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Revolutionizing Connectivity Through 5G Technology

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Abstract*— *The article explores the foundations and developments of 5G technology, emphasizing how it differs from earlier iterations and how it has the potential to revolutionize contemporary communication. It highlights 5G's significant influence on day-to-day living by examining how both established and cutting-edge technology have been integrated to create it. The study looks at important 5G applications, especially in manufacturing, transportation, healthcare, and other sectors where it spurs efficiency and innovation. 5G is positioned as a key component of next-generation connectivity because to its enhanced data throughput, decreased latency, and expanded network coverage. The study also discusses the significant obstacles that enterprises and researchers must overcome in order to satisfy the constantly rising needs for security, scalability, and dependability. This article gives a thorough review of 5G's role in transforming the digital world while overcoming implementation challenges by showing how it is changing mobile communication and opening up new opportunities.

I. INTRODUCTION

The most recent development in wireless communication is Fifth Generation (5G) technology, which is establishing a new benchmark for mobile networks. 5G stands out from its predecessors thanks to its revolutionary features, which include seamless connectivity between machines, devices, and people, allowing for previously unheard-of levels of performance and potential. 5G has revolutionized the user experience and opened up prospects for a variety of sectors by providing high-speed internet connection anywhere, at any time [1].

In the development of wireless communication, 5G technology marks a revolutionary turning point that presents previously unheard-of chances for industry-wide innovation. The first section of this study examines the development of 5G, following its path from previous mobile network generations to its present condition. To comprehend how these developments allow for faster data rates, lower latency, and better network coverage, the technological underpinnings of 5G—such as its reliance on millimeter waves, massive MIMO, beamforming, and tiny cell networks—are investigated [2].

To provide remarkable speed and connectivity, 5G technology makes use of cutting-edge high-bandwidth technologies, such as millimeter-wave (mmWave) and sub-6 GHz spectrums. 5G, in contrast to earlier generations, is based on a dense network of tiny cell stations that are positioned thoughtfully on rooftops and other objects like light poles. Because mmWave transmissions, which operate in the 30 to 300 GHz band, offer the high speeds that 5G promises but have major restrictions, this infrastructure is crucial. Physical barriers like trees, buildings, and even bad weather can readily interfere with these signals, which have a limited range. 5G addresses these obstacles by deploying a large number of tiny cells, guaranteeing reliable, fast connectivity and opening the door for creative applications in daily life and industry [3]. After 1G and 4G, mobile telecommunications have advanced significantly with 5G, or the Fifth-Generation mobile network. With the help of this innovative technology, people, machines, and objects will all be seamlessly integrated to form a highly interconnected environment. In addition to changing user experiences, 5G's increased efficiency and dependability open up new application possibilities by bridging disparate industries. 5G, with its lightning-fast speeds, low latency, and unmatched network reliability, is set to become a key component of the Internet of Things (IoT) ecosystem. Next-generation applications and services are made possible by this revolutionary stage in mobile telecommunication standards. In addition to entertainment, 5G will be crucial in creating smart cities, where linked systems like public transit, traffic control, and environmental monitoring will improve sustainability, efficiency, and safety. 5G is also anticipated to transform industries including manufacturing with smart factories that use automation and artificial intelligence, and healthcare with telemedicine, driverless cars, and remote surgery. 5G is poised to revolutionize the digital landscape and spur innovation worldwide by tackling significant connection and scalability issues [4]. The ability of 5G technology to satisfy the constantly rising demand for high-speed mobile data in today's hyperconnected world is one of its biggest benefits. 5G's increased capacity and sophisticated network architecture allow for smooth HD video streaming, quick uploads and downloads, and the real-time responsiveness needed for applications like virtual reality and online gaming. The expansion of smart devices is another benefit of 5G technology, which guarantees that the expanding Internet of Things (IoT) ecosystem can operate effectively without network congestion. It is perfect for industrial automation, large-scale events, and congested urban settings due to its capacity to manage enormous numbers of connections at once [5]. Although there are many advantages to the rollout of 5G networks, there are also some important drawbacks, such as the requirement for substantial infrastructure construction and the resolution of privacy and security issues. The fundamental technology of 5G is examined in this study along with its revolutionary applications and potential to completely change a number of sectors. The development of 5G is primarily driven by the explosive growth of the Internet of Things (IoT) ecosystem and the spike in demand for wireless internet. In contrast to earlier generations, 5G demands sophisticated algorithms, cutting-edge radio technologies, and creative architectures to achieve the high-performance requirements. Innovative methods to wireless system design, such hybrid beamforming, are changing the game. 5G promises to deliver dependable, scalable solutions to satisfy the expanding demands of consumers and industry through seamless connectivity and ultra-reliable, high-speed multi-gigabit data transfer. This study explores how these developments are making it possible for 5G to provide performance that is unmatched and spur innovation in a variety of industries.

II. TECHNOLOGY OVERVIEW

Massive MIMO, network slicing, and edge computing are the three main pillars upon which 5G mobile communication networks are built. Each of these pillars is essential to improving the network's performance, efficiency, and capacity. Large arrays of antennas are used in base stations and devices for massive MIMO (Multiple Input, Multiple Output), especially in millimeter-wave bands and at frequencies higher than 1 GHz. High-speed data transfer and increased dependability are made possible by this technology, which expands the capacity and coverage of 5G networks, particularly in highly populated areas.

III. EVOLUTION OF 5G TECHNOLOGY

With the introduction of 1G in 1979, the first-generation mobile network—which was typified by analog technology—was born. In contrast to contemporary mobile networks, 1G phones encoded phone numbers directly into the handsets rather than using SIM cards. Those with substantial disposable incomes or business professionals were the main users of these early mobile phones because they were big, heavy, and excessively expensive. Although the analog system provided simple voice communication, it was devoid of features seen in contemporary networks, such as text messaging and data transfer. Notwithstanding its drawbacks, 1G set the stage for the mobile communication revolution and ushered in a period of wireless communication that would develop quickly over the ensuing decades.

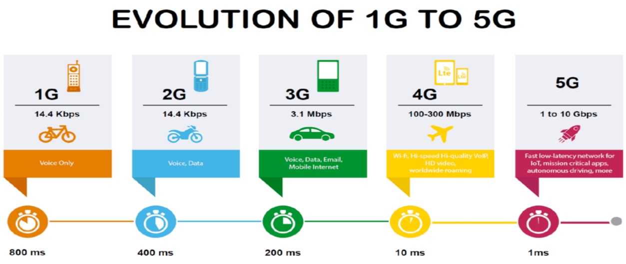

Fig.1: The Evolution of 5G

The first generation of digital mobile networks was represented by 2G technologies, which included CDMA, GSM, and TDMA. Remarkably, the word "1G" was applied retroactively to the older analog systems during this time [6]. 2G networks, which were first implemented in Finland in 1991, brought about the transition from analog to digital and provided better sound quality along with more dependable and secure communication. Data services, such as SMS (Short Message Service) text messaging, which became a game-changing feature, also started with this generation [7]. Notable developments occurred within the 2G framework: the 2.5G network, which included General Packet Radio Service (GPRS), made it possible for users to access a limited range of internet services using basic packet-switched data transmission [8]. The 2.75G network, where GPRS developed into Enhanced Data rates for GSM Evolution (EDGE), further improved this capacity [9]. Faster data transfer speeds made possible by EDGE laid the foundation for more sophisticated mobile internet services. Later generations of mobile technology were made possible by these advancements, with 2G networks serving as the basis for voice and data communication on mobile devices [10].

Table 1: 2G technology

2nd Generation	Technology	Data Rates
2G	GSM	10 kbps/user
2G	CDMA	10 Kbps
2.5G	GPRS	~51 Kbps
2.5G	EDGE	~200 Kbps

By providing far faster internet speeds than its predecessors, 3G technology, which was first deployed in 1998, represented a major advancement in mobile communication. Mobile devices may now access the internet more quickly and reliably thanks to the rise in data transfer rate from 2G's maximum of 200 kbps to several Mbps. The creation of new services like video calls, mobile television, and wireless voice communication via the internet—all of which gained popularity in the early 2000s—was made possible by this speed boost. Together with these capabilities, 3G networks enabled mobile broadband, enabling users to stream films, access web content, and run data-intensive apps on their cellphones for the first time. Since 3G networks allowed for seamless connectivity for a wide range of apps and services, they also significantly contributed to the growing adoption of smartphones. Additionally, 3G technology revolutionized how consumers used mobile technology by laying the foundation for more sophisticated apps like social media on the go, mobile gaming, and GPS navigation.

Table 2: 3G technology

2nd Generation	Technology	Data Rates
2G	GSM	10 kbps/user
2G	CDMA	10 Kbps
2.5G	GPRS	~51 Kbps
2.5G	EDGE	~200 Kbps

The next big step in the development of mobile networks was the formal introduction of 4G technologies, such as WiMAX and LTE, in 2008. With download and upload rates of up to 100 Mbps and 50 Mbps, respectively, these networks significantly increased internet connection speeds compared to the previous 3G generation. 4G networks were perfect for high-bandwidth applications like HD video streaming, mobile gaming, video conferencing, and real-time social media interactions because of their speed and efficiency gains.

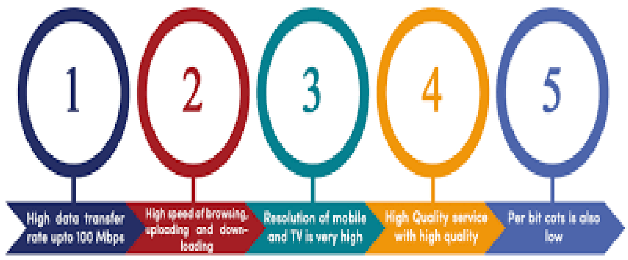

Fig.2. Advantages of 4G Network

Reliance on all-IP (Internet Protocol) networks is one of the main characteristics of 4G networks, allowing for the smooth integration of multimedia, data, and phone services. With its reduced latency, improved coverage, and more dependable performance in high-demand settings like congested cities and public gatherings, LTE (Long-Term Evolution) emerged as the leading 4G technology. Furthermore, 4G networks helped mobile broadband expand quickly and ushered in the "mobile-first" era, in which users depended more and more on their smartphones for productivity, entertainment, and internet access. Furthermore, by offering the quick, dependable, and scalable connectivity required to support these technologies, 4G networks set the stage for upcoming advancements like the Internet of Things (IoT), driverless cars, and smart cities [7] [8].

Table 3: Evolution of 5G [5]

Generation	Technology	Data Rates
1G	Analog (AMPS, TACS)	~2.4 Kbps
2G	GSM, CDMA	~14.4 Kbps - 64 Kbps
2.5G	GPRS	~56 Kbps - 115 Kbps
2.75G	EDGE	~200 Kbps - 384 Kbps
3G	UMTS/WCDMA	~384 Kbps
3G	CDMA2000	~384 Kbps
3.5G	HSDPA/HSUPA	~5-30 Mbps
3.5G	EVDO	~5-31 Mbps
4G	WiMAX, LTE	~100 Mbps - 1 Gbps
4.5G	LTE-A, LTE-A Pro	~1 Gbps - 3 Gbps
5G	mmWave, Massive MIMO, Network Slicing	~10 Gbps and beyond

5G, a revolutionary advancement in wireless connectivity, is the apex of mobile communication technology. It provides the framework for next-generation networks, allowing for previously unheard-of breakthroughs in a number of industries. Fundamentally, 5G is based on three main use cases that transform the way systems and devices interact. The foundation of the Internet of Things (IoT) ecosystem is Massive Machine-Type Communication (mMTC), which enables the simultaneous connectivity of millions of devices. By facilitating seamless device interconnectivity on a never-before-seen scale, this capacity is anticipated to completely transform sectors including smart agriculture, healthcare, and logistics. The user experience for high-bandwidth activities like 4K video streaming, virtual reality, and mobile gaming is improved by enhanced mobile broadband, or eMBB, which increases data speeds and network capacity. In order to satisfy rising consumer and industrial needs, this use case greatly expands the capabilities of the current cellular infrastructure. Mission-critical applications benefit greatly from Ultra-Reliable Low-Latency Communication (URLLC), which provides almost instantaneous data transmission with few delays. These include industrial automation, remote surgery, and driverless cars, where accuracy and dependability are crucial. To further enhance performance and resource allocation, 5G networks also offer cutting-edge technology like beamforming, network slicing, and edge computing. 5G is expected to propel the digital transformation of industries and enrich daily life by enabling a broad range of applications and providing improved speed, reliability, and scalability [13].

IV. 5G CELLULAR FRAMEWORK

There are several obstacles to overcome while designing 5G networks, particularly when it comes to spectral congestion and growing user expectations. By substituting several low-power transmitters that effectively cover smaller service areas for high-power transmitters, the cellular concept offers a workable answer to these problems. The success of 5G technology is based on this architecture, which is fundamental to contemporary wireless networks. The fundamental idea behind the cellular concept is the division of geographical areas into manageable segments, or "cell footprints," using hexagonal cells. Despite being a simplified model, the hexagonal form accurately depicts the best configuration for reducing overlap and increasing coverage. By giving each cell, a share of the available spectrum while minimizing interference with nearby cells, hexagons enable effective frequency reuse [14]. Given the exponential growth in demand for mobile services, this arrangement is very important. In these cells, base stations are essential for preserving connectivity. Depending on where they reside in the cell, they are classified as either center-excited or edge-excited. While edge-excited cells use sectored directional antennas, which concentrate signals toward particular regions to improve performance, center-excited cells usually use omnidirectional antennas, which transmit signals uniformly in all directions. Nearby cells are given distinct frequency groups in order to control interference and guarantee the best possible use of the spectrum.

