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The Strategic Role of Drilling Jigs in Drilling Precision

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A B T R A C T

In modern production processes, particularly in drilling, accuracy and efficiency are critical factors determining the quality of the final product. However, achieving high precision often faces challenges, especially in small and medium-sized industries (SMIs) that lack technological capabilities and human resources. One technical solution that has been widely adopted and proven effective is the use of drilling jigs. A jig is a tool designed to hold and guide the workpiece, enabling drilling processes to be performed consistently and precisely, even without reliance on CNC machines or highly skilled operators. This study reviews five scientific articles discussing the design, fabrication, and performance evaluation of jigs in various industrial applications, ranging from gear manufacturing to the production of car fog lamps. Based on the analysis results, the use of jigs has been proven to significantly reduce defect rates (e.g., from 26 units to 6 units in the study by Alqodri & Sirait) and produce holes with very low dimensional deviations (±0.1 mm, as in the study by Haider et al.). Additionally, the success of jig usage is greatly influenced by geometric design, jig materials (such as aluminum 6061 and amutit steel), and integration with machining parameters like tool tip angle and feed rate. Furthermore, CAD-based design approaches and the utilization of CNC technology also enhance the efficiency of the jig manufacturing process, as demonstrated in the fog lamp jig manufacturing study. Despite challenges such as tool wear or errors in G-code input, the success rate of 70% from 10 tested specimens indicates that jigs continue to provide positive contributions. Therefore, it can be concluded that drilling jigs are a strategic solution that not only improves drilling efficiency and accuracy but also supports productivity, workplace safety, and sustainable industrial competitiveness, particularly in the small and medium-sized manufacturing sector.

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INTRODUCTION

Advancements in modern manufacturing technology have made significant contributions to improving production efficiency and final product quality, particularly in machining processes such as drilling. One of the main challenges in drilling operations is achieving high accuracy when creating holes, which is critical in the assembly of machine components or other mechanical structures. Inaccuracies during drilling can lead to various issues, including dimensional errors, tool wear, material waste, and high rates of defective or rejected products (Safril et al 2023; Safril et al., 2024).

These challenges become even more complex for small and medium enterprises (SMEs), which often face limitations in terms of skilled labor, access to modern equipment such as CNC machines, and capital investment. Therefore, there is a need for technical solutions that are not only effective but also economical. One efficient solution is the use of production aids in the form of drilling jigs, which ensure consistency and accuracy in drilling operations without requiring highly skilled operators. Jigs can also reduce reliance on additional precision measuring tools and speed up the overall workflow (Nur et al., 2020).

Research conducted by Alqodri and Sirait (2023) demonstrated that implementing a jig using the Design for Manufacture and Assembly (DFMA) approach at PT Duo Work Engineering significantly improved the efficiency of the drilling process in gear components. The number of defective products dropped dramatically from 26 units to just 6 units over six working days, and the production success rate increased from 83.3% to 96.6%. This indicates that jigs can significantly enhance production effectiveness.

Another study by Haider et al. (2024) emphasized that a jig specifically designed for use with a manual drilling machine can deliver highly precise results with a very small tolerance of ±0.1 mm. Without requiring layout marking or center punching, this process saves both time and production costs, offering a viable alternative for industries unable to invest in high-cost CNC machines. Furthermore, research by Mufarrih et al. (2022) highlighted the importance of selecting appropriate process parameters —such as drill point angle and feed rate—to ensure round and accurate holes. The study showed that increasing the angle and feed rate actually resulted in greater roundness deviations, thus underscoring the critical need for optimal parameter selection in machining processes.

In the automotive industry context, the development of jigs for components such as fog lamps has also proven to improve both production efficiency and precision. Nanda et al. (2023) developed a small-scale jig for fog lamp production with a 70% success rate out of 10 test specimens. This study demonstrated that even with some technical challenges, such as cutting tool wear that caused shape defects, jigs were still effective in streamlining production.

