# Chapter 7
# Role and Scope of OEE to Improve Additive Manufacturing Processes in Biomedical Industries

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## 1 Introduction

Overall Equipment Effectiveness (OEE) is a metric used to evaluate the efficiency of manufacturing processes. It considers three components: availability, performance, and quality. The implementation of OEE in additive manufacturing processes in the biomedical industries can help improve the efficiency and quality of production, leading to cost savings and improved patient outcomes [1–4]. Here are some steps to implement OEE in additive manufacturing:

- Define the scope of the analysis: Determine the machines and processes to be analyzed, as well as the specific components of OEE that will be measured. For example, if a company wants to analyze a 3D printer used to produce surgical implants, they may focus on availability (how often the machine is running), performance (how efficiently it is running), and quality (how many defective parts are produced) [4–6].

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- Collect data: In order to calculate OEE, data needs to be collected on machine uptime, speed, and quality. This can be done manually or through automation using sensors and software. Data collection should be continuous to provide real-time feedback [4].
- Analyze the data: Use the collected data to calculate OEE for the defined scope. Identify areas of low OEE and investigate root causes. This can help identify specific areas for improvement [5, 6].
- Implement improvements: Based on the analysis, make improvements to increase OEE. This may include maintenance, machine upgrades, process changes, or training for operators. It is important to track the impact of improvements on OEE [1, 7].
- Continuously monitor and adjust: Once improvements have been made, continue to monitor OEE to ensure that improvements are sustained. Adjustments may need to be made to maintain or further improve OEE [1, 7].
- By implementing OEE, companies in the biomedical industry can improve their additive manufacturing processes, leading to increased efficiency and improved quality. This can ultimately result in cost savings and better patient outcomes [2, 3].

## 2 Literature Review

There is a growing body of literature exploring the application of Overall Equipment Effectiveness (OEE) in Additive Manufacturing (AM) processes. OEE is a widely used metric for evaluating manufacturing efficiency and has been applied to a range of industries. In recent years, it has gained popularity in the additive manufacturing community as a way to optimize production processes and improve quality control [8]. Several studies have investigated the application of OEE in additive manufacturing for various industries, including aerospace, automotive, and biomedical. For example, a study by Hubner et al. [9] analyzed the OEE of an AM system used to produce aerospace components. The study found that OEE was affected by factors such as machine downtime and production quality. By monitoring OEE and making improvements, the authors were able to reduce production costs and improve the overall efficiency of the system. Another study applied OEE to a 3D printing process used in automotive manufacturing [10]. The authors found that OEE was impacted by factors such as material waste and equipment downtime. By addressing these issues, they were able to increase the OEE of the system by 20%. In the biomedical industry, OEE has been applied to additive manufacturing processes used to produce medical devices and implants. For example, in a study, OEE is used to enhance the processes of an Additive manufacturing (AM) system in order to produce custom orthopedic implants. The study found that OEE was impacted by factors such as machine maintenance and process optimization [2, 11]. By making improvements to the system based on OEE analysis, the authors were able to increase the efficiency of the process and reduce production costs. Overall, the literature suggests that OEE can be a useful tool for optimizing additive manufacturing processes across a range of industries. By monitoring OEE and making improvements, companies can increase the efficiency of their production processes, reduce costs, and improve the quality of their products [11–14].

### 2.1 Overall Equipment Effectiveness (OEE) Paradigm

OEE is a widely recognized performance metric used to evaluate the efficiency of manufacturing processes. OEE measures three key components: availability, performance, and quality. The application of OEE has been studied in various industries, including automotive, aerospace, food processing, and pharmaceuticals. In the automotive industry, OEE has been used to evaluate the efficiency of assembly lines, stamping operations, and painting processes. A study published in the Journal of Cleaner Production applied OEE to evaluate the efficiency of an automotive paint shop. The study demonstrated that OEE provided a comprehensive assessment of the paint shop, highlighting areas for improvement and reducing downtime [15, 16]. In the aerospace industry, OEE has been applied to evaluate the efficiency of manufacturing processes for aircraft engines, landing gears, and airframes. OEE to evaluate the efficiency of a landing gear assembly line and the study showed that OEE was effective in identifying areas for improvement and reducing downtime [17, 18]. In the food processing industry, OEE has been used to evaluate the efficiency of production processes for various products, including dairy, meat, and bakery products. A study published in the Journal of Food Engineering applied OEE to evaluate the efficiency of a cheese production line. The study demonstrated that OEE provided a comprehensive assessment of the cheese production line, identifying areas for improvement and reducing downtime [19]. In the pharmaceutical industry, OEE has been applied to evaluate the efficiency of manufacturing processes for drug products. A study published in the Journal of Pharmaceutical Innovation applied OEE to evaluate the efficiency of a tablet manufacturing process. The study demonstrated that OEE provided a comprehensive assessment of the tablet manufacturing process, identifying areas for improvement and reducing downtime [20].