A key component of the cellular concept, frequency reuse is made possible by this approach, allowing an increasing number of customers to be served by a limited number of channels. More base stations can be added to the network as demand for 5G services rises, enhancing capacity and coverage even more. Supporting the enormous connection needed for applications like the Internet of Things (IoT), driverless cars, and smart city infrastructure depends on this scalability. Furthermore, 5G networks' cellular model guarantees low latency and great reliability, opening the door for ground-breaking applications that were not possible with previous mobile network generations. The foundation of 5G's capacity to deliver quicker, more dependable connectivity ultimately rests on the cellular notion, opening the door for revolutionary services and applications in a variety of sectors.

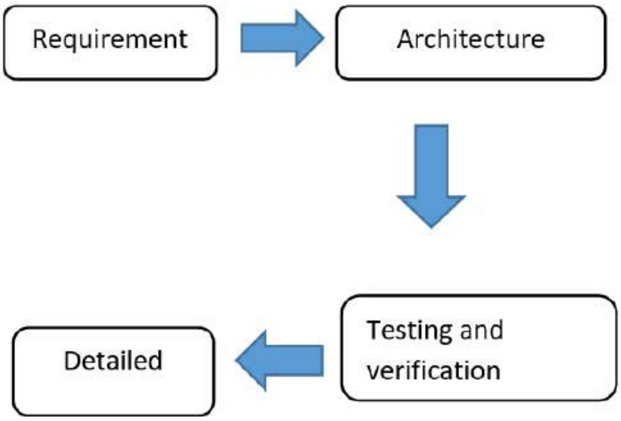

Fig.3: The standardization phases

V. CRITICAL 5G DEVELOPMENT

With important advancements propelling its uptake and success, 5G technology represents a dramatic shift in mobile communication. These developments cover a wide range of topics, including hardware, apps, security protocols, and infrastructure.

1. **Millimeter Wave (mmWave) Technology:** mmWave frequencies, which range from 30 to 300 GHz, are one of the most important innovations in 5G. Ultra-high-speed data transfer is made possible by these higher frequencies, but they have drawbacks including a short range and an increased vulnerability to obstructions. Dense networks of tiny cells are being used to solve this.
2. **Massive MIMO (Multiple Input, Multiple Output):** By using a lot of antennas at base stations, massive MIMO technology improves spectral efficiency and makes more network capacity possible. Supporting an increasing number of devices in urban and densely populated areas depends on this innovation.
3. **Network Slicing:** A single physical 5G network can be split up into several virtual networks that are suited to different industries or applications thanks to network slicing. For instance, IoT gadgets might put energy economy ahead of speed, yet autonomous cars need ultra-low latency.

VI. REAL-WORLD IMPACT OF 5G TECHNOLOGY

Here are some impacts of the 5G technology in real-world:

1. **Energy Efficiency and Sustainability:** Energy consumption is now a major concern as 5G networks grow. Green technologies for base stations and the use of AI for dynamic resource allocation are two examples of how hardware and software advancements are being made to maximize energy efficiency.
2. **Enhanced Mobile Broadband:** Enables customers to enjoy higher internet speeds for activities like online gaming, streaming HD videos, and augmented reality (AR).
3. **Autonomous Vehicles:** Enhances safety and makes it possible for self-driving cars to be developed by facilitating real-time communication between automobiles, infrastructure, and pedestrians.
4. **Smart Cities:** Makes it easier for IoT devices to be integrated into urban settings, improving waste collection, traffic control, and energy use for better city services.
5. **Telemedicine and Remote Healthcare:** Enhances access to healthcare services, particularly in distant places, by supporting remote procedures, high-quality video consultations, and health monitoring.
6. **Industry 4.0 and Smart Manufacturing:** Uses automation, robotics, and networked sensors to transform manufacturing, increasing output and facilitating predictive maintenance.
7. **Improved Public Safety:** Safety and disaster management are improved by 5G-enabled surveillance systems, intelligent emergency services, and real-time data exchange among first responders.
8. **Enhanced Immersive Experiences:** Powers augmented reality (AR) and virtual reality (VR) applications, providing high bandwidth and low latency immersive gaming, training, and educational experiences.
9. **Massive IoT Connectivity:** Enables applications in smart homes, agriculture, logistics, and environmental monitoring by connecting billions of IoT devices.

10. **Energy Efficiency:** Greener technologies and sustainability initiatives benefit from 5G's low latency and high efficiency, which optimize energy use across a range of industries.
11. **Innovation in Entertainment:** 5G will transform the way people consume material by enabling new entertainment formats, live sports broadcasting, and streaming of ultra high-quality video.

These uses demonstrate how 5G is expected to revolutionize a number of industries, fostering creativity, efficiency, and new opportunities for consumers and businesses alike.

VII. THE FUTURE OF 5G TECHNOLOGY

The way we connect, communicate, and engage with the world around us is about to undergo a radical change thanks to 5G technology. 5G promises to solve a wide range of current issues across industries thanks to its cutting-edge features, which include extremely fast speeds, low latency, and remarkable data handling capabilities. When properly utilized, 5G has the potential to solve issues that have long stood in the way of advancement. Improved connectivity, better communication, richer user experiences, and a significant boost in productivity are some of the main advantages of 5G. For a variety of uses, such as mission-critical communications, augmented and virtual reality, and real-time video streaming, it will enable quick data transfer and offer smooth connections. Low latency and fast connectivity provided by 5G will transform sectors like manufacturing, healthcare, and transportation, opening the door for innovations like driverless cars, smart cities, and remote surgery. With quicker reaction times and more dependable services, the technology also promises better consumer experiences. Additionally, 5G is made to accommodate the growing demand for energy efficiency, with green technology and dynamic resource allocation being used as optimizations to lessen the environmental impact. Despite all of 5G's benefits, there are obstacles to its adoption that academics are trying to solve. In order to solve problems like network congestion and coverage and guarantee the provision of smooth, high-quality services, technologies like beamforming and massive MIMO (Multiple Input Multiple Output) are essential. In conclusion, it is critical to thoroughly consider the advantages and potential disadvantages of 5G as it develops further. The technology will ultimately propel the next phase of innovation and digital transformation by redefining connectivity globally, improving personal experiences, and reshaping industries.

VIII. CONCLUSION

With higher speeds, lower latency, and more reliability, 5G mobile communication technology marks a substantial advancement in mobile networking. It is anticipated that these developments would transform industries and open up a plethora of new applications. However, there are unique difficulties associated with the deployment of 5G networks. To get over these challenges and guarantee the safe, effective, and long-term rollout of 5G technology, research and innovation must continue.

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Exploring the Nexus between Debt Financing and Firm Performance: A Robustness Analysis Using Instrumental Variables

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***Keywords*— Debt Financing, Firm Performance, Return on Equity (ROE), Return on Assets (ROA), Financial Leverage, Instrumental Variables.**

***Abstract*— *This study explores the impact of debt financing on firm performance, focusing on addressing the challenges of endogeneity and collinearity in regression models. Using a sample of firms from the CSMAR database, we investigate how different forms of debt financing short-term debt, long-term debt, and total debt affect firm performance metrics, specifically Return on Equity (ROE) and Return on Assets (ROA). To mitigate potential biases in traditional regression models, we employ Generalized Two-Stage Least Squares (G2SLS) and instrumental variable (IV) techniques. Our results show that long-term debt (LTDTA) and total debt to total assets (TDTA) have significant effects on firm performance, with some mixed relationships observed between debt financing variables and performance outcomes. The study further addresses issues of collinearity and endogeneity, demonstrating that the use of robust standard errors and instrumental variables provides more reliable estimates. The findings highlight the importance of strategic debt management for firms aiming to optimize performance while minimizing risks associated with excessive leverage. This study contributes to the literature on capital structure and firm performance, offering implications for financial managers, investors, and policymakers. Future research could extend these findings by exploring the effects of other financing sources and firm-specific characteristics across different industries.*

I. INTRODUCTION

Small and medium-sized enterprises (SMEs) play an integral role in global economic development, particularly in emerging economies where they contribute significantly to employment generation, innovation, and GDP growth. In China, SMEs are the backbone of the economy, accounting for more than 60% of the nation's GDP and 80% of urban employment (Zhao, 2020). Their contribution is especially critical in fostering regional development and driving technological innovation, yet they face considerable challenges in accessing financing. Debt financing, often seen as a primary source of external capital for these firms, can be a double-edged sword—while it provides necessary funds for growth and expansion, it also introduces the risk of financial distress if not managed properly.

The role of debt in financing SME growth is particularly relevant in the context of China, where SMEs often struggle with obtaining financing from traditional sources. Despite policy reforms to enhance credit access, SMEs still face difficulties in securing loans due to high perceived risks, insufficient collateral, and weak financial structures (Chen et al., 2021). As a result, understanding the impact of debt financing on firm performance is crucial for both SMEs and policymakers aiming to foster sustainable economic growth. Debt financing can have varying effects on the performance of SMEs, with research offering mixed results. On one hand, studies suggest that debt can provide necessary liquidity, improve firm efficiency, and facilitate expansion (Babenko et al., 2021). On the other hand, excessive debt can lead to financial distress, increasing the cost of capital and reducing profitability (Chen et al., 2021). While debt financing can potentially improve performance by allowing firms to scale operations and capitalize on growth opportunities, it may also negatively affect firm value if the debt burden becomes unmanageable (Ramezani et al., 2020).

The existing literature on debt financing and firm performance has primarily focused on SMEs in developed economies, with less attention given to emerging economies like China. This is especially true for listed SMEs, where the dynamics of debt financing may differ due to the influence of external investors, market conditions, and government policies (He & Li, 2022). In particular, little empirical research has focused on SMEs listed on the Shenzhen SME Board, one of China's key platforms for financing innovation and supporting small enterprises. The Shenzhen SME Board offers a unique environment for SMEs, as firms listed here often face less stringent regulatory requirements compared to those on the main board, yet still struggle with financing constraints typical of smaller businesses.

Although there is growing interest in understanding the financial behavior of listed SMEs in China, few studies have specifically addressed the role of debt financing in influencing firm performance within this context. Notably, there is a lack of consensus on how different types of debt, such as long-term versus short-term debt, affect the profitability, growth, and stability of SMEs. The mixed results in existing studies highlight the need for further exploration of this relationship, particularly in the context of Chinese SMEs that are publicly listed and operate under different market dynamics than their private counterparts.

Moreover, there is a significant gap in the literature regarding the role of governance structures and agency costs in shaping the relationship between debt financing and firm performance in listed SMEs. Agency theory suggests that conflicts between shareholders and managers can influence how firms manage debt, which, in turn, impacts their performance (Li & Tang, 2021). For listed SMEs, where ownership and management structures are often more dispersed, understanding the role of agency costs is crucial for comprehending how debt financing decisions are made and their subsequent effects on performance.

Given these gaps, the current study aims to contribute to the understanding of how debt financing impacts the performance of SMEs listed on the Shenzhen SME Board. Specifically, this study investigates how the structure of debt both long-term and short-term affects key performance indicators, such as profitability, growth, and financial stability. The research also explores the moderating role of governance structures and agency costs in this relationship. By addressing these gaps, the study seeks to provide valuable insights for policymakers and practitioners looking to improve the financial management and sustainability of listed SMEs in China.

II. REVIEW OF RELATED LITERATURE

2.1 Theoretical Review: Theory of Corporate Performance

The concept of corporate performance has been widely explored in management and finance literature, where it is considered a key measure of a company's success and growth potential. Understanding corporate performance involves evaluating a firm's ability to achieve its objectives efficiently and effectively, encompassing a wide range of factors, both financial and non-financial. The traditional view of corporate performance primarily focuses on financial metrics such as profitability, growth, and shareholder value. According to Kaplan & Norton (1992), one of the earliest contributions to the development of performance measurement systems, corporate performance should be viewed through a balanced lens, integrating both financial outcomes and operational processes. This framework laid the foundation for the Balanced Scorecard, which takes into account not only financial measures but also customer satisfaction, internal business processes, and learning and growth, which are seen as long-term drivers of performance.

A more refined view of corporate performance is proposed by Barney (1991), who suggests that sustained competitive advantage, driven by resource-based capabilities, significantly influences a firm's performance. Barney's Resource-Based View (RBV) emphasizes that a firm's internal resources, such as its organizational capabilities and assets, determine how well it performs in a competitive market. This perspective links firm performance to its ability to leverage unique and valuable resources, making the firm more adaptable and profitable in the long run.

In contrast, Porter's (1985) Competitive Advantage theory highlights the external forces influencing corporate performance. According to Porter, performance is shaped by the firm's strategy to position itself in the market either through cost leadership, differentiation, or focus. Firms that effectively align their strategy with market demands achieve superior performance outcomes. The emphasis here is on strategic decisions that align the firm's resources with its external environment, underscoring the interplay between internal capabilities and market dynamics.

These perspectives, however, only capture a portion of corporate performance, prompting a need for more multidimensional approaches. Groves et al. (2008) argue that corporate performance also involves a deeper understanding of organizational behavior, leadership, and the effectiveness of internal controls and governance. According to them, high-performing organizations exhibit strong leadership, clear communication, and the ability to inspire and motivate employees toward a unified set of strategic goals. The conceptualization of corporate performance remains dynamic, with both theoretical frameworks and evolving models continually adapting to new economic, managerial, and market realities. For this study, we draw on the Multidimensional Performance Framework, incorporating financial metrics and operational efficiency, as well as the firm's capacity to innovate and maintain a competitive position within its industry.

2.2 Univariate Effectiveness

Univariate effectiveness pertains to the use of single financial indicators to evaluate a firm's performance. These indicators are often grounded in traditional financial theory and typically include measures such as return on equity (ROE), return on assets (ROA), earnings per share (EPS), and financial leverage ratios. Penman (2013) argues that these metrics are often adequate for assessing short-term profitability and financial health, but they fail to offer a comprehensive view of the firm's long-term value creation or sustainability. The reliance on univariate metrics can obscure a firm's potential for growth, customer engagement, or operational efficiency—factors that are critical for long-term corporate success.