Another study by Haider et al. (2024) confirmed that jigs can also serve as solutions for small industries lacking CNC drilling machines. They designed a low-cost precision jig that could be used with a manual drill by semi-skilled operators, yet still achieved hole tolerances of up to ±0.1 mm. Additionally, this jig eliminated the need for marking and center punching, which typically add time to the process. Meanwhile, Mufarrih et al. (2022) revealed that the accuracy of drilling results is also heavily influenced by technical parameters such as drill point angle and feed rate. Mismatched settings can lead to hole shape deviations, particularly in terms of roundness. Therefore, optimal jig design must be accompanied by proper selection of process parameters.

In the automotive sector, Nanda et al. (2023) developed a small-scale jig for car fog lamp production, achieving a 70% success rate from 10 test specimens. This research shows that despite the small scale, jigs can support productivity and product quality as long as proper design and quality control processes are applied.

From these findings, it can be concluded that drilling jigs play an important role in supporting the efficiency, accuracy, and consistency of the production process, particularly in drilling. The implementation of jigs is not only a practical solution for large industries but also holds significant potential to sustainably improve the

competitiveness of small and medium enterprises.

The novelty of this review lies in its comprehensive approach to integrating five different experimental studies on the design and application of drilling jigs, with a specific focus on implementation in small and medium-sized enterprises (SMEs). Unlike previous studies that focused on a single technical aspect, this article synthesizes jig design, material selection, machining parameters, and prototype validation strategies based on CAD and DFMA. This approach reveals that the combination of smaller drill point angles and lower feed rates significantly improves hole roundness, and that wood-based iterative prototyping is effective in reducing defect rates by more than 50%. These findings contribute new insights into strengthening the argument that drilling jigs are low-cost precision solutions that can replace expensive technologies like CNC machines while improving ergonomics and productivity in small-scale manufacturing production lines.

Overall, these studies demonstrate that the use and design of drilling jigs play a strategic role in improving production performance, in terms of product quality, time efficiency, and reduced operational costs. Therefore, a deep understanding of jig design, analysis, and implementation is essential for widespread adoption—particularly among small and medium-sized industries striving to compete productively and sustainably.

METHOD

1.1. Literature Review

In modern manufacturing, the use of jigs has become one of the main technical solutions to ensure accuracy and efficiency in production processes, especially in drilling operations. A jig is a supporting tool designed to hold, guide, and position the workpiece so that machining processes can be carried out precisely, without heavy dependence on operator skill (Nur et al., 2020). The use of jigs enables repeatable processes with consistent results and reduces the likelihood of human errors that could lead to defective or non-compliant products.

To improve manufacturing efficiency, the Design for Manufacture and Assembly (DFMA) approach is widely adopted in jig design processes. DFMA emphasizes the importance of simplifying designs and aligning them with existing production facilities to reduce costs, speed up production, and improve the quality of the final product (Alqodri & Sirait, 2023). This is particularly relevant in small and medium enterprises (SMEs), where limited capital is a barrier to investing in CNC machines. In this context, jigs are proven to be economical alternatives capable of delivering CNC-level precision at a much lower investment cost, as demonstrated by Haider et al. (2024) in the development of a precision jig for drilling gas stove cylinders using a manual drilling machine.

Beyond cost efficiency, drilling precision is also a key focus in jig-related research. The study by Mufarrih et al. (2022) showed that technical variables such as drill point angle and feed rate have a significant impact on hole roundness when drilling composite KFRP (Kevlar Fiber Reinforced Polymer) material. The findings emphasize the importance of integrating jig design with proper cutting parameter selection to achieve optimal hole quality—where smaller drill angles and lower feed rates result in lower roundness deviations.

