufacturing practices. Thus, information about how parts are batched together in jobs is available for manufacturing each set of

parts. Also, for each possible job, the best practices of the product and process designs for PBF-EB define the orientation and nesting of all the parts to be produced in the build volume. Therefore, the complete build nesting is available together with the printing time. Thus, the nesting decisions only relate to the best alternative jobs to select for production.

With these assumptions, *scheduling decisions* focus on: i) the choice of the production facility (that includes production and PP1) for each job, ii) the schedule of jobs for each production facility, iii) the choice of the PP2 facility, if needed; iv) the schedule of parts for each PP2 facility. Decisions i) and iii) are allocation decisions, while ii) and iv) are scheduling decisions. The objective of the study is to minimize the makespan (c_{max}).

3. SOLUTION METHOD

To solve the addressed scheduling problem, a genetic algorithm (GA) has been developed, whose flowchart is given in Figure 2.

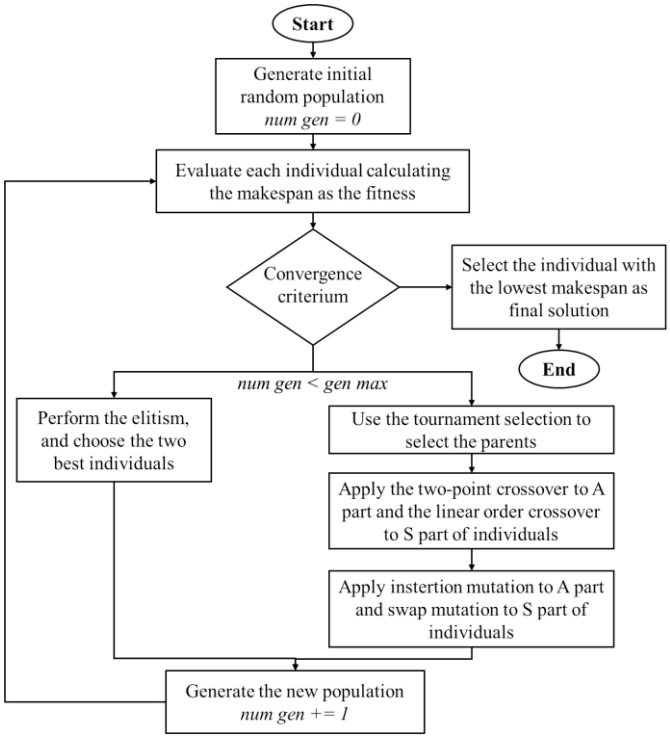

Figure 2. Flowchart of the used genetic algorithm

3.1 Encoding representation, initial population and stopping criterion

Each individual (i.e., each incumbent solution) consists of two main parts. The first component indicates the allocation decision on PBF-EB+PP1 and PP2 stages (A), while the second indicates the schedules in PBF-EB+PP1 and PP2 (S). For example, Fig. 3 shows an incumbent solution for a problem with four jobs composed of eight parts and three factories, among which only two contain the PP2 machines.

S	1	4	2	3	5	4	3	6	1	2	8	7
A	1	1	3	2	1	1	2	1	2	2	1	2

Figure 3. Individual encoding for a problem with 4 jobs, 8 parts, 3 AM-PP1 parallel stages, 2 PP2 parallel stages

In the first 4 positions of S there is the schedule of the 4 jobs, while in the other positions of S there is the schedule of the 7 parts. Instead, the A array is composed of the allocation of the 4 jobs in the 3 parallel facilities in the first 4 positions, while the other positions contain the allocation of the 7 parts in the 2 PP2 machines.

For each individual, its fitness function is the makespan of the associated incumbent solution. The initial population is randomly generated.

The stopping criterion involves fixing a finite number of generations.

3.2 Selection and offprings generation

The algorithm for the selection steps uses the tournament selection (TTS) method (Alhijawi et al., 2023). For the crossover phase, the two-point crossover is used for the allocation part of the individual (A), while the Linear Order Crossover (LOX) for the scheduling part (S) (Werner, 2013). Moreover, mutation is used in the algorithm besides crossover, and, specifically, the insertion mutation is used in A while the swap mutation in S. Last, the elitism principle is also applied to safeguard the retention of high-quality solutions (Chen et al., 2023).

4. CASE STUDY

The problem previously described was solved by the proposed GA in a realistic case study. The case study consists of producing twelve distinct parts distributed in multiple jobs. All the parts have a different geometry; each part is identified by a part ID, a number from 1 to 12. Each job may contain one or multiple quantities of the same part (part ID) or a mix of parts. Nesting decisions were a priori assumed. Each job is identified by a Job ID, which is a number. Each job can be repeated multiple times. The jobs were grouped into two subsets (fully described in Tables Table 1-Table 3), which are tested and scheduled. The parts were assumed to be produced in PBF-EB/M machines, specifically, in an Arcam A2X by GE Additive (Galati et al., 2023).