Tobin's Q, a ratio of a firm's market value to the replacement cost of its assets, is another widely discussed financial metric that seeks to provide insight into the market's valuation of the firm's future growth prospects. Studies by Scherer & Ross (1990) show that Tobin's Q is a useful indicator of how efficiently firms allocate their capital, but its reliance on market perceptions and future growth projections makes it vulnerable to market volatility and investor sentiment. Similarly, Lynch et al. (2014) suggest that ROE and ROA, while useful for short-term financial assessments, fail to account for broader strategic performance and intangible assets such as brand equity or intellectual property.

Despite these limitations, univariate measures remain useful for initial assessments of a firm's profitability, particularly in industries with stable market conditions where short-term financial outcomes may be the most relevant indicator of corporate health.

2.3 Multivariate Effectiveness

Multivariate effectiveness, by contrast, takes a more holistic approach to corporate performance measurement, incorporating multiple indicators that capture various facets of organizational success. The Balanced Scorecard framework developed by Kaplan and Norton (1992) is a key model in this area, proposing that firms should use a combination of financial, customer, internal business process, and learning and growth indicators to evaluate performance. By integrating non-financial metrics, firms can gain a deeper understanding of their competitive position and areas requiring improvement.

Andersen & Buch (2002) contend that multivariate performance models, such as the EFQM Excellence Model or the European Foundation for Quality Management (EFQM), provide a more accurate and reliable representation of a firm's overall effectiveness. These models encompass a range of factors, from financial results to leadership practices, customer satisfaction, employee engagement, and innovation. The holistic nature of multivariate frameworks ensures that performance assessments are not biased by a narrow focus on financial outcomes but instead reflect the complex, multifaceted reality of business operations.

Moreover, the multivariate approach is particularly beneficial when evaluating firms in dynamic industries, where non-financial metrics such as customer loyalty, employee satisfaction, and innovation capacity are essential for sustaining competitive advantage. In these cases, traditional financial measures alone are insufficient, and the inclusion of operational and strategic metrics provides a more comprehensive view of firm performance.

2.4 Empirical Review: The Impact of Debt Financing on Firm Performance

The effect of debt financing on corporate performance has been a subject of considerable empirical research, especially in the context of emerging markets where capital structure decisions can have profound implications for firm sustainability and growth. Debt financing allows firms to leverage external capital for expansion, R&D, and operational improvements. However, it also introduces financial risk, which can influence a firm's overall performance.

Modigliani & Miller (1958) originally posited that under perfect market conditions, the capital structure of a firm would not affect its total value, a theory known as the Modigliani-Miller theorem. However, in reality, firms face market imperfections, such as taxes, bankruptcy costs, and agency problems, which mean that the capital structure does, in fact, impact firm performance. The Trade-off Theory, proposed by Kraus & Litzenberger (1973), suggests that firms weigh the benefits of debt (tax shields) against the costs (bankruptcy risk and agency costs) to determine their optimal capital structure. According to this theory, moderate levels of debt can enhance firm performance by lowering the overall cost of capital, but excessive debt can lead to financial distress, adversely impacting performance.

In developing economies, Mollah & Lipy (2014) have shown that debt financing plays a critical role in improving firm performance, particularly when the cost of equity capital is high and external financing options are limited. The study found that for firms in Bangladesh, debt financing increased profitability and growth rates, particularly for small- and medium-sized enterprises (SMEs). However, this relationship becomes negative at higher levels of debt, where firms face increased debt servicing costs that erode profitability and lead to financial distress.

In contrast, Frank & Goyal (2009) analyzed the impact of debt financing on firms in the US and found a negative relationship between debt levels and performance for firms with high leverage ratios. The authors argue that highly leveraged firms are more vulnerable to economic downturns and may struggle to meet their debt obligations, leading to lower profitability, reduced investment, and diminished firm value.

Further, studies in the Chinese market, such as Chen et al. (2018), reveal that the relationship between debt financing and performance is highly contingent on firm size and industry sector. For example, in the technology and manufacturing sectors, where firms often require significant investment for expansion, moderate debt usage can lead to higher performance. However, firms in consumer-facing sectors, such as retail and hospitality, face greater risks when relying on debt financing, particularly in volatile market conditions. The empirical evidence on the relationship between debt and firm performance suggests that firms must carefully manage their debt levels to optimize their performance. While moderate debt can enable firms to leverage opportunities for growth, excessive debt can constrain financial flexibility, increase risk exposure, and undermine long-term performance.

The literature on corporate performance and debt financing provides valuable insights into the complex relationship between financial leverage and firm success. While traditional univariate measures of performance such as profitability ratios offer a straightforward view of a firm's financial health, they fall short of capturing the broader picture of organizational performance. Multivariate performance frameworks, such as the Balanced Scorecard, offer a more comprehensive approach by incorporating both financial and non-financial factors.

Empirical studies consistently show that while debt financing can facilitate growth, it also introduces risk. The impact of debt on firm performance varies across industries, firm size, and the economic environment, suggesting that capital structure decisions must be tailored to the specific needs and risks faced by the firm. The evidence emphasizes the importance of a balanced approach to debt financing, where firms optimize leverage without overexposing themselves to financial risk. For firms seeking to maximize their performance, it is essential to not only monitor financial metrics but also consider strategic, operational, and customer-centric factors that contribute to long-term sustainability. As the global business landscape continues to evolve, the integration of diverse performance measures will remain critical to understanding and driving corporate success.

III. DATA AND METHODOLOGY

This study employs a combination of correlational and descriptive research designs. The correlational design is utilized to explore the relationships between various factors influencing the dependent variable, specifically firm performance. The goal is to understand which debt measure (e.g., short-term or long-term debt) causes variations in performance. The descriptive design is employed to characterize the study area, particularly focusing on the firms within the target population.

According to the Promotion Law of China (2003), Small and Medium Enterprises (SMEs) are defined as having fewer than 100 employees (for small firms) or 500 employees (for medium firms), total assets of less than 40 million RMB, and annual sales revenue under 300 million RMB. The population for this study consists of SMEs in the manufacturing, wholesale, and retail sectors, including industries such as food, textiles, motor vehicles, hotels/restaurants, construction, telecommunications, and transport. All firms included in this research are publicly listed on the Shenzhen Stock Exchange. The sample includes firms with debt financing reflected in their annual panel data from 2011 to 2018.

The primary source of data for this research is secondary data obtained from the China Stock Market & Accounting Research Database (CSMAR), developed by Shenzhen GTA Information Technology Company. The financial statements used include the income statement (comprehensive statement of financial performance) and the balance sheet (end-of-year financial position) of the selected firms. After filtering based on the criteria outlined in Appendix 1, the final sample consists of 2,071 SMEs, resulting in 13,751 observations across the 8-year period (2011-2018). Of these firms, 800 (38.62%) are from the traditional manufacturing industry, 651 (31.43%) are from the wholesale sector, and 620 (29.93%) are from the retail sector. Table 6 (4.1) presents the descriptive statistics for the variables used in the model.

3.1 Description of Variables

This study investigates the effect of debt financing on firm performance in Chinese SMEs. Firm performance is measured using two key indicators: Return on Equity (ROE) and Tobin's Q. These dependent variables are regressed against debt financing indicators to assess the impact on firm performance. This can be seen in Table 1 .

Table 1: Dependent Variables Measures

Variable	Measurement	Formula	Reference
Firm Performance	Return on Equity (ROE)	EBIT/Total Equity	Nirajini (2013)
	Tobin Q	Total Market Value / Total Assets	Tobin (1999)

Debt financing is measured using three indicators: short-term debt to total assets (STDTA), long-term debt to total assets (LTDTA), and total debt to total assets (TDTA). While each measure has its own importance, Rajan and Zingales (1999) suggest that breaking down total debt into short-term and long-term components may not be essential for Chinese SMEs due to their preference for short-term debt financing. This is because the firms in this sample generally avoid long-term debt due to concerns about bankruptcy risks, as the assets of these SMEs are less volatile than those of larger firms. Therefore, the analysis focuses primarily on short-term debt financing and its impact on firm performance. Table 2 shows the independent variables.

Table 2: Independent Variable Determinants

Variable	Measurement	Formula	Reference
Debt Financing	Short-Term Debt to Total Asset (STDTA)	Short-Term Debt / Total Assets	Rajan (1999)
	Long-Term Debt to Total Asset (LTDTA)	Long-Term Debt / Total Assets	Nirajini & Priya (2003)
	Total Debt to Total Asset (TDTA)	Total Debt / Total Assets	Nirajini & Priya (2013)

3.2 Control Variables

In addition to debt financing, the study controls for other variables that might influence firm performance, following the methodology of Michaelas et al. (2000). These control variables include firm size, firm age, sales growth, and total asset turnover. Although these variables do not directly measure firm performance or capital structure, they may impact the results and are therefore included in the model. This is shown in Table 3.

Table 3: Control Variables

Control Variable	Measurement	Formula
Firm Size	Log of total assets	ln(Total Assets)
Firm Age	Age of the firm	Today's date - Founding date
Sales Growth	Sales growth	(Sales at Year-End - Sales at Start of Year) / Sales at Start of Year
Total Asset Turnover	Asset turnover	Total Sales / Average Total Assets

3.3 Model Estimation

In previous studies, both time-series and cross-sectional methods have been employed to investigate the relationship between debt financing and capital structure (Brealey et al., 2011; Titman & Wessels, 1988). However, panel data methods have become increasingly popular in recent research, including works by Michaelas et al. (2000) and Frank & Goyal (2009). Panel data combines both time-series and cross-sectional data, allowing for better control of individual and time effects, which might correlate with the independent variables in the model. As per Hsiao (2003), panel data provides a large number of observations, increasing degrees of freedom and decreasing multicollinearity among variables. The study employs panel data regression models, including fixed effects and random effects, to analyze the data over an 8-year period (2011–2018). This approach allows for constant heterogeneity in the results and improves the accuracy of the estimation.

The econometric model can be specified as:

$$\mathbf{y} = \alpha_{it} + \beta^1 X_{it} + \mu \quad (1)$$

Where:

Y = Dependent Variables, Xit, $_i$=1…N, $_t$=1…T, α_{it} = Constant (intercept) of y.

The analysis follows the specifications of Nwude et al. (2020) and Park & Jang (2018). The dependent variables, ROE and Tobin Q, will be regressed on the three measures of debt financing (STDTA, LTDTA, and TDTA) as well as the control variables. The following econometric models was used for the analysis as seen in Table 4.

Table 4: Estimated econometric equation models

Equation 1model:(Y1)=αit + β1STDRit + β2SIZEit + β3SGit + β4TAit + β5taxit + β6FAit + μ
Equation 2model (Y1)= αit + β1LTDRit + β2SIZEit + β3SGit + β4TAit + β5taxit + β6FAit + μ
Equation 3Model (Y1) = αit + β1TDRit + β2SIZEit + β3SGit + β4TAit + β5taxit + β6FAit + μ
Equation 4Model (Y1) = αit + β1STDTAit + β2LTDTA+ β3TDTA + β4SIZEit + β5SGit + β6TAit + β7taxit + β8FAit + μ
Equation 5Model (Y2) = αit + β1STDTAit + β2SIZEit + β3SGit + β4TAit + β5taxit + β6FAit + μ
Equation 6Model(Y2) = αit + β1LTDTAit + β2SIZEit + β3SGit + β4TAit + β5taxit + β6FAit + μ
Equation 7Model (Y2) = αit + β1TDTAit + β2SIZEit + β3SGit + β4TAit + β5taxit + β6FAit. + μ
Equation 8Model (Y2) = αit + β1STDTAit + β2 LTDTA+ β3TDTA+ β4SIZEit + β5SGit + β6TAit + β7taxit + β8FAit. + μ

- *Y1=Return on Equity   Y2= Tobin Q*

IV. EMPIRICAL FINDINGS AND DATA ANALYSIS

This section presents the empirical findings of the study, which aims to analyze the effect of debt financing on the growth of small and medium-sized enterprises (SMEs), measured through Return on Equity (ROE) and Tobin's Q. We investigate the relationship between various debt financing measures and firm performance by using descriptive statistics, correlation analysis, and regression models.

4.1 Descriptive Statistical Analysis

The descriptive statistics provide an overview of the sample data, including mean, standard deviation, variance, minimum and maximum values, percentiles, and tests for normality (skewness and kurtosis). The sample comprises a range of observations (from 13,335 to 13,750), with the aim of summarizing how the variables are distributed. The descriptive statistics for the key variables used in this study are shown in Table 5. It reveals the following:

ROE has a mean of 0.114, indicating modest profitability, but with high variance (6.907), suggesting significant variation in firm performance. Tobin's Q has a mean of 2.217, which indicates strong market capitalization and investor confidence in the firms under the Shenzhen 100 share index. Firm Size (FS) shows a mean value of 21.887, with significant variation across firms, while Sales Growth (SG) has a mean of 19.214, indicating positive growth trends during the study period. Tax (TAX) has a mean value of 321,000,000, with some firms reporting a significant range in tax liabilities. In terms of distribution, all variables (dependent, independent, and control variables) exhibit leptokurtic distribution (kurtosis > 3), indicating that the data are heavily tailed with higher-than-normal peaks. This suggests the presence of outliers or extreme values.