In practice, jig development requires an iterative prototyping approach to minimize design risks. For instance, Haider et al. (2024) began their jig fabrication process by designing a wooden prototype before producing it in metal. This step allowed for early evaluation of shape, strength, and functionality in a cost-effective manner. On the other hand, Aulia Nanda et al. (2023) implemented a CAD and CNC- based system to design and produce a small-scale automotive fog lamp jig. The process began with a 3D design using Autodesk Inventor, followed by G-code conversion, and testing on a VFP-1000A CNC machine. Jig manufacturing success was assessed based on conformity with design specifications, where 70% of test specimens met the standard.

Another equally important aspect is work safety and ergonomics. The presence of a jig makes the drilling process more stable by

firmly clamping the workpiece, reducing the risk of vibration and work-related accidents. Additionally, jigs reduce the physical workload of operators since high skill is no longer required to achieve precision results (Nur et al., 2020).

Various types of jigs are also developed to suit the shape and requirements of different workpieces. For cylindrical objects, the use of V-blocks and guide bushings is key to maintaining workpiece stability during drilling. This combination allows drilling to be performed perpendicularly and consistently along the workpiece axis, even under machine vibration.

Overall, previous studies show that jig design contributes not only to improved product quality but also to cost efficiency, work safety, and mass production capability. Integrating thoughtful mechanical design, appropriate jig materials, and technologies such as CAD and CNC constitutes a comprehensive approach needed for effective jig implementation in modern manufacturing.

1.2. Flowchart of Jig Development Process

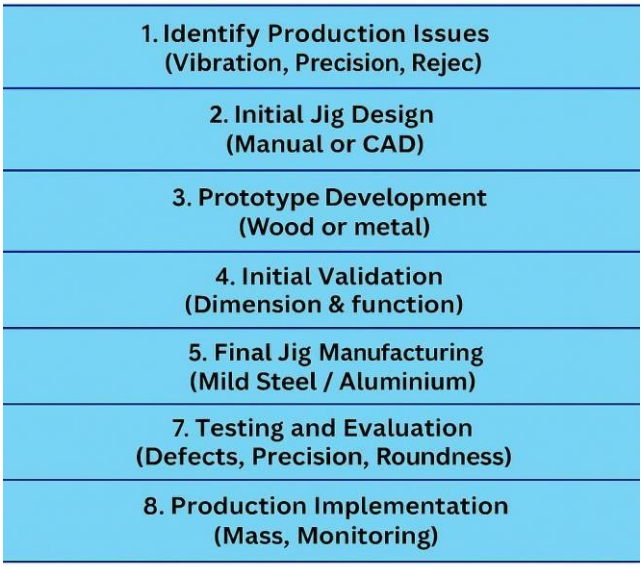


Fig 1. Flowchart of jig

The development process of jig drilling as a precision production tool can be carried out through eight structured stages that represent a systematic approach in manufacturing engineering.

The first step begins with the identification of production problems. This stage is carried out through direct observation of the production process on-site. Common issues identified include inaccuracies in hole positioning, high rates of defective products (rejects), lengthy processing times, and reliance on operators with high skill levels. The objective of this stage is to clearly identify the root causes of inefficiency or product quality discrepancies.

After the issues are identified, the next step is to design the initial jig, either manually or using computer-aided design software such as SolidWorks or Autodesk Inventor. At this stage, the design includes determining the basic structure of the jig, component dimensions, clamping systems, and the position and diameter of the bushing holes that will guide the drill bit.

The third stage is the creation of a prototype, typically using inexpensive materials such as wood or soft metal. This prototype serves as an initial model to test the form and functionality without incurring significant costs. The use of prototypes is highly beneficial for detecting design errors early on before the permanent fabrication of the jig is carried out. Once the prototype is available, initial validation is conducted. This stage involves testing the jig dimensions, hole position accuracy, workpiece stability when clamped, and the smoothness of the drilling process. The results of this validation

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determine whether the initial design can proceed or requires revisions.

If weaknesses or shortcomings are found in the prototype or initial design, the design iteration stage is continued. Here, the initial design is refined based on the findings from the previous stage. The new design can be additional alternatives (Alternative 1, Alternative 2, and so on) that are more suitable for functional and ergonomic needs in the field.