OEE is an effective tool to evaluate the efficiency of an AM system for producing complex metal parts. The study demonstrated that OEE was an effective tool for identifying inefficiencies in the AM process, including machine downtime, material waste, and inconsistent product quality. The study also highlighted the importance of optimizing the AM process by selecting suitable parameters, such as feedstock material, build orientation, and machine settings [21–25]. Another study stated that OEE to evaluate the efficiency of a laser powder bed fusion (LPBF) AM system for producing titanium alloy parts. The study demonstrated that OEE provided a comprehensive assessment of the LPBF process, identifying areas for improvement and reducing downtime. The study also highlighted the importance of monitoring and controlling the process parameters, such as laser power, scanning speed, and layer thickness, to optimize the AM process [26–28]. Overall, the application of OEE in AM provides a valuable tool for manufacturers to evaluate the efficiency of their production process and identify areas for improvement. The successful implementation of OEE requires careful selection of suitable parameters, consistent monitoring of process variables, and continuous improvement efforts to optimize the AM process.

### 2.1.1 OEE in Biomedical Industries

In production and manufacturing industries, OEE has been used extensively to identify the efficiency and effectiveness of various production processes. This metric has been applied in the manufacturing of automotive components, electronic devices, food processing, pharmaceuticals, and other industries. The use of OEE in these industries has resulted in significant improvements in efficiency, productivity, and profitability. A study published in the International Journal of Production Economics evaluated the effectiveness of OEE in the manufacturing of automotive components. The study demonstrated that OEE provided a comprehensive assessment of the manufacturing process, highlighting areas of inefficiency, and improving the overall equipment utilization. The study also showed that the use of OEE resulted in a significant increase in productivity and profitability [23, 29–31]. In the electronics industry, OEE has been applied to evaluate the efficiency of various production processes. A study published in the International Journal of Production Research evaluated the effectiveness of OEE in the production of electronic circuit boards. The study demonstrated that OEE provided a comprehensive assessment of the production process, highlighting areas for improvement, and increasing the equipment utilization rate. The use of OEE resulted in a significant increase in productivity and profitability [32–34] (Fig. 1).

In the food processing industry, OEE has been used to evaluate the efficiency of production processes for various products, including dairy, meat, and bakery products. A study published in the Journal of Productivity and Performance Management applied OEE to evaluate the efficiency of a cheese production line. The study demonstrated that OEE provided a comprehensive assessment of the cheese production line, identifying areas for improvement and reducing downtime [35–37]. In the pharmaceutical industry, OEE has been applied to evaluate the efficiency of manufacturing processes for drug products. The study demonstrated that OEE provided a comprehensive assessment of the tablet manufacturing process, identifying areas for improvement and reducing downtime [38].

- Calculations and formulas to find/enhance OEE:

Overall Equipment Effectiveness (OEE) is a widely used performance metric to evaluate the efficiency of manufacturing processes. It measures the availability, performance, and quality of a process, and can be calculated using the following formula [1–4]:

In general,

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

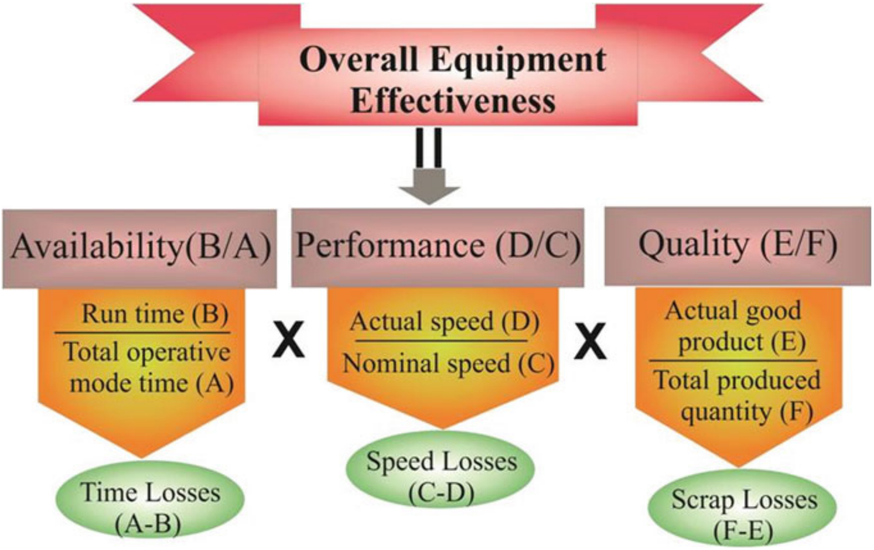


**Fig. 1** Elements of overall equipment effectiveness [1]

where Availability = (Operating time–downtime)/Operating time

Performance = (Ideal cycle time × Total count)/Operating time

Quality = Good count/Total count.

The availability metric measures the percentage of time that a machine or process is available for production. It is calculated by subtracting the total downtime from the operating time and dividing by the operating time. Downtime can include unplanned stops, changeovers, maintenance, and any other non-productive time. The performance metric measures the efficiency of the process. It is calculated by multiplying the total count by the ideal cycle time and dividing by the operating time. The ideal cycle time is the time it should take to produce one unit of the product, assuming no downtime or defects. The quality metric measures the percentage of good units produced. It is calculated by dividing the number of good units produced by the total count of units produced.

There are various strategies that can be implemented to enhance OEE in additive manufacturing processes in the bio-medical industry. These include:

- Reducing setup time: By optimizing the setup process and reducing the time, it takes to prepare the machine for production, more time can be allocated for production, increasing availability.
- Improving maintenance procedures: Regular maintenance and inspection of machines can help prevent breakdowns and reduce downtime.
- Streamlining production flow: By optimizing the flow of materials and products through the manufacturing process, the overall performance can be improved.

- Implementing quality control measures: Ensuring that products meet quality standards can reduce the amount of rework required and improve overall quality.
- Investing in training: Providing employees with training and support can help improve their skills and knowledge, leading to better performance and quality.

By implementing strategies to enhance OEE, companies can improve their production processes and reduce downtime, ultimately leading to increased productivity and profitability. In conclusion, the application of OEE has been studied in various industries and has been demonstrated to be effective in evaluating the efficiency of manufacturing processes. OEE provides a comprehensive assessment of the manufacturing process, identifying areas for improvement and reducing downtime. The application of OEE in AM has gained attention as the technology has become increasingly prevalent in various industries [1]. OEE in AM refers to a comprehensive assessment of the performance of the AM process, which includes measuring the efficiency of the equipment, the quality of the output, and the availability of the equipment.

## *2.2 Additive Manufacturing (AM) Paradigm*

Additive manufacturing (AM) has revolutionized the manufacturing industry by enabling the production of complex and customized parts with greater design freedom and reduced lead time. AM, also known as 3D printing, is a process of building a 3D object layer by layer from a digital model [39]. One of the significant advantages of AM is its ability to reduce material waste, as only the material required for the part is used. This makes AM an environmentally friendly alternative to traditional manufacturing methods such as subtractive manufacturing, which generate a significant amount of waste material [40]. AM has also enabled the production of parts with unique geometries and internal structures that are impossible to create using conventional manufacturing methods. This has led to the development of lightweight parts with superior strength-to-weight ratios, which are particularly useful in the aerospace and automotive industries [41, 42]. Furthermore, AM has enabled the production of personalized products such as medical implants, dental crowns, and hearing aids, which are customized to fit an individual's unique anatomy. However, there are also some challenges associated with AM, such as the need for high-precision and specialized equipment, the limited range of available materials, and the potential for inconsistent product quality [2, 43].