Table 5: Descriptive Statistics

Variables	Obs.	Mean	Std. Dev.	Min	Median	Max	Skewness	Kurtosis	variance
ROE	**13667**	**0.114**	**6.907**	**(72.146)**	**0.62**	**713.204**	**87.211**	**8575.017**	**47.708**
TOBINQ	13335	2.217	2.950	0.153	1.684	126.951	24.251	840.157	8.705
STDTA	13750	0.337	0.274	0.003	8300000	12.172	20.094	767.761	0.075
LTDTA	13607	0.070	0.529	(0.093)	990000	61.056	112.531	12969	0.280
TDTA	13607	0.408	0.622	0.007	7850000	63.971	80.265	8029.564	0.387
FS	13750	21.887	1.188	17.019	06.251	27386	0.677	3.890	0
S.G	13712	19.214	151.484	100.000)	11.284	10700	47.516	2775.78	22900
TAX	13750	321000000	1230000000	(21000000)	85000000	39000000	15.326	338.958	1.52E+18
TAT	13711	0.680	0.470	0.002	0.590	11.841	5.077	66.581	0.221
FA	13751	17.903	5.398	1.000	.0251	69.000	0.677	10.739	1.412

Source*: *Survey Data

4.2 Correlation Analysis

To determine the strength and direction of relationships between the variables, a pairwise correlation analysis was conducted. The results are shown in Table 6. STDTA (Short-term Debt to Total Assets) is positively correlated with both ROE and Tobin Q, suggesting that short-term debt financing tends to improve firm performance. LTDTA (Long-term Debt to Total Assets) shows a negative and insignificant relationship with ROE, but a positive and significant correlation with Tobin Q.

TDTA (Total Debt to Total Assets) demonstrates a positive and significant correlation with both ROE and Tobin Q, indicating that total debt financing improves both profitability and market performance. Firm Size (FS) has a negative and insignificant correlation with ROE, but is positively correlated with debt measures (STDTA, LTDTA, TDTA), showing that larger firms use more debt. Sales Growth (SG) is negatively correlated with ROE but positively associated with debt financing (STDTA, LTDTA, TDTA), suggesting that smaller SMEs may face difficulties in leveraging debt to achieve higher growth.

Table 6: Pairwise correlation analysis

Variable	ROE	TOBIN Q	STDTA	LTDTA	TDTA	FS	SG	TAX	TAT	FA
ROE	1									
TOBIN Q	0.0356*	1								
STDTA	0.0280*	0.1189*	1							
LTDTA	-0.0146	0.3449*	0.1092*	1						
TDTA	0.0191*	0.3474*	0.5347*	0.8984*	1					
FS	0.0307*	-.2824*	0.1742*	.0224*	0.0959*	1				
SG	0.0026	-0.0041	0.0128	.0012	0.0067	-0.0076	1			
TAX	0.0002	-.0389*	0.0646*	.0079	0.0359*	0.4591*	-0.0061	1		
TAT	-0.0011	0.0738*	0.1401*	-.0219*	..0428*	0.092*	0.1166*	0.1188*	1	
FA	0.0184*	0.788*	0.1244*	.0179*	.0701*	0.1539*	0.0058	0.0571*	0.0328*	1

SOURCE: (Survey Data, based on CSMAR database)

4.3 Statistical Significance

The correlation values presented are statistically significant at a 5% confidence level, as indicated by the * symbol next to the coefficient values.

4.4 Panel Data Regression: Results and Analysis

This study employed a fixed-effects model for all three estimated equation models. Subsequently, a robustness test was conducted to assess the uniqueness and ambiguity inherent in the data before finalizing the results. The use of the fixed-effects model allows for accounting for time-series fluctuations and controlling for unbalanced or unobserved heterogeneity in the dataset. The regression results for the model ROE=STDTA +TDTA+FS+SG+TA+Tax+ FA from the fixed-effects model significantly differ from those obtained for the Tobin Q, as shown in Tables 7 and 8. The variations primarily concern the control variables, and further analysis with instrumental variables is recommended to explore the underlying issues driving these changes. The subsequent tables show ROE and Tobin Q as dependent variables, with explanatory variables regressed against them.

Table 7: ROE Regression Model Y1

VARIABLES	**Model 1 ROE(Y2)**	**Model 2 ROE(Y2)**	**Model 3 ROE(Y2)**	**Model 4 ROE (Y2)**
STDTA	5.3836*** (0.7335) 0.000			5.7051*** (0.7517) 0.000
LTDTA		1.2112 (1.2568) 0.335		2.8982 (1.2732) 0.023
TDTA			5.1019*** (0.6926) 0.000	Omitted
FS	-1.9841*** (0.1839) 0.000	-1.8985*** (0.1905) 0.000	-2.2405*** (0.1909) 0.000	-2.1752*** (0.1935) 0.000
SG	0.0005 (0.0004) 0.235	0.0005 (0.0004) 0.271	0.0004 (0.0004) 0.000	0.00039 (0.0004) 0.376
Tax	2.59e-10 (1.60e-10) 0.106	2.35e-10 (1.73e-10) 0.000	3.27e-10 (1.73e-10) 0.058	3.18e-10 (1.73e-10) 0.065
TA	-1.1217*** (0.2821) 0.000	-1.0913*** (0.3010) 0.000	-1.2040*** (0.2994) 0.000	-1.2717*** (0.3016) 0.000

FA	0.1610***	0.1772***	0.1877***	0.1808***
	(0.0370)	(0.0376)	(0.0374)	(0.0375)
	0.000	0.000	0.000	0.000
_cons	39.5785***	39.1138***	44.5370***	43.2243***
	(3.6532)	(3.7942)	(3.7704)	(3.8232)
	0.000	0.000	0.000	000
R2	0.0137	0.0098	0.0144	0.0029
Adjusted R	0.0134	0.0095	0.0142	0.0027
Observation (N)	13,632	13,489	13,489	13489
F-value	26.29	18.49	27.46	24.15
Haussmann Test	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect

Source: Survey Data 2014, based on CSMAR database

Note: Standard errors in parentheses. P < 0.001, p < 0.05

Table 8: Tobin Q Regression Model Y2

VARIABLES	**Model 1** **Tobin Q(Y2)**	**Model 2** **Tobin Q(Y2)**	**Model 3** **Tobin Q(Y2)**	**Model 4** **Tobin Q(Y2)**
STDTA	.2238			-.5628***
	(0.1021)			(0.0975)
	0.028			0.000
LTDTA		1.7432***		1.7681***
		(0.0342)		(0.0344)
		0.000		0.000
TDTA			1.4438***	Omitted
			(0.0317)	
			0.000	
FS	-1.5494***	-1.5012***	-1.5018***	-1.5063***
	(0.0574)	(0.5072)	(0.0517)	(0.0506)
	0.000	0.000	0.000	0.000
SG	-0.0002	-0.0002	-0.0002	-0.0002
	(0.0002)	(.0001)	(0.0002)	(0.0001)
	0.261	0.175	0.089	0.238
Tax	1.03e-10	1.09e-10	1.18e-10	1.06e-10

	(4.96e-11)	(4.68e-11)	(4.77e-11)	(4.68e-11)
	0.038	0.020	0.013	0.024
	1.05387***	0.8317***	1.0011***	
	(0.0897)	(0.0804)	(0.0821)	
	0.000	0.000	0.000	
				0.7644***
TA				(0.0811)
				0.000
FA	0.2839***	0.2731***	0.2717***	0.2745***
	(0.1154)	(0.0102)	(0.0104)	(0.0102)
	0.000	0.000	0.000	0.000
_cons	30.2457****	29.4903***	28.9389***	29.8031***
	(1.1495)	(1.0145)	(1.0352)	(1.0145)
	0.000	0.000	0.000	0.000
R2	0.0831	0.2606	0.2311	0.1648
Adjusted R	0.0830	0.2603	0.2300	0.1645
Observation (N)	13301	13165	13165	13165
F-value	167.05	642.56	548.02	557.15
Haussmann Test	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect

Source :(Survey Data, based on CSMAR database)

Note: Standard errors in parenthesis, *p<.05, **p<.01, ***p<.001

4.5 Interpretation of Results

Hypothesis 1: Short-term Debt, Long-term Debt, Total Debt, and ROE

The first hypothesis posited a negative relationship between long-term debt, short-term debt, total debt, and Return on Equity (ROE). Previous literature, including studies by Khan (2011), Salim and Yadav (2012), and Zeitun and Tian (2007), has reported a negative relationship between debt and ROE.

The regression results in Table 7 reject Hypothesis 1, revealing that debt financing (STDTA, LTDTA, and TDTA) has a positive and significant relationship with firm performance, as measured by ROE. For instance, STDTA (β = 5.38) and TDTA (β = 5.10) exhibit statistically significant positive coefficients ($p < 0.001$), indicating that increases in short-term and total debt are associated with higher returns on equity. The positive relationship could be explained by the fact that firms with profitable operations may efficiently use debt financing to support their working capital needs. However, LTDTA, while showing a positive relationship with ROE, is statistically insignificant, suggesting that long-term debt does not significantly impact equity returns for the firms in this study. This result aligns with the findings of Chowdhury and Chowdhury (2013), who noted that lower return rates could enhance performance in highly leveraged firms.

Hypothesis 2: Long-term Debt, Short-term Debt, Total Debt, and Tobin Q

The second hypothesis proposed that long-term debt, short-term debt, and total debt positively influence Tobin's Q. Previous studies by Salim, Sheikh, Khan, and Mesquita (2011, 2012) found a positive correlation between debt and market performance (Tobin Q). The regression results in Table 8 support Hypothesis 2, indicating a positive and significant relationship between debt financing (STDTA, LTDTA, and TDTA) and Tobin Q. For example, STDTA (β = 0.22), LTDTA (β = 1.74), and TDTA (β = 1.44) are positively related to Tobin Q, suggesting that higher debt levels lead to higher market valuations. This aligns with the theoretical expectation that debt financing can enhance firm value by increasing market confidence. However, the positive but insignificant effect of STDTA in Model 1 could be attributed to the fact that highly leveraged firms may encounter increased bankruptcy costs and agency costs once they surpass an optimal debt structure. This finding supports the view that excessively high leverage can increase liquidity risks and diminish market value, as noted by Zeitun and Tian (2007).

4.6 Control Variables and Firm Performance

As observed in the results, the control variables, including firm size (FS), tax, and fixed assets (FA), consistently show significant relationships with both ROE and Tobin Q across all models. These variables are crucial in explaining firm performance, as larger firms often benefit from economies of scale, and fixed assets provide the collateral needed to access cheaper debt financing.

The analysis reveals a complex relationship between debt financing and firm performance. While short-term and total debt exhibit a positive and significant impact on ROE, long-term debt does not significantly affect ROE. Conversely, all types of debt are positively associated with Tobin Q, implying that higher leverage may improve market performance, potentially due to higher returns on equity.

4.7 Robustness Test

The initial regression analysis revealed conflicting results, with some variables showing both positive and negative relationships and others being statistically insignificant. To ensure the robustness of the results and to address potential causes for these inconsistencies, a secondary regression was conducted. This test aimed to identify whether the variations in the results were due to endogeneity or other underlying issues, and to provide a more reliable confirmation of the initial findings. A potential concern of endogeneity exists between debt financing and firm performance due to the consistent and continuous nature of debt financing. Additionally, the firm's Total Debt to Asset (TDTA) ratio appears unaffected and exhibits an omission in value. This issue was investigated using the Hausman test to determine whether the regressors were exogenous or endogenous. The results suggested a difference in the significance of the independent variables between the two regressions, further supporting the need to test for endogeneity.

Given that the early stages of debt financing are not influenced by current firm performance, the researcher used the short-term debt to total assets (STDTA), long-term debt to total assets (LTDTA), and lagged independent variables as instruments for total debt financing. The Generalized Two-Stage Least Squares (G2SLS) method was employed to address potential endogeneity, with the results compared to those obtained using robust standard errors. The final regression results, presented in Tables 4.5 and 4.6, show that the robustness test yields consistent results, reaffirming the conclusions of the initial analysis. For brevity, only the main explanatory variables are shown.

Table 9: Robustness Test 1 – IV Regression Results for ROE

VARIABLES	Model 1 ROE(Y2)	Model 2 ROE(Y2)	Model 3 ROE(Y2)	4 ROE (Y2)
STDTA	5.3811			2.8680
	(6.0861)			(3.2356)
	0.377			0.375
LTDTA		1.1370		0
		(1.6611)		
		0.494		
TDTA			4.8368	2.7898
			(5.6124)	(3.4343)
			0.389	0.417
FS	-1.9903	-1.8845	-1.5919	2.7897
	(2.0615)	(1.9398)	(1.6584)	(3.4343)

	0.334	0.331	0.337	0.417
SG	0.0004	0.0004	0.0004	0.0004
	(0.0004)	(0.0003)	(0.0002)	(0.0003)
	0.209	0.205	0.187	0.210
TAT	-1.2534	-1.0963	-1.3083	-1.2711
	(1.4655)	(1.2951)	(1.5229)	(1.485)
	0.392	0.397	.390	0.392
FA	0.1720	0.1834	0.19514	0.1878
	(0.1845)	(0.1929)	(0.2040)	(0.1966)
	0.351	0.342	0.339	0.339
_cons	39.7087	38.7881	43.8896	42.5753
	(40.8530)	(39.804)	(45.2505)	(43.8374)
	0.331	.330	0.332	0.331
R2	0.0032	0.0024	0.0044	0.0046
Adjusted R	0.0024	0.0014	0.0024	0.0026
Observation (N)	13,488	13,402	13,402	13402
Wald Chi 2	4.80	2.96	3.08	3.39
G2SLS IV regress	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect

Note: Robust standard errors are in parentheses. *P < 0.05, **P < 0.01, ***P < 0.001.

The results from Table 10 indicate collinearity between variables, confirming the existence of endogeneity. However, the G2SLS method and robust standard errors mitigate these issues, with small standard errors and significant p-values supporting the robustness of the findings.

Table 10: Robustness Test 2 – IV Regression Results for Tobin's Q

VARIABLES	**Model 1**	**Model 2**	**Model 3**	**Model 4**
	Tobin Q	**Tobin Q**	**Tobin Q**	**Tobin Q**
STDTA	-0.1778			0
	(1.4012)			(omitted)
	0.899			
LTDTA		1.7434***		2.3432
		(0.02297)		(1.2402)
		0.000		0.059
TDTA			1.4435***	-0.5733
			(0.2721)	(1.1965)
			0.000	0.632

_cons	31.6093***	29.2184***	28.6213***	29.5556***
	(5.7476)	(4.9391)	(4.9023)	(5.0371)
	0.000	000	0.000	0.000
R2	0.0943	0.1421	0.1710	0.1613
N	13,159	13,079	13,079	13079
Wald Chi 2	57.31	8569.82	131.63	14267.48
XT. IV regress	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect

Note: Robust standard errors are in parentheses. *P < 0.05, **P < 0.01, ***P < 0.001.