Once the final design is determined, the next stage is the fabrication of the final jig. At this stage, the jig is made using primary materials such as mild steel or aluminum. Material selection is based on load resistance, machinability, and environmental factors such as corrosion potential. The fabrication process is carried out using manual machining methods (drilling, turning, milling) or CNC-based methods for high accuracy.

The seventh step is testing and evaluating the fabricated jig. Evaluation involves technical parameters such as hole size precision, roundness, drilling stability, and processing time efficiency. If possible, a comparison is made between processes with and without the jig to assess the effectiveness of jig implementation in a real production context.

The final stage is the full implementation of the jig into the production line. After the jig passes evaluation and is proven to improve precision and efficiency, it is then used in mass production. During this stage, regular monitoring is conducted to ensure the jig's performance remains stable, and maintenance or replacement is performed if wear occurs.

Table 1. Comparison of Drilling Jig Research Studies

Researcher	Research Object	Method	Result Accuracy	Remarks
Haider et al. (2024)	Gas Stove Cylinder	Manual Jig	±0.1 mm	Effective without CNC
Mufarrih et al. (2022)	KFRP (composite)	Influence of Drill Angle & Speed	Optimal roundness	Process parameters are critical
Alqodri & Sirait (2023)	Gear at PT Duo	Iterative DFMA	Rejects reduced 26 → 6	Increased productivity
Nanda et al. (2023)	Car Fog Lamp	CAD & CNC	70% accuracy	Limited by cutting tool wear
Nur et al. (2020)	General Cylinder	V-block Jig	Stable	Effective heat treatment

The methodology used in this review is a systematic approach to five experimental articles relevant to the topic of drilling jigs. The first step is to identify primary journal articles based on topic relevance, research methods, and experimental results. Articles were selected from journals on mechanical engineering, manufacturing engineering, and industrial engineering. Next, a synthesis was performed on the main information from each article, such as the research object, methods used, significant results, and contributions to improving efficiency and precision in drilling. This information was processed and summarized in a comparison table to clarify the differences and similarities between each study. An analysis was performed to identify relevant research trends and gaps.

Table 2. Comparison of Studies from Various Articles on the Use of Drilling Jigs

Author	Research Object	Method	Main Findings	Contribution
Haider et al. (2024)	Precision Drilling Jig for Gas Stove	Design and testing of manual jig based on wood & mild steel prototype	Reduced setup time and defects caused by misalignment	Low-cost precision solution for SMEs
Mufarrih et al. (2022)	KFRP (composite)	Full factorial L9, variation of drill angle and feed rate	Small angle & low feed rate produced best roundness	Identification of most significant process parameters
Nur et al. (2020)	Cylindrical workpiece drilling	V-block jig design with guiding bushings	Improved hole accuracy and stability	Validation of bushing importance for round objects
Nanda et al. (2023)	Car Fog Lamp	CNC jig design based on Inventor & testing 10 samples	70% success rate, failed due to tool wear	Suitable for small-scale automotive industry
Alqodri & Sirait	Gear at PT Duo	DFMA-based design	Reject rate reduced	DFMA

(2023)	Work & iterations	2	prototype	from 26 to 6 units	implementation for practical production efficiency

RESULT AND DISCUSSION

Various studies on the use of drilling jigs in manufacturing processes have shown that this supporting tool plays a crucial role in improving both efficiency and precision in drilling—across large-scale and small-scale industries alike. Cross-study comparisons reveal that well-designed jigs not only optimize product quality but also reduce dependency on high-tech machinery or highly skilled operators.

In the context of small-scale industries, as shown by Haider et al. (2024), the development of a precision jig used on a manual drilling machine was able to produce holes with a deviation tolerance of just about ±0.1 mm. This level of precision was achieved even without the use of CNC machines, making it a highly relevant and cost-effective solution for small and medium-sized enterprises (SMEs). The use of jigs also eliminates the need for layout marking and center punching, accelerating production time and reducing human error.