The production process is as follows: (i) all the jobs are printed in the PBF-EB/M machine (AM phase); (ii) the parts of each job are freed from the cake of powder material and cleaned (PP1); (iii) the supports are removed (PP1); (iv) 11 part types undergo a process of surface finishing (PP2).

4.1. Data and information

Table 1. Job set 1: job ID, composition, job height, PBF-EB and PP1 processing times

Job ID (qty)	Composition of the job: sum of part ID (qty)	Job height (mm)	PBF-EB unit time (h/job)	PP1 unit time (h/job)
2(3)	2(1)	140.0	17.52	1.75
6(2)	4(1)	160.0	19.07	2.5
8(1)	4(9)	160.0	27.38	7.8
10(2)	6(1)	282.0	43.23	2.97
11(1)	5(7)	32.0	9.22	6.08
12(1)	5(6)+7(8)	153.1	26.77	11.83
20(2)	1(7)+3(4+s)+8(1)+9(2)+10(1)	61.5	14.35	8.09
21(2)	2(6)+3(3+s)+4(2)+5(1)+7(1)+11(5)+12(1)	164.7	33.17	13.57
22(1)	2(5)+3(14+s)+7(3)+9(10)+12(2)	170.3	33.78	17.75
24(2)	1(3)+3(6+s)+8(2)+11(5)	93.0	18.7	10.90

Table 2. Job set 2: job ID, composition, job height, PBF-EB and PP1 processing times

Job ID (qty)	Composition: sum of part ID(qty)	Job height (mm)	PBF-EB time (h/job)	PP1 time (h/job)
1(4)	1(1)	60.0	7.73	1.75
2(13)	2(1)	140.0	17.52	1.75
10(2)	6(1)	282.0	43.23	2.97
12(2)	5(6)+7(8)	153.1	26.77	11.83
17(2)	4(9+s)	165.0	28.05	8.52
20(2)	1(7)+3(4+s)+8(1)+9(2)+10(1)	61.5	14.35	8.09
23(1)	1(7)+3(4+s)+5(2)+8(2)+9(2)	60.0	15.13	9.67
25(1)	2(12)+3(22+s)+5(6)+11(6)+12(3)	248.8	55.20	29.93

Table 2 describe the two tested job sets. For each job ID, the quantity to be produced is given in the first column, together with the composition of the job (sum of part IDs each followed by the quantity and "s" if supports are needed), the build height, and the AM and PP1 unit processing times. The PP1 times are the sum of cake separation, cleaning, and support removal tasks. The first job set contains 17 jobs, composed of 171 parts, and the second contains 27 jobs, which are 161 parts in total. Table 3 shows the PP2 details of the 12 parts, in which the given PP2 processing times is the sum of all the PP2 needed tasks; as shown in the table, part 4 does not need PP2 processing.

Table 3. Part set: ID part, PP2 processing time

ID part	1	2	3	5	6	7	8	9	10	11	12
PP2 unit time (h/part)	0.2	0.5	0.5	1	1.5	1.5	2	1	1	4	2

Finally, Table 4 shows the total processing time for each production phase for each job-set; the total processing time is given by the sum of the processing times of all the quantities to be produced in the job-set.

Table 4. Total processing time (pt) for job-sets 1 and 2

	Tot. jobs	Tot. parts	AM pt (h)	PP1 pt (h)	PP2 pt (h)	Total pt (h)
Job-set 1	17	171	406.73	124.77	186.90	718.40
Job-set 2	27	161	553.78	132.17	126.75	812.70

The facilities were strategically located in various European cities, and various production networks were tested. Specifically, six scenarios were evaluated, as reported in Table 5: the production locations can be up to 10 (Li et al., 2019), among which PP2 operations were located in up to 3 locations; this implies an average ratio of 3 PBF-EB machines for each PP2 machine (Kapadia et al., 2019). The travel time between any pair of cities (not shown in the paper for reasons of conciseness) was computed by considering travel times, rest periods, and loading/unloading times.

Table 5. Scenarios of production locations

Scenario	1	2	3	4	5	6
PBF-EB - PP1 facilities	2	3	5	6	9	10
PP2 facilities	1	1	2	2	3	3

In summary, the two job sets are scheduled in the six system scenarios using the proposed GA algorithm to minimize the makespan. The GA parameters have been set as in Table 6 after preliminary testing. For each job set-scenario, five replicates are run to handle the algorithm stochasticity.