The results from Table 4.6 further indicate the presence of collinearity in the variables, leading to omitted standard errors and biased results. However, the firm performance measures show consistent and significant results after applying robust standard errors and addressing endogeneity using the G2SLS method.

4.8 Other Measures of Firm Performance

Return on Assets (ROA) is another commonly used indicator of firm performance, as it measures a company's profitability relative to its total assets. It provides stakeholders with insight into the company's efficiency in utilizing its assets to generate earnings. As part of the robustness testing, the study also examined ROA, following the methodology of Ni Yin Zhu and Wan Mai (2014), to assess the firm's future profitability.

The regression results for ROA, presented in Table 10 align with the previous findings, confirming the robustness of the results. The analysis suggests that the effects of debt financing on firm performance remain consistent, whether measured using ROE or ROA, supporting the conclusion that debt financing plays a significant role in shaping firm performance

Table 11: Robustness Test 3 – Measure of Firm Performance Using ROA

	ROE			
VARIABLES	**Model (1)**	**Model (2)**	**Model (3)**	**Model (4) All sample**
STDTA	-3.9854***			4.9516*
	(.6516)			(1.9099)
	0.000			0.010
LTDTA		-223.289		-244.3161*
		(17.17197)		(207.7934)
		0.000		0.000
TDTA			-5.2762***	omitted
			(0.63055)	
			0.000	
_cons	0.5368	-108.2436	-3.1892	-114.378***
	(1.2616)	(9.3594)	(1.4389)	(10.3783)
	0.670	0.000	0.027	0.000
R^2	-	-	-	-
Observation (N)	13,523	13437	13437	13437
Wald Chi 2	50.19	160.91	83.11	144.76

Note: Robust standard errors are in parentheses. *P < 0.05, **P < 0.01, ***P < 0.001.

V. CONCLUSION AND STUDY IMPLICATIONS

This study aimed to investigate the relationship between debt financing and firm performance, with particular attention given to addressing the challenges of endogeneity and collinearity in regression models. The findings underscore the complexities involved in understanding how various types of debt financing, such as short-term and long-term debt, affect firm performance, as measured by metrics like Return on Equity (ROE) and Return on Assets (ROA). Through the application of Generalized Two-Stage Least Squares (G2SLS) and instrumental variable (IV) regression techniques, we have provided more reliable estimates that account for potential biases inherent in the traditional ordinary least squares (OLS) method.

The robustness tests confirmed that debt financing, particularly long-term debt, has a significant impact on firm performance. Specifically, the results indicated that long-term debt to total assets (LTDTA) and total debt to total assets (TDTA) are significant determinants of performance metrics, including ROE and ROA, under certain conditions. Despite the presence of some conflicting relationships between variables (e.g., positive and negative coefficients), the use of instrumental variables helped to mitigate the issue of endogeneity and provided a more accurate reflection of the true causal relationships between debt financing and firm performance.

Importantly, the study also found that the regression, such as debt financing ratios, exhibit signs of collinearity, which can lead to biased estimates if not properly addressed. The use of robust standard errors in the regression models helped to alleviate this concern, providing more reliable statistical inference. Additionally, the results demonstrated that firm-specific characteristics (e.g., firm size, sales growth, total assets) also play a crucial role in shaping performance outcomes, reinforcing the need for firms to carefully manage their capital structures to enhance long-term profitability.

5.1 Implications for Practitioners

For financial managers, policymakers, and investors, the findings of this study offer valuable insights into how different types of debt financing influence a firm's performance. Given the significant impact of long-term debt and total debt on firm performance, it is critical for companies to balance their debt obligations with their capacity to generate returns, especially in a dynamic economic environment. The study highlights the importance of using financial leverage judiciously, as excessive reliance on debt may lead to underperformance or financial instability, while optimal debt levels can drive growth and profitability.

For policymakers, the results suggest that regulatory frameworks should encourage businesses to adopt sustainable and strategic debt financing practices that support long-term growth without overburdening firms with debt-related risks. Moreover, fostering transparency in financial reporting and strengthening corporate governance can help mitigate risks associated with poor debt management.

5.2 Implications for Future Research

This study contributes to the growing body of literature on the relationship between debt financing and firm performance. However, several avenues for future research remain. First, future studies could examine the relationship between debt financing and firm performance in different industries, as the impact of debt may vary depending on the sector. Additionally, exploring the role of external factors, such as economic cycles, regulatory changes, and market conditions, could provide further insights into how debt financing decisions are influenced by the broader environment.

Another potential area for further investigation is the exploration of different financing sources, such as equity and hybrid instruments, and their comparative effects on firm performance. Incorporating these variables into the analysis would enrich our understanding of the trade-offs between debt and equity financing in optimizing firm performance.

Finally, expanding the research to include other performance measures, such as market value or stock performance, could offer a more comprehensive assessment of how debt financing influences operational and financial performance.

5.3 Conclusion

In conclusion, this study reinforces the importance of considering debt financing decisions carefully and accounting for potential biases and endogeneity when analyzing their impact on firm performance. Through the use of advanced statistical techniques like G2SLS and IV regression, we were able to provide robust and reliable findings that offer practical insights for managers, policymakers, and researchers alike. By addressing collinearity and endogeneity issues, this study contributes to a more accurate understanding of the complex relationships between debt financing and firm performance, highlighting the need for a balanced approach to debt management that aligns with long-term strategic goals.

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Predicting the surface roughness and Tolerance using regression analysis while performing a boring operation in AA6061 Alloy

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Abstract*— *Aluminium alloys are widely used in aerospace applications and AA6061 is one of the popular alloy which is extensively used in spacecraft mechanical hardware. Some of the mechanical hardware of spacecraft mechanisms call for stringent tolerances in larger diameter holes. These holes are achieved through boring operation on CNC machining centre by utilizing precision boring head and boring bar. Surface roughness and tolerance of the hole plays an important role in functioning of the system. In the current work experiments are carried out to study the significant input process parameters which influence the surface roughness and tolerance of holes. This was done using ANOVA. Also, a model was developed based on linear regression analysis. It was found that optimum cutting parameters predicted by Taguchi method improved surface finish and tolerance of holes

I. INTRODUCTION

Spacecraft consists of several mechanical hardware such as mechanisms, thermal subsystems, and electronics packages. From vast experience and available resources, it is evident that to achieve geometric and dimensional tolerances, complex shapes and surface finishes required by these spacecraft mechanical hardware, machining is the best method of manufacturing. Machining is a manufacturing process where the material is removed by using different cutting tools on different machine tools to obtain close tolerances and surface finish.

Aluminium alloys are widely used in aerospace applications owing to their good specific stiffness and strength. AA6061 is one such alloy which is commonly used in several spacecraft mechanical hardware components as it can be heat treated and has good corrosion resistance properties. Also, it is easily machinable using several machining operations.

Yahya, E. et.al (2016) performed the machining experimental work on AA6061 alloy using a vertical milling machine to study the effect of tool flutes, cutting speed, depth of cut and feed rate on surface roughness and cutting force. Their work established a relationship between input parameters and output parameters using the response surface method. The tests were done using the Taguchi technique and results were analyzed using ANOVA. Their work concluded that surface roughness has only two significant parameters (tool flutes and depth of cut) which affected surface machining. Gutema, E. M. et.al (2022) explored the implications of cutting parameters like cutting speed, feed rate and cutting depth; and nose radius on surface roughness and temperature in the workpiece while turning the AA6061 work piece. Further, desirability analysis optimization was performed to find the optimum values. Their work stressed the importance of cutting speed as the most influencing parameter compared to other parameters. Sivaiah, P., & Chakradhar, D. (2018) discussed on optimum cutting conditions in turning 17-4 precipitation-hardened stainless steel using the Taguchi optimization method. Input parameters like cooling environment (cryogenic, MQL and dry) were considered apart from cutting parameters, to study their effects on surface roughness and flank wear. Aggarwal, A et.al (2008) investigated the effects of cutting parameters, nose radius and cutting environment on power consumption of a CNC turning machine while machining AISI P-20 tool steel. Their work utilized Response Surface Methodology (RSM) and Taguchi methodology. Their work discussed that cryogenic working conditions contributed more in reducing the power consumption other than the cutting speed, which remained the highest influencing parameter in power consumption. Karkalos, N. E., Efkolidis, N., Kyratsis, P., & Markopoulos, A. P. (2019) conducted a comparison study for performance of various neural network models like Multi-Layer Perceptron (MLP), the Radial Basis Function Neural Network (RBF-NN), and the Adaptive Neuro-Fuzzy Inference System (ANFIS) models with the performance of multiple regression model for drilling experiments on an AA6082-T6 workpiece. The experiment was conducted for different cutting parameters and also with three cutting tools (solid carbide drilling tools) diameters of 8mm, 10mm and 12mm. The depth of holes drilled was 30mm. The work concluded that the MLP method performed better in all cases compared to other methods. However other than

multiple regression models, MLP was observed to be competitive for smaller data sets. Sastry, M. N. P et.al (2012) investigated the effect of process parameters on MRR using RSM while machining Aluminium alloy and resin using an HSS cutting tool. A close relationship between observed and predicted values was observed. Do Duc, T et.al (2020) presented a method of predicting the surface roughness in the hole-turning operation of 3X13 steel. An experimental matrix was prepared using Central Composite Design (CCD) and RSM was used to develop a quadratic polynomial model to predict surface roughness. Apart from this SVM algorithm was also used and their study showed SVM to be a better process for predicting surface roughness. Aamir, M et.al (2021) investigated the effect of the multi-spindle drilling process on dimensional hole tolerances, such as hole size, circularity, cylindricity, and perpendicularity. In addition to this, defects during drilling operation was also studied. The materials considered for the study were AA2024, AA6061 and AA5083. Their work used an uncoated carbide twist drill of 6mm diameter. AA2024 was found to have more dimensional stability compared to other materials. Spindle speed is found to influence the most in affecting the hole size and cylindricity errors. Trinh, V. L. (2024) reviewed the methods followed in predicting the surface roughness of the machining processes. The benefits like reduced cost, improved cutting conditions and enhanced quality in predicting surface roughness, are mentioned in the work. Deshpande, A. A., & Rehman, M. A. A. (2022) reviewed the machining process modelling literature related to surface roughness. The effectiveness of different statistical and mathematical models like RSM, Fuzzy Logic, Artificial Neural Networks (ANN) and Support Vector Machines (SVM) are discussed in the work.

Spacecraft mechanisms like solar array deployment mechanisms, solar array drive mechanisms, dual gimbal antenna, antenna pointing mechanisms etc., play a crucial role in the success of a spacecraft mission. These mechanisms comprise complex shapes, stringent tolerances and high surface finishes, critical for mechanism functioning. Some of the mechanisms call for the close tolerated holes whose dimensional accuracies are in the range of a few microns and surface finish in the range of 0.4 to 1.6 microns. For larger diameter holes and holes for which standard reamers are unavailable, a boring operation is known to be the best alternative to achieve these stringent requirements. Boring is a subtractive manufacturing technique used to enlarge a previously produced hole yet enhance its dimensional accuracy and surface finish. The process uses a single-point cutting tool to remove material parts from the interior of a workpiece.

Apart from achieving the stringent tolerances, high surface finishes and complex shapes of the components, realizing the hardware in the short lead times to meet the project schedules is also a challenging requirement. Realizing the hardware with short lead times without

Figure.1 : Boring operation on 3-Axis CNC Vertical machining Centre, DMG MORI D650V compromising the quality requires the maximum utilization of the machine and machining parameters. To achieve the correct balance among these a study has to be carried out for fixing the ideal machining parameters. Taguchi method was found to be the most popular method in Design Of Experiments and regression analysis to be most suitable if data set is small. To the best of the authors' knowledge no work related to boring of AA6061 is done.

Hence, in this work prediction of surface roughness using regression analysis is carried out while boring the AA6061 material.

II. EXPERIMENTAL METHODOLOGY

Taguchi L9 Design Of Experiments (DOEs) are used to optimize parameters for the surface roughness and tolerance of the hole on AA 6061 alloy. Depth of cut, Feed and Speed were the parameters taken in to consideration. Since three levels and three factors considered, L9 orthogonal array (OA) is used in this study. Design of experimental (DOE) has been used for reducing the number of experiments. The experimental plan having values with units, symbols and levels are listed in the Table 1.

AA6061 material with dimensions 250 mm × 150 mm × 25 mm was used for the experimental study for boring of holes with diameter of 22 mm as per experimental plan and for the confirmation tests and evaluation of the obtained models. Nine holes of each three with the diameter 21.6 mm, 21.4 mm and 21.2 mm were machined at feed of 2000 mm/min, speed of 6000 rpm and depth of cut 0.5 mm by circular pocket milling operation on DMG MORI D650V 3-Axis CNC vertical machining centre. As per the experimental plan, each hole was enlarged to the diameter of $22^{+0.021}_{+0.00}\ mm$ by boring operation in two passes with a precision digital boring head of make Microkom and carbide tool insert as shown in Fig.1 and Fig.2. The hole diameter of 22 mm with H7 tolerance was selected as the same dimension is found to repeat in several of spacecraft mechanical hardware.