### 2.2.1 AM in Production and Manufacturing

AM, also known as 3D printing, is a rapidly growing field that has the potential to revolutionize the manufacturing industry. The application of AM has been studied extensively in recent years, and numerous studies have investigated its use in various industries and production processes. In the aerospace industry, AM has been used to produce complex parts for aircraft engines, landing gears, and airframes. A study published in the Journal of Aircraft Engineering and Aerospace Technology demonstrated the potential of AM to reduce the weight of aircraft components, resulting in significant fuel savings and reduced emissions [44]. In the automotive industry, AM has been used to produce lightweight parts with complex geometries, reducing vehicle weight and improving fuel efficiency. A study published in the International Journal of Automotive Technology demonstrated the use of AM to produce automotive components with superior strength-to-weight ratios, improving vehicle performance and reducing material waste [45].

In the medical industry, AM has been used to produce customized implants, prosthetics, and surgical tools. A study demonstrated the use of AM to produce patient-specific orthopedic implants, resulting in improved surgical outcomes and reduced surgery time. In the production of consumer goods, AM has been used to produce customized products with unique designs and features [46]. Another study concluded the use of AM to produce personalized jewelry, resulting in increased customer satisfaction and improved profitability for the manufacturer. Overall, the application of AM has been studied extensively in various industries and production processes, demonstrating its potential to reduce material waste, improve product performance, and enable the production of customized products. As technology advances and more materials become available, the potential applications of AM in production and manufacturing are expected to grow, leading to further improvements in efficiency, sustainability, and product quality [46–49]. Overall, AM has transformed the biomedical industry by providing new design possibilities, reducing material waste, and enabling the production of customized and complex parts. As technology advances and more materials become available, the potential applications of AM in manufacturing are expected to grow, leading to further improvements in efficiency, sustainability, and product quality.

### *2.3 Findings of the Literature*

AM is revolutionizing the biomedical industry by enabling the production of patient-specific implants, prostheses, and other medical devices with high precision and accuracy. However, the success of AM relies on the efficiency of the production process, which can be improved by implementing OEE as a performance metric. OEE provides a comprehensive assessment of the production process by measuring three key components: availability, performance, and quality. The application of OEE in various industries, including automotive, aerospace, food processing, and pharmaceuticals, has been extensively studied and has demonstrated significant improvements in efficiency and productivity.

The implementation of OEE in AM processes can be challenging due to the complexity of the process and the various factors that can affect the performance of the equipment. However, several studies have shown that OEE can be effectively applied to improve AM processes in the biomedical industry. The studies showed that OEE provided a comprehensive assessment of the process, identifying areas for improvement and reducing downtime. Similarly, OEE can be applied to evaluate the efficiency of a selective laser sintering (SLS) process for producing biomedical devices. The study demonstrated that OEE was effective in identifying areas for improvement and reducing downtime [50]. Moreover, the implementation of OEE in AM processes can result in significant cost savings for the biomedical industry. OEE to evaluate the efficiency of a 3D printing process for manufacturing prostheses and it was observed that this gizmo is effective in reducing the production cost by identifying areas for improvement and reducing the downtime of the equipment [21]. The implementation of OEE in AM processes has the potential to improve the efficiency and productivity of the biomedical industry by providing a comprehensive assessment of the production process. OEE can identify areas for improvement, reduce downtime, and result in significant cost savings. However, further research is needed to develop a standardized approach for implementing OEE in AM processes. The results of this research will aid in the development of efficient and cost-effective AM processes that can revolutionize the biomedical industry.

## 3 Conclusion

OEE has been widely adopted in manufacturing industries as a performance metric to evaluate the efficiency of production processes. With the rapid development of AM technologies, there has been a growing interest in applying OEE to evaluate and improve AM processes, especially in the biomedical industry.

In a study, the researchers applied OEE to evaluate an AM process for producing customized dental implants. The study showed that OEE provided a comprehensive assessment of the AM process, highlighting areas for improvement and reducing the time and cost required for process optimization. The OEE metric incorporated unique characteristics to enhance AM processes, such as build time and material usage and provided a more accurate evaluation of AM efficiency. In the biomedical industry, OEE has been applied to evaluate the efficiency of AM processes for producing orthopedic implants, dental prostheses, and other medical devices. For example, a study published in the Journal of Medical Systems applied OEE to evaluate an AM process for producing cranial implants. The study showed that OEE was effective in identifying the causes of machine downtime and quality issues, and helped to improve the overall efficiency of the AM process. In conclusion, the application of OEE to AM processes in the biomedical industry has shown promising results in terms of improving efficiency, reducing costs, and improving quality. Further research is needed to develop more specialized OEE calculation methods for specific AM processes and to evaluate the impact of OEE on patient outcomes.

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