Table 6 Values of the parameters of the algorithm

Algorithm parameter	Value
Population size	50
Num. of generations	50
Tournament size	4
Crossover rate	0.8
Swap mutation rate	0.5

Mutation rate	0.1
Elitism number	2

4.2 Numerical results and discussion

The numerical results are shown in Table 7, which shows the average makespan of the solutions to the scheduling problems of the two job-sets in the 6 tested scenarios.

Table 7. Numerical results for each scenario

Scenario	PBF-EB - PP1 Factories	PP2 Factories	c_{max} Job-set 1	c_{max} Job-set 2
1	2	1	296.65	312.28
2	3	1	264.33	245.47
3	5	2	161.04	162.37
4	6	2	157.50	154.91
5	9	3	137.89	134.01
6	10	3	134.51	133.23

As the table shows, with the minimum number of parallel facilities and PP2 machines, it takes around 12 days to complete the production of job-set 1, and more than 13 days to complete job-set 2. Adding one PBF-EB and one PP1 machines decreases the makespan of 1.35 days and 2.78 days for job-sets 1 and 2, respectively. In general, when moving from scenario 1 to 6, the makespan decreases, as expected, for both job-sets. Figure 4 graphically shows the results of the case study. The lines represent the average makespan over the five replicates of each scenario for the two job-sets (black for job-set 1, grey for 2), the horizontal axis reports the configuration of each scenario. As the figure shows, a significant makespan improvement is reached when moving from scenario 2 to 3, i.e., when adding one more PP2 machine and one more PBF-EB+PP1 factory. In this case, the makespan moves from around 11 to 6.71 days for job-set 1, and from around 10 to 6.77 days for job-set 2.

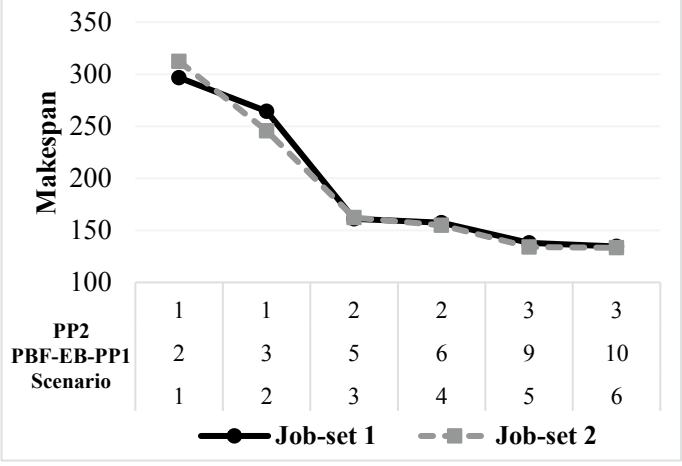

Figure 4. Results of the case study

The makespan improvement from this scenario to the ones with a larger number of machines exists; however, in these cases, the gain is small. For instance, from scenarios 3 to 6, the makespan improvement is around 1 day for both job-sets, while the number of machines is doubled.

Interestingly, if the two job-sets are compared in terms of makespan of the scheduling solutions, the time needed to produce all the parts included in the job-sets is similar. However, the second job-set includes 10 more parts than job-set 1, and around 100 hours of total processing times more than job-set 1.

5. CONCLUSION

Differently from conventional manufacturing, Additive Manufacturing (AM) allows the production of materials and geometries with high complexity and superior performance. For its innovative characteristics, it is nowadays a pillar production technology for all industries, especially for spare parts, aerospace, and medical products.

Such new technological paradigm calls for new methodologies also in production planning and control to handle its peculiarities. Specifically, new scheduling and nesting methods are needed to handle daily operations in production systems using AM technologies.

This paper addressed, through a case study, a scheduling problem for a distributed systems composed of various facilities producing parts with a powder bed fusion process with electron beam (PBF-EB). Each facility has a PBF-EB machine, and one stage for post-processing operations such as cleaning and support removal; moreover, a subset of facilities also has a third stage for surface finishing and post-heat treatments. The problem is to find an optimal schedule of parts in the distributed system to minimize the makespan. Nesting decisions were assumed to be made a priori by technology experts.

A genetic algorithm was developed for solving such problems, which was able to find efficient solutions for the case study. Also, two sets of parts were tested and scheduled by the proposed algorithm.

The preliminary results presented in the paper showed that the time to produce the complete set of parts was around ten days for a system composed only of 2 PBF-EB machines and one machine for finishing and post-heat operations. Adding one of the latter machines can drastically improve the time to produce the set of parts.

Future research will be devoted to understanding how different nesting decisions impact on the time to produce the whole set of parts; also, nesting will be embedded in the decision process, by developing new algorithms that will be able to handle a joint scheduling and nesting problem.

REFERENCES

Alhijawi, B., and Awajan, A. (2023). Genetic algorithms: Theory, genetic operators, solutions, and applications. *Evolutionary Intelligence*, 1-12.