On the other hand, the study by Mufarrih et al. (2022) emphasized that the quality of drilling—particularly hole roundness in Kevlar Fiber Reinforced Polymer (KFRP) composite materials—is heavily influenced by technical parameters such as drill point angle and feed rate. A combination of a small drill angle (100°) and a low feed rate (50 mm/min) was found to deliver the best results in maintaining hole roundness. This research highlights that jigs are even more effective when used in conjunction with optimized machining parameters.

In addition to technical aspects, the practical benefits of jigs are also evident in their application in automotive component production. Nanda et al. (2023) designed a fog lamp jig using CNC machines based on 3D design from Autodesk Inventor. Although the success rate reached only 70% (out of 10 test specimens), the primary cause of failure was not the jig itself but rather tool wear. This shows that the success of a jig is also affected by tool condition and machining parameters.

Meanwhile, Nur et al. (2020) developed a jig for cylindrical workpieces, which pose unique challenges due to their tendency to rotate or shift during drilling. The use of V-blocks, clamping systems, and precisely heat-treated bushings created a more stable and accurate drilling system. This demonstrates the importance of material selection and reinforcement processes for key jig components.

In large industrial environments, redesign approaches—as seen in the study by Alqodri and Sirait (2023)—show the critical role of continuous design evaluation. Through two design iterations, an optimal jig form was finally achieved that improved production efficiency and reduced product defects from 16.7% to only 3.4%.

Overall, these studies provide a comprehensive picture that the success of jig implementation depends on several factors: accurate geometric design, appropriate material selection, early-stage validation (prototyping), and synchronization with machining process parameters. The integration of both technical and managerial aspects in the jig development process is key to ensuring its effectiveness in actual production settings.

CONCLUSION

Based on a comprehensive synthesis of five reviewed research articles, it can be confirmed that the drilling jig is a crucial component in optimizing the drilling process within the manufacturing industry—applicable across small, medium, and large industrial scales. The primary function of a jig is not only to support and guide the workpiece and cutting tool, but also to serve as a systematic solution for ensuring hole precision, product consistency, and overall production efficiency.

The analyzed studies indicate that jigs can substitute for CNC machines in achieving drilling accuracy, especially in situations where high-tech machinery investment is not feasible. The use of jigs enables semi-skilled operators to produce precision- quality holes with very low dimensional deviation, even without manual layout marking and center punching. This directly impacts shorter production cycle times, reduced defect rates, and lower operational costs. From a technical standpoint, jig effectiveness is influenced by several key factors, including geometric design that aligns with the shape of the workpiece, material selection that offers durability and resistance to wear, and the application of heat treatment to enhance the strength of components such as bushings. The studies also stress the importance of early-stage design validation through prototyping— whether with wood or other soft materials—to identify potential flaws before final fabrication.

Test results also suggest that successful jig performance must be supported by proper machining parameters to achieve optimal drilling outcomes. For example, in drilling KFRP material, it was found that increasing drill point angle and feed rate without proper control could cause significant roundness deviations. Therefore, integrating sound jig design with optimal cutting parameters is essential for successful jig implementation. Moreover, efficiency evaluations in small-scale automotive industries show that jigs not only accelerate production but also add value in terms of quality and output control. However, it is important to note that production failures are not always caused by jig design; external factors such as tool wear, improper CNC settings, or non-conforming specifications also play a role.

In conclusion, the drilling jig is a simple yet highly effective technological approach. It offers an innovative alternative to meet high-precision requirements at low cost and can be widely applied across various industrial sectors. Jig design that incorporates ergonomic principles, design flexibility, early validation, and continuous evaluation will enhance manufacturing performance—making production processes more adaptive, accurate, and competitive.

Therefore, this study recommends that jig development be continuously improved—in terms of design, manufacturing technology, and systematic application in production environments. This approach is not only relevant to technical efficiency but also serves as a strategic solution in driving the transformation of industries toward smart and sustainable manufacturing.

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