Process Parameters	Unit	Symbol	Levels		
			1	2	3
Depth of Cut	mm	d	0.1	0.15	0.2
Feed	mm/min	f	100	250	500
Speed	rpm	s	4000	6000	8000

Table 1 Process parameters and their levels

A portable surface roughness tester Surtronic S-128 of make Taylor-Hobson was utilized to measure R_a (arithmetic mean surface roughness) value of holes produced by boring operation on the basis of the ISO 4287-1997 norms. Eq (1) defines R_a value. R_a value was considered for observation, as this parameter is the widely used parameter for measuring surface roughness in our organization.

$$R_a = \frac{1}{L}\int_0^L |z(x)|dx \qquad (1)$$

Where

L = Evaluation Length

z(x) = Profile height function

Average of three measurements of R_a (in µm) in each hole, measured by using portable surface roughness tester (as shown in Fig 2a) was considered. A cutoff length of 0.4 mm for each measurement was considered while taking R_a readings.

The diameter of the tolerated hole of $\emptyset 22^{+0.021}_{+0.00}\ mm$ was measured using 3-point digital bore micrometer by

(a) (b)

Figure 2: a). Precision Digital Boring head MicroKom – BluFlex 2 b). Boring bar with Carbide Insert

(a) (b)

Figure 3: a) Portable surface roughness tester Surtronic S-128 b.) 3-Point Digital Bore Micrometers by Mitutoyo

Run	Process parameters			Experimental results		S/N ratio results	
	d mm	f mm/min	s rpm	Surface roughness Ra (μm)	Tolerance of the hole (mm)	Ra (dB)	Tolerance (dB)
1.	0.1	100	4000	0.6	0.037	4.4370	28.6360
2.	0.1	250	6000	0.8	0.092	1.9382	20.7242
3.	0.1	500	8000	1.2	0.094	-1.5836	20.5374
4.	0.15	100	6000	0.4	0.089	7.9588	21.0122
5.	0.15	250	8000	0.3	0.099	10.4576	20.0873
6.	0.15	500	4000	0.8	0.046	1.9382	26.7448
7.	0.2	100	8000	0.3	0.107	10.4576	19.4123
8.	0.2	250	4000	0.4	0.056	7.9588	25.0362
9.	0.2	300	6000	1.0	0.092	0.0000	20.7242

Table 2 Experimental plan, Experimental results and S/N ratios

Mitutoyo (as shown in Fig 2b). The average of three values was taken while measuring the tolerance of the hole.

III. RESULTS AND DISCUSSIONS

The S/N ratio is defined as the ratio of mean of readings to the standard deviation of the same and is used to measure the quality characteristic deviating from the desired value by the Taguchi technique. Taguchi used the term signal for wanted value i.e mean and noise for unwanted value i.e standard deviation, which are determined for a response. Taguchi divided S/N ratio into three categories namely, higher-the-better, nominal-the-better and smaller-the-better. In the present work smaller-the-better Eqn. (2) is used for Ra and tolerance achieved. The achieved results and S/N values for Ra and tolerance, are listed in Table 2.

S/N ratio for smaller the better = $-10 \log \frac{1}{n} \sum (R)^2$ (2)

Where, n = No. of observations

R = Observed data for each response

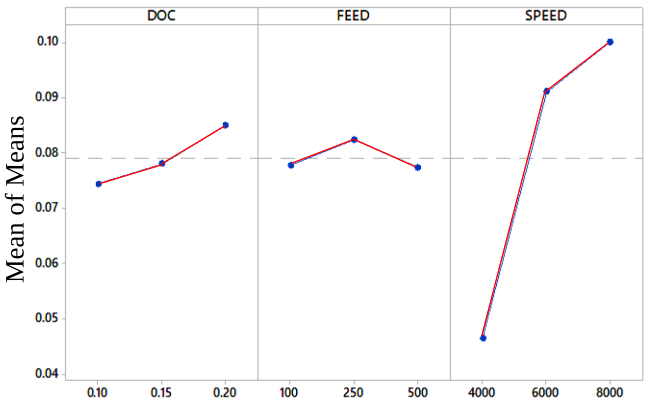

Figure 5: Effect of process parameters on tolerance of hole

a. Effect of Process parameters on Ra and tolerance of hole

Fig. 4 depicts the effect of process parameter viz. depth of cut (DOC) (d) in mm, Feed (f) in mm/min and Speed (s) in RPM, on Ra. Results show that R_a value decreased with increasing depth of cut but slightly raised with further increasing DOC. R_a value showed jump in the value with

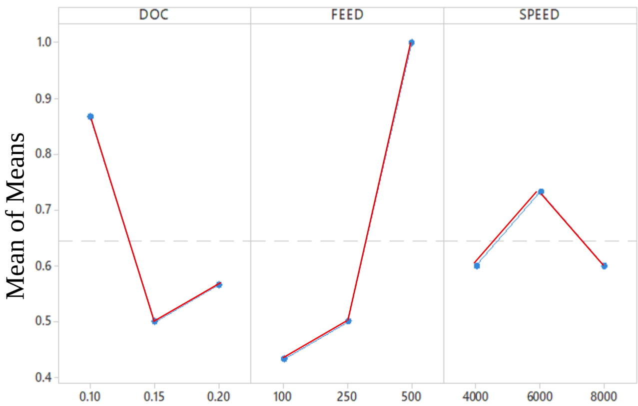

Figure 4: Effect of process parameters on R_a

increasing feed rate. With increasing the cutting speed R_a is observed to increase but reduces with further rise in the cutting speed.

Fig. 5 depicts the effect of process parameters on tolerance of holes. It is observed that increasing the DOC is affecting the tolerance of holes. Same but more significant

Effect of speed on tolerance of the holes is noticed, with sharp decline in hole quality with increase in speed. However, feed rate seems to affect the hole quality but tend to improve it with increase in its values.

Process Parameters	Symbol	Mean S/N ratio			Rank
		Level 1	Level 2	Level 3	
Depth of Cut (mm)	d	1.5972	**6.7849**	6.1388	2
Feed (mm/min)	f	**7.6178**	6.7849	0.1182	1
Speed (rpm)	s	4.7780	3.2990	**6.4438**	3

Table 3 Mean S/N ratio response table for R_a

Process Parameters	Symbol	Mean S/N ratio			Rank
		Level 1	Level 2	Level 3	
Depth of Cut (mm)	d	**23.30**	22.61	21.72	2
Feed (mm/min)	f	**23.02**	21.95	22.67	3
Speed (rpm)	s	**26.81**	20.82	20.01	1

Table 4 Mean S/N ratio response table for tolerance of holes

b. Selection of optimum cutting conditions for Ra and tolerance of hole

The obtained S/N ratio response table for R_a is shown in Table 3 and Fig. 6 depicts the mean S/N ratio graph obtained in R software. Higher S/N means there is minimum variation difference between required output and measured output. It can be seen from Fig 4 that the highest mean value of S/N ratio for R_a is obtained for DOC value of 0.15mm, federate of 100mm/min and speed value of 8000 RPM. Thus the predicted optimum cutting parameters for obtaining the best surface finish i,e least R_a value are DOC = 0.15 mm, f = 100 mm/min and N = 8000 RPM.

It can be seen from Fig. 7 that the highest mean value of S/N ratio for tolerance of hole is obtained for DOC value of 0.1 mm, federate of 100 mm/min and speed value of 4000 RPM. Thus the predicted optimum cutting parameters for obtaining the best tolerance value for hole i.e least tolerance value are DOC = 0.1 mm, f = 100 mm/min and N = 4000 RPM.

c. Conformation Test

To validate the Taguchi predicted optimum conditions conformation test needs to be conducted.

The predicted S/N ratio is calculated based on the formula given in Eqn. (3) (Sivaiah, P., & Chakradhar, D. (2018))

$$\varepsilon_{predicted} = \varepsilon_i + \sum_{i=1}^{n} (\varepsilon_0 - \varepsilon_i) \quad (3)$$

Where

ε_i= Total mean S/N ratio
ε_0= Mean S/N ratio at an optimal level
n= No. of input process parameters

The conformation experiments were conducted at the Taguchi predicted optimum cutting conditions, and the results are tabulated in Table 5 and Table 6.

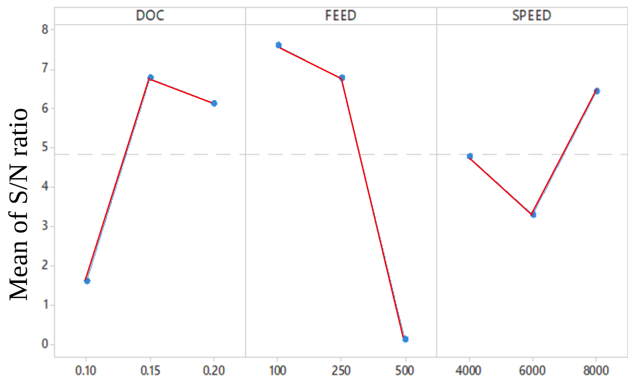

Figure 6: Mean S/N ratio of R_a

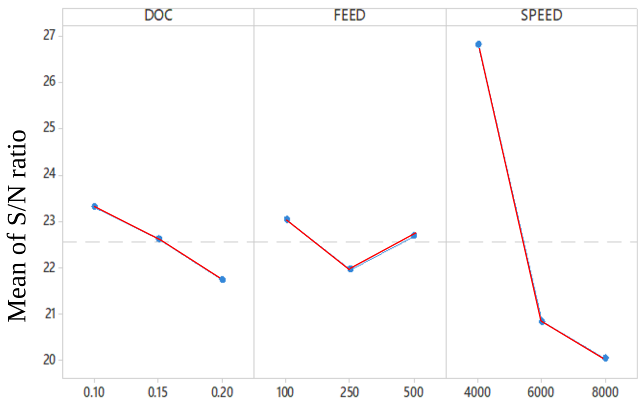

Figure 7: Mean S/N ratio of tolerance of holes

Improvement in S/N ratio for R_a and tolerance of holes is observed at the optimum cutting conditions (d2-f1-s3) when compared to the S/N ratio of initial process parameters d2-f2-s2. The S/N ratio for R_a at the optimum

	Initial process parameters	Optimal process parameters	
		Prediction	Experiment
Level	d2-f2-s2	d2-f1-s3	d2-f1-s3
Surface roughness (µm)	0.59		0.30
S/N ratio (dB)	7.188	11.165	10.45
Improvement in S/N ratio (dB)		45.38 %	
% improvement in R_a		49.15 %	

Table 5 Conformation test results for R_a

	Initial process parameters	Optimal process parameters	
		Prediction	Experiment
Level	d2-f2-s2	d1-f1-s1	d1-f1-s1
Hole tolerance (mm)	0.14		0.040
S/N ratio (dB)	20.292	28.032	27.958
Improvement in S/N ratio (dB)		34.64 %	
% improvement in hole tolerance		71.42 %	

Table 6 Conformation test results for tolerance of holes

cutting conditions is found to be 10.45 as against value at initial process parameters which is 7.188. Percentage improvement in R_a while using optimum cutting conditions when compared to initial process parameters, is found to be 49.15%. Also, for R_a the variation between predicted S/N ratio and S/N ratio obtained after conducting the experiment at optimum conditions, is found to be 6.40% with respect to the predicted value.

The S/N ratio for tolerance of holes at the optimum cutting conditions(d1-f1-s1) is found to be 27.958 as against value at initial conditions which is 20.292. Percentage improvement in hole tolerance while using optimum cutting conditions when compared to initial process parameters is observed to be 71.42%. Also, for the tolerance of holes, the variation between predicted S/N ratio and S/N ratio obtained after conducting the experiment at optimum conditions, is found to be 0.26% with respect to the predicted value.

IV. ANOVA FOR R_a AND TOLERANCE OF HOLES

One of the aims of the experiment conducted is to determine the significant input parameters which affect the R_a and tolerance of holes. ANOVA is most widely used statistical tool which determines the significant input parameters that affect output parameters. Table 3 and Table 4 present the significance of input process parameters on R_a and tolerance of holes, respectively. The rank column shows the significance of an input parameter on the output parameter.

From the Table 3 it is evident that R_a was mostly influenced in the order of feed rate, DOC and speed respectively. Whereas from the Table 4, tolerance of hole was mostly influenced in the order of speed, DOC and feed respectively. From ANOVA analysis it is observed that both R_a and tolerance of holes are affected greatly by DOC which ranks 2 for both the parameters as seen in Table 3 and Table 4 respectively.

V. MODELING

Since predicting the R_a and tolerance holes for different diameters through experiments is practically difficult in nature, need for a reliable mathematical model for predicting R_a and tolerance for holes is required. From literature survey it was noticed that mathematical model developed using regression method is found to be reliable in predicting the output parameters pertaining to machining processes and in particular conventional machining processes.

Hence, in the present study most widely used statistical tool, regression analysis is used to develop a mathematical model for output parameters R_a and tolerance of holes, based on the dependent input parameters DOC, feed and speed.

The predictive equations for R_a and tolerance of holes, based on regression analysis are shown in Eqn. (3) and (4) respectively

$$R_a = 0.98 - 5.47 \times d + 0.00104 \times f - 0.00031 \times s + 0.0033 \times d \times f + 0.00026 \times d \times s \quad (R^2 = 80.25\%) \qquad (3)$$

$$Tolerance = -0.0462 + 0.261 \times d - 0.000129 \times f + 0.000024 \times s + 0.000747 \times d \times f - 0.000061 \times d \times s$$

$$(R^2 = 88.72\%) \qquad (4)$$

The co-efficient of determination (Sivaiah, P., & Chakradhar, D. (2018)) R^2 was used to check the capability of the developed models. The co-efficient of determination value varies from zero to one, closer to one better is the model in predicting the values. In the present study, the developed regression models for R_a and tolerance of holes have R^2 of 80.25% and 88.72% respectively. To validate the developed models, conformation tests were conducted and results are mentioned in Table 7 and Table 8.

For R_a from Table 7 conformation tests for performed for run numbers 2, 4 and 8 and error between predicted model and experimental values are varying from -7.5% to 11%. Similarly, for tolerance of holes mentioned Table 8, the error is varying from -2.17% to -7.86%.

Run	Ra (µm)		Error %
	Experimental	Predicted	
2	0.8	0.74	-7.5
4	0.4	0.37	-7.5
8	0.4	0.44	11

Run	Tolerance of the hole (mm)		Error %
	Experimental	Predicted	
4	0.089	0.082	-7.86
6	0.046	0.045	-2.17
9	0.092	0.088	-4.34

Table 8 Conformation results for the developed models for tolerance of holes

Further to test the modelled equations Eqn. (3) and (4), experiments were conducted for two set of process parameters as mentioned in Table 9. From the table it is observed that variation is less for R_a and slightly more for the tolerance of the holes. Percentage of variation between predicted and experiment values for R_a was found to be 7.5% and 6.67% for first and second set respectively. Whereas for tolerance of hole, percentage of variation was found to be 10% and 5% for first set and second set respectively.

VI. CONCLUSION

Following are the conclusions drawn from the experiments conducted

- The predicted optimum cutting parameters for hole diameter $22^{+0.021}_{+0.00}\ mm$, obtaining the best surface finish i.e least R_a value are d = 0.15 mm, f = 100 mm/min and s = 8000RPM. The optimum conditions are determined using Taguchi method and is represented as d2-f1-s3. The R_a value at these optimum cutting conditions was found to improve by 49.15% compared to d2-f2-s2 values. the predicted optimum cutting parameters for obtaining the best tolerance value for hole i.e least tolerance value are d = 0.1 mm, f = 100 mm/min and s = 4000 RPM. The optimum conditions determined is represented as d1-f1-s1. The tolerance of holes at these optimum conditions was found to improve by 71.42% compared to d2-f2-s2 values.
- ANOVA has shown that R_a was mostly influenced by feed rate, DOC and speed respectively. Whereas tolerance of hole was mostly influenced by speed, DOC and feed respectively.
- Experiment was further conducted for the two set of process parameters viz Set 1: d = 0.15 mm, f = 150 mm/min, s = 2000 RPM and Set 2: d = 0.15 mm, f = 280 mm/min, s = 2200 RPM, to conform the equations modelled using linear regression analysis. It was observed that percentage of variation between predicted and experiment values for R_a was found to be 7.5% and 6.67% for first and second set respectively. Whereas for tolerance of hole, percentage of variation was found to be 10% and 5% for first set and second set respectively.

Diameter of the hole (mm)	Process Parameters from models	Ra (µm)		Tolerance(mm)		% of variation w.r.t predicted	
		Predicted	Experiment	Predicted	Experiment	R_a	Tol
22	d = 0.15, f = 150, s = 2000	0.4	0.43	0.02	0.018	7.5	10
	d = 0.15, f = 280, s = 2200	0.6	0.56	0.02	0.019	6.67	5

Table 9 Conformation results for the developed model for surface roughness of hole

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A Welding Defect Detection Algorithm Based on Deep Learning

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***Keywords*— Deep learning, SCConv, Weld defect, YOLOv8**

Abstract*— *In order to meet the needs of process inspection technology for industrial equipment, image recognition technology based on deep learning has shown great potential in the field of welding defects. In this paper, an improved YOLOv8 algorithm is proposed to improve the welding defect identification ability of the workpiece. Through experimental verification on selected data sets in kaggle, this study evaluates the detection performance of YOLOv8 improved algorithm that integrates SCConv in C2f module at Backbone level. The experimental results show that the improved YOLOv8 has improved the accuracy of welding defect detection compared with the traditional version, and has certain application potential.

I. INTRODUCTION

In the field of industrial equipment, welding process is an important technical requirement, good welding technology can ensure the solidity and integrity of welded joints, avoid product quality problems and safety hazards caused by welding defects, at the same time, improve production efficiency, reduce production costs in large engineering projects, welding process can significantly affect the cost and schedule of the project. Some welding processes can achieve automatic welding, improve production efficiency and product quality, reduce labor costs and energy consumption, and in the welding process due to material properties, process parameters, equipment status and other factors, there may be cracks, pores, slag and other welding defects, if these defects are not found and treated in time, It may lead to product failure or even safety accidents during use. Through welding defect detection, these defects can be found and dealt with in time, thereby preventing potential quality problems and safety hazards.

The traditional detection process is mainly manual detection after the equipment is welded by the workers, and this method is not only time-consuming and labor-intensive, but also leads to workers' inattention during a long time working, resulting in some defects not being discovered [1]. Some researchers use relevant physical information to detect welding defects, such as Droubi [2] et al. Defects in carbon steel welds can be detected and identified by evaluating information such as peak amplitude and RMS value. Y [3] et al. studied pulsed induction thermal imaging (PIT) for detecting hidden defects in stainless steel welds, while Bebiano [4] et al. proposed a new detection mode, which simulated the data of relevant welding defects by using interference arc. The disturbance generated by the simulated arc is captured by the spectrometer, and then the correlation detection algorithm is used to indicate the existence and location of these defects.

With the continuous development of deep learning technology, many researchers begin to use deep learning technology for non-destructive testing of welding defects, especially in computer vision and algorithms. For example, (H [5], Bing Zhu [6], Yang [7], R [8]) and others use relevant neural network models to detect welding images after X-ray processing. Liu et al. proposed an improved and optimized fast multipath vision transformer (FMPVIT) framework for welding defect detection and identification [9], Li [10] et al. designed a welding defect detection method based on cross-layer feature fusion, and used an irregular long weld extraction algorithm based on drift gauss to improve efficiency and accuracy. Oh et al, [11] proposed a FAST R-CNN automatic detection method for welding defects based on deep learning. In 2016, Joseph Redmon et al. proposed a one-stage object detection network [12], which has the advantage of fast detection speed and can process about 45 frames of images per second. The author named it You Only Look Once, Therefore, the first generation of YOLO algorithm was born [13]. The core idea of YOLO algorithm is to transform the object detection task into a regression problem, and use convolutional neural network to infer images directly to achieve real-time object detection. Now YOLO series algorithms have been updated for many generations and are widely used in the field of target detection. For object surface defect detection, Hatab [14] et al proposed a steel surface defect detection system based on YOLO algorithm, and Zhao [15] et al proposed a model named LDD-YOLO based on YOLOv5 for steel surface defect detection. M [16] et al. designed a YOLO-HMC network, which realized more accurate and efficient identification of micro-sized PCB board defects with fewer model parameters. Gao [17] et al. improved the YOLOv5 algorithm. RepVGG module, NAM and lightweight uncoupled head RD-Head are introduced to improve the detection performance of the algorithm and are applied to weld feature detection. While Light-YOLO-Welding, a new type of lightweight detector based on improved YOLOv4 developed by L [18] et al., is used to detect weld feature points. In this study, we proposed an improved YOLOv8 welding defect detection algorithm based on YOLOv8 target detection algorithm. The experimental results show that the detection accuracy of the improved algorithm is improved, and the performance of various indexes is good.

II. INTRODUCTION TO EXPERIMENTAL MODEL

YOLOv8 is a new generation of object detection algorithm introduced by ultralytics for real-time object detection. Based on the previous YOLO version, YOLOv8 introduced new features and optimizations, including a more complex network architecture, a more optimized training flow, and a more powerful feature extraction capability [19].

Its general architecture is composed of Backbone (backbone network), Neck (neck network) and Head (head network), and its network structure is shown in Figure 1:

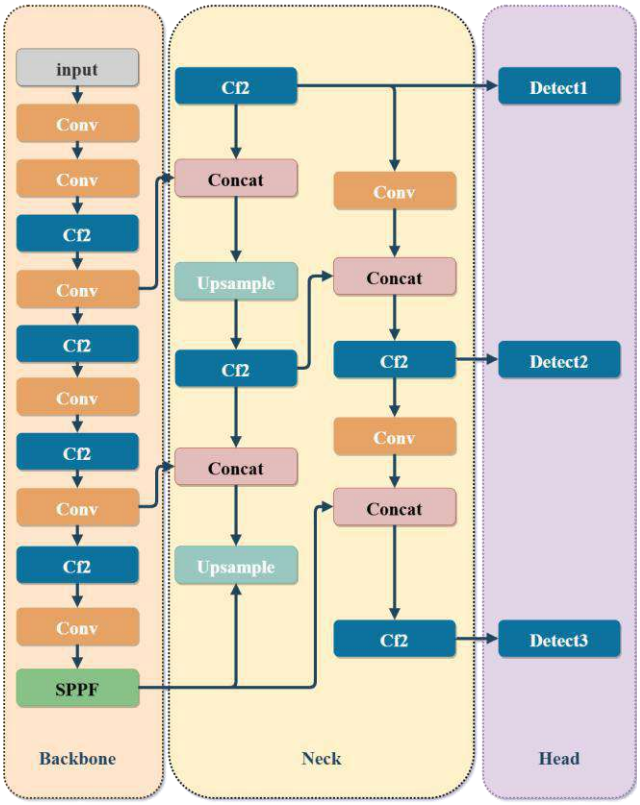

Fig.1: YOLOv8 network structure diagram

Backbone is responsible for feature extraction. It adopts a series of convolutional and deconvolution layers to extract feature information of different levels from input images. Using ResNet' s idea for reference, Backbone uses residual connections to reduce the size of the network, reduce the computational complexity and the number of parameters, and improve the running speed and efficiency of the model [20]. In this part, the C2f module is adopted as the basic constituent unit, and new structures and improved technologies are introduced, such as Depthwise Separable Convolution and DilatedConvolution, etc., to further optimize the capability of feature extraction and make the extracted features more representative and differentiated. So the target detection task can be carried out better. Compared with C3 module of YOLOv5, C2f module has fewer parameters and better feature extraction capability. It is the foundation and key component of the whole model, which provides strong support for the subsequent Neck and Head network parts, and jointly realizes the efficient and accurate target detection task.

Through multi-scale feature fusion, SPPF module in YOLOv8 pooled, splicing and fused feature maps of different scales, effectively expanded the sensitivity field and extracted rich information. By optimizing the algorithm, the computational load was reduced, the accuracy was improved by using large kernel convolution, and the detection ability of targets of different sizes was enhanced, thus improving the performance and robustness of the model.

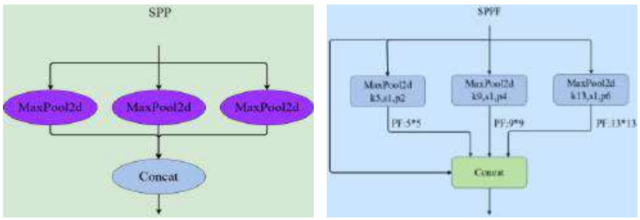

Fig.2: Comparison between SPP module and SPPF module

SPP works by concatenating inputs with three parallel MaxPool layers. The three MaxPool tiers typically use 5*5, 9*9, and 13*13 kernels. This allows features at different scales to be captured at the same time, thereby reducing identification errors due to changes in the scale of the input image. SPPF, on the other hand, connects three MaxPool layers with 5*5 kernel in series, and then combines them together through residual connection, which reduces the redundant calculation between feature graphs and improves the reasoning speed of the model [21].

The Neck part is responsible for multi-scale feature fusion, which enhances the feature representation ability by fusing feature maps from different stages of Backbone. The deep feature map carries stronger semantic features and weaker positioning information. Shallow feature maps carry strong positional information and weak semantic features [22]. Yolov8 uses PAN-FPN (Path Aggregation network-feature Pyramid Network) as its Feature Pyramid Network, and fuses feature maps from different stages of the backbone network to form feature maps with more semantic information and multi-scale perception. Through bottom-up and top-down path aggregation, feature maps of different scales are fused to achieve cross-scale information transfer, which further enhances the representation of multi-scale features and improves the detection ability of the model for objects of different sizes and shapes [23]. At the same time of feature fusion, the Neck network can further process and fuse the splicing features through modules and structures such as convolutional layer and residual connection, and extract more representative feature information, so that the model can identify and locate the target more accurately and improve the accuracy of target detection [24]. Hierarchical feature selection and fusion mechanisms are also introduced, such as the application of the latest lightweight neck network structures such as HS-FPN, which further reduces the number of model parameters and computational complexity, while improving the model performance.

Compared with YOLOv5 and YOLOv6, YOLOv8 removes the convolutional layer structure in the up-sampling stage of PAN-FPN and directly feeds the features output in different stages of Backbone into the up-sampling operation. The C3 module and RepBlock were also replaced with the C2f module [25]. The number of parameters and computational complexity of the model are reduced, and the computational efficiency is improved.

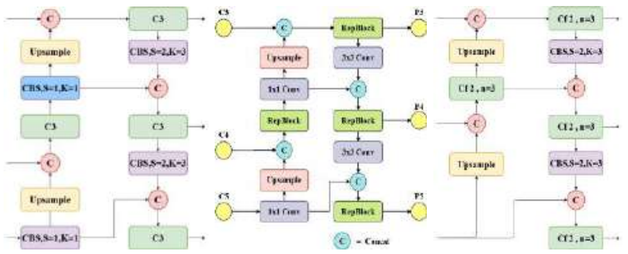

Fig.3: Comparison of YOLOv5, YOLOv6 and YOLOv8 Backbone

The Head part is responsible for further processing and integration of multi-scale features after neck network fusion, that is, the final target detection and classification task. The anchor-based is improved to Anchor-free, which does not rely on predefined Anchor frames, and flexibly processes targets of different sizes and shapes by directly predicting the position and shape of the target on the image or feature map [26]. The number of box prediction is reduced, the training process is simplified, and the flexibility and accuracy of detection are improved. The detection head consists of a series of convolutional and deconvolution layers that are used to generate detection results. It can accurately locate objects in the input image, predict the boundary box regression value of each anchor box and the confidence of the existence of the target, so that the model can accurately determine the location range of objects in the image [27]. The classification head uses Global Average Pooling to process each feature map, reduce the dimension of the feature map, analyze the extracted features, judge the probability that the target in the image belongs to each category, and achieve accurate classification of the target. Finally, after non-maximum suppression processing, the threshold is adjusted by adaptive adjustment. The boundary box with the highest confidence is retained, the duplicate detection box is removed, the false detection and missing detection are reduced, and the detection accuracy is effectively improved.

III. ALGORITHM IMPROVEMENT AND OPTIMIZATION

YOLOv8 mainly uses convolutional neural networks as the main means of feature extraction. The key information of the target detection task, such as the edge, texture, shape and other features of the object, is extracted from the input image, so as to carry out accurate target recognition and positioning. This process converts the original high-dimensional image data into low-dimensional feature vectors, which not only simplifies the complex data, but also reduces the amount of computation, significantly improves the training and inference efficiency of the model, and enhances the generalization ability of the model. By learning more representative and general features, Yolov8 can adapt to work on different scenarios and data sets, so that it can maintain excellent performance in different environments and achieve efficient and accurate detection results.

C2f module is a convolutional neural network module for feature extraction. By fusing feature maps from different levels, the model can make use of both details and semantic information, so as to better capture complex features in images, improve the accuracy of target detection, and retain rich gradient flow information [28]. However, stacking operation may cause the problem of channel information redundancy, and the use of a general convolution kernel may affect the detection of the receptor field, which may lead to the omission of target detection in complex scenes, especially when there is a lot of background interference, multiple detection targets or occlusion.

Spatial and Channel Reconstruction Convolution (SCConv) is a new convolutional neural network (CNN) module, which aims to improve the compression efficiency and feature representation capability of CNN by reducing the space and channel redundancy of features [29]. The module is composed of space reconstruction unit (SRU) and channel reconstruction unit (CRU). SRU supplants spatial redundancy through separation and reconstruction operations, while CRU adopts split-transform-fusion strategy to reduce channel redundancy [30].

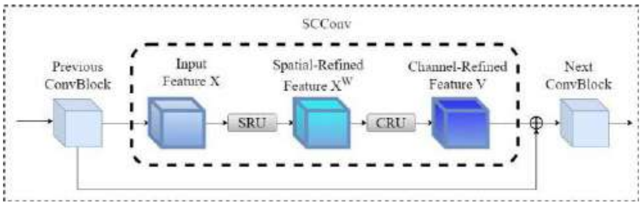

Fig.4: SCConv module structure diagram

SRU first receives input feature X, reduces the scale difference between feature maps through group normalization, then generates weights to weight features, separates features into multiple subsets, and finally generates refined spatial feature output through transformation and recombination [31]. CRU is responsible for segmentation and compression of SRU output features, using 1×1 convolution kernel to reduce the number of channels, then extracting "rich features" through GWC and PWC operations, and finally using SKNet method to adaptively merge these features to obtain channel extracted feature Y [32]. These two units work together to not only reduce redundant features, but also improve the performance of the model and the efficiency of feature characterization.

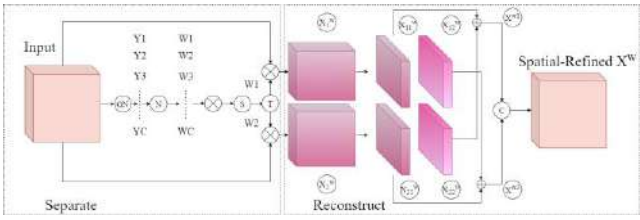

Figure 5: SRU structure

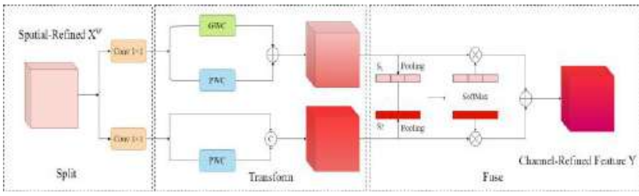

Fig.6: CRU structure diagram

SCConv as a plug-and-play architecture unit, we replace the general convolution in the Cf2 module with the SCConv module as shown in Figure 7:

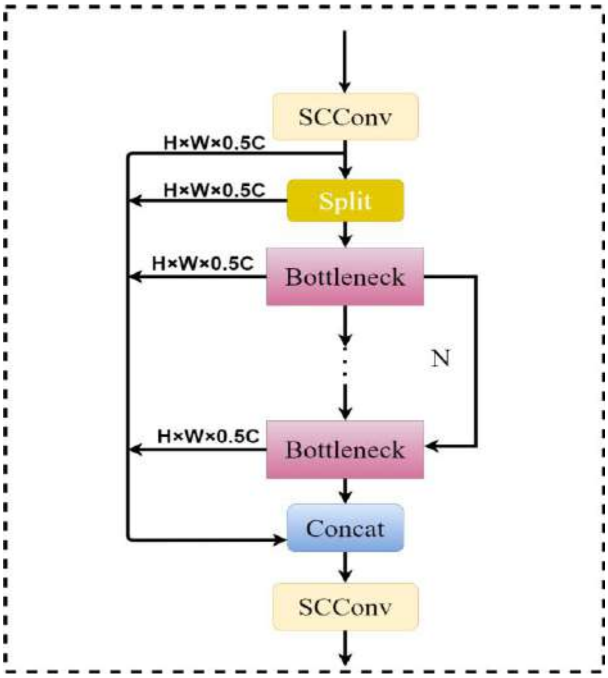

Fig.7: Improved Cf2 module structure

General convolution unified processing of all areas and features of the image, it is difficult to distinguish important differences, may pay too much attention to insignificant features and ignore welding defect related features, resulting in redundant information. SCConv, with its spatial and channel reconstruction capabilities, can extract welding defect related features in a targeted manner, highlight important information, make the network more focused on key features, and improve detection accuracy [33].

In the field of welding defect detection, general convolution has many limitations. In the face of weld defects of different types, scales and environments, it is unstable, difficult to adapt to changes, and the generalization ability is limited. For example, in actual industrial scenarios, the shape, size and ambient light conditions of welding defects are different, and general convolution cannot effectively deal with these complex and changeable situations. Moreover, the features extracted by general convolution are relatively simple, and it is difficult to capture the fine and complex structural information of weld defects. It is easy to be ignored when detecting some tiny cracks or defects hidden in complex background, resulting in the accuracy of detection is affected. The SCConv module, with its special structural design, can better adapt to various welding defects. By learning more representative and robust feature representations, the detection effect of changing weld defects is good, and the reliability of the model in practical industrial applications is improved. At the same time, SCConv can better capture key information such as shape, texture and edge of weld defects by simultaneously reconstructing space and channel dimensions, and form a more discriminating feature representation, which is conducive to accurate detection and identification of welding defects. In addition, in terms of computational efficiency, general convolution processing of high-resolution welding images requires a large amount of computation and is slow. SCConv can effectively decompose and reassemble feature maps, reduce unnecessary computation operations, improve computing resource utilization while maintaining attention to important features, and realize faster detection speed, which is conducive to real-time detection in industrial production.

IV. EXPERIMENT AND RESULT ANALYSIS

4.1 Experimental environment and experimental data

The open data set was selected from the kaggle website and the selected images were annotated by the labelimg tool. The data set contained more than 3000 images, and two types of data -good welding and bad welding - were divided into training set, verification set and prediction set in proportion. Among the selected data, welds such as edge bite, burn through, wrong edge, crater, porosity and crack are classified as bad weldinng, while the rest are good welding. Part of the data to be tested is shown in FIG.

Fig.8: part of the data image to be detected

The research model development language is Python, the deep learning frame is Pytorch1.4.0, the CUDA version is 11.18.

4.2 Experiment and result analysis

To verify the improved performance of YOLOV8 model, Precision, Recall, Average Precision (AP, Average Precision) and average precision (mAP, average precision) were selected in this experiment. mean Average Precision) as a key evaluation indicator. Among them, the accuracy rate directly reflects the correct proportion of the model prediction, which is a direct reflection of the overall accuracy. The recall rate focuses on the sensitivity of the model to positive instances and reveals the ability of the model to capture the target. By synthesizing the accuracy of different recall rates, the performance of the model under various thresholds was evaluated. The mean average accuracy provides a uniform standard for measuring the average performance of the model across all categories, thus more fully reflecting the overall effect of the model. Although these four indicators have different focuses, they are interrelated and provide strong support for the optimization of the model and the improvement of the prediction accuracy.

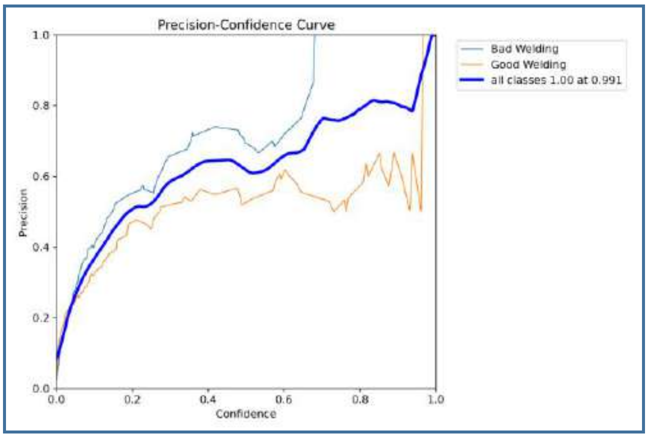

Fig.9: Feedback curve of the improved Precision-confidence curve

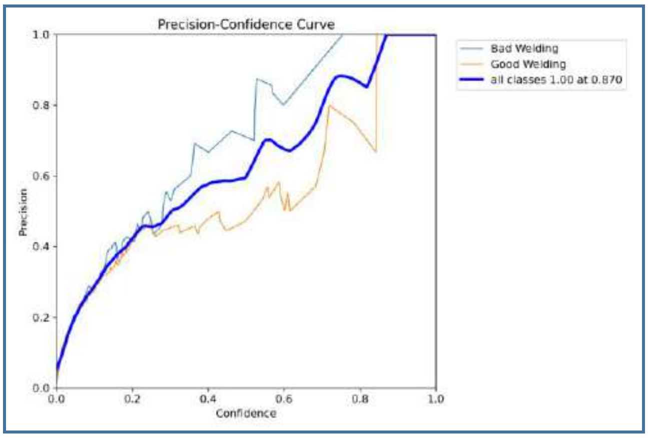

Fig.10: Precision-confidence curve Feedback curve before improvement

Table 1: Comparison of relevant experimental data

Arithmetic	Precision ratio	Recall rate	Map
YOLOv8	0.398	0.392	0.212
YOLOv8（SCConv）	0.627	0.5	0.471

V. CONCLUSION

In this experiment, we carried out the operation in strict accordance with the standard process. A suitable model environment is built to ensure the accuracy and stability of each parameter and configuration. All the required data sets are obtained legally from the Internet, and the data sets are from reliable and authoritative sources. When constructing relevant data sets, in order to reflect the diversity and representativeness of data, we selected experimental data sets with a large number of references, which could almost fully reflect various situations in practical application scenarios, and then trained the YOLOv8 detection algorithm after the introduction of SCConv based on these data sets. After data training, we evaluate the performance of the model. The results show that the precision of YOLOv8 detection algorithm after the introduction of SCConv reaches 0.627, which is indeed improved to a certain extent compared with the accuracy of 0.398 before the improvement, indicating that the introduction of SCConv can optimize the detection ability of the algorithm to a certain extent. However, although we used a large number of experimental data sets in data selection, the actual experimental results show that the improved algorithm does not perform well in welding trace detection. This may mean that there are still some problems in data processing and data selection that have not been discovered or solved. In view of this situation, in the following research, we will focus on the two perspectives of data processing and data selection, in-depth analysis of possible problems, and explore corresponding optimization strategies to further improve the performance of the algorithm in welding trace detection, so that it can better meet the needs of practical applications.

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XKFHnet: Xception Kronecker Forward Fractional Net for Intrusion Detection in Cloud

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Abstract— *In this new era of on-demand cloud computing, security is crucial. To find breaches in the cloud computing environment, researchers have surveyed a number of intrusion detection methods. The majority of them discuss conventional abuse and anomaly detection methods. By positioning the analysing component outside the virtual machine, usually at the hypervisor, Virtual Machine Introspection techniques are highly useful in identifying various stealth attacks that target user-level and kernel-level processes operating in VMs. Techniques such as Hypervisor Introspection protect the hypervisor and stop a compromised hypervisor from attacking virtual machines that run on it. Through the use of hardware-assisted used in virtualization-enabled technologies, introspection approaches examine the hypervisor. Our paper's primary goal is to present a thorough literature review of the many intrusion detection methods that have been suggested for cloud environments, along with an evaluation of their capacity to detect attacks. To clarify the vulnerabilities in the cloud, we offer a threat model and attack taxonomy. Our taxonomy of IDS techniques offers a thorough analysis of approaches together with their distinguishing characteristics, and it represents the state of the art in classification. In the survey, we have given a thorough understanding of methods based on Virtual Machine Introspection and Hypervisor Introspection. With the help of our study, researchers should be able to start investigating intrusion detection techniques in cloud environments.*

I. INTRODUCTION

With its various characteristics for increasing corporate efficiencies, cost-benefit analysis, and advantages over traditional computing processes, cloud computing has been in the spotlight for around 20 years [1]. The capacity to implement cloud-based threats and attacks has made it possible for hackers, attackers, and cyber invaders to have a high-quality plan globally, which means they can significantly impact the quality of the cloud environment. Numerous kinds of assaults can target cloud computing. These consist of identity theft, malicious insiders, unsecured interfaces and APIs, data loss, data breaches, and unknown risk profiles [2]. DoS/DDoS attacks and other cloud-based threats have the ability to quickly deactivate a target and cause significant financial losses. Threats and attacks continue to expand significantly and continuously, with an extended volume and criticality, even with the abundance of traditional threat detection systems. An entity that aims to take advantage of system weaknesses is referred to as an intruder in cybersecurity. Techniques based on anomalies or signatures can be used to identify intrusions.

While the anomaly-based approach, which