Aloui, A., and Hadj-Hamou, K. (2021). A heuristic approach for a scheduling problem in additive manufacturing under technological constraints. *Computers & Industrial Engineering*, 154, 107115.

Careri, F., Khan, R. H., Todd, C., and Attallah, M. M. (2023). Additive manufacturing of heat exchangers in aerospace applications: A review. *Applied Thermal Engineering*, 121387.

Chen, H., Fang, Z., and Zhong, C. (2023). Research on hybrid flow-shop scheduling based on improved genetic algorithm. *In 2023 IEEE 18th Conference on Industrial Electronics and Applications* (ICIEA) (pp. 1315-1320). IEEE.

De Antón, J., Villafáñez, F., Poza, D., and López-Paredes, A. (2023). A framework for production planning in additive manufacturing. *International Journal of Production Research*, 1-18.

Galati, M., Giordano, M., and Iuliano, L. (2023). Process-aware optimisation of lattice structure by electron beam powder bed fusion. *Progress in Additive Manufacturing*, 8(3), 477-493.

Galati, M., Defanti, S., Saboori, A., Rizza, G., Tognoli, E., Vincenzi, N., Gatto, A. and Iuliano, L. (2022). An investigation on the processing conditions of Ti-6Al-2Sn-4Zr-2Mo by electron beam powder bed fusion: Microstructure, defect distribution, mechanical properties and dimensional accuracy. *Additive Manufacturing*, 50, 102564.

Guo, J., Bai, J., Liu, K., and Wei, J. (2018). Surface quality improvement of selective laser sintered polyamide 12 by precision grinding and magnetic field-assisted finishing. *Materials & Design*, 138, 39-45.

ISO/ASTM 52900:2015 - Additive manufacturing - General principles - Terminology

Kapadia, M. S., Starly, B., Thomas, A., Uzsoy, R., and Warsing, D. (2019). Impact of scheduling policies on the performance of an additive manufacturing production system. *Procedia Manufacturing*, 39, 447-456.

Kucukkoc, I. (2024). Scheduling of distributed additive manufacturing machines considering carbon emissions. *An International Journal of Optimization and Control: Theories & Applications (IJOCTA)*, *14*(1), 20-31.

Kulshrestha, N., Agrawal, S., and Shree, D. (2024). Spare parts management in industry 4.0 era: a literature review. *Journal of Quality in Maintenance Engineering*.

Lee, S. J., and Kim, B. S. (2023). Two-stage meta-heuristic for part-packing and build-scheduling problem in parallel additive manufacturing. *Applied Soft Computing*, 110132.

Li, Q., Zhang, D., Wang, S., and Kucukkoc, I. (2019). A dynamic order acceptance and scheduling approach for additive manufacturing on-demand production. *The International Journal of Advanced Manufacturing Technology*, 105, 3711-3729.

Liu, L., Wu, Z., and Yu, Y. (2023). A branch-and-price algorithm to perform single-machine scheduling for additive manufacturing. *Journal of Management Science and Engineering*, 8(2), 273-286.

Mahmood, M. A., Chioibasu, D., Ur Rehman, A., Mihai, S., and Popescu, A. C. (2022). Post-processing techniques to enhance the quality of metallic parts produced by additive manufacturing. *Metals*, 12(1), 77.

Oh, Y., Witherell, P., Lu, Y., & Sprock, T. (2020). Nesting and scheduling problems for additive manufacturing: A taxonomy and review. *Additive Manufacturing*, 36, 101492.

Pastore, E., Alfieri, A., Matta, A., & Previtali, B. (2023). Analytical models for flow time estimation of additive manufacturing machines. *International Journal of Production Research*, 1-17.

Rohaninejad, M., Tavakkoli-Moghaddam, R., Vahedi-Nouri, B., Hanzálek, Z., and Shirazian, S. (2022). A hybrid learning-based meta-heuristic algorithm for scheduling of an additive manufacturing system consisting of parallel SLM machines. *International Journal of Production Research*, 60(20), 6205-6225.

Wartbichler, R., Clemens, H., Mayer, S., Ghibaudo, C., Rizza, G., Galati, M., ... & Ugues, D. (2021). On the Formation mechanism of banded microstructures in electron beam melted Ti–48Al–2Cr–2Nb and the design of heat treatments as remedial action. *Advanced engineering materials*, 23(12), 2101199.

Werner, F. (2013). A survey of genetic algorithms for shop scheduling problems. *Heuristics: theory and applications*, 161-222.

Ying, K. C., and Lin, S. W. (2023). Minimizing makespan in two-stage assembly additive manufacturing: A reinforcement learning iterated greedy algorithm. *Applied Soft Computing*, 138, 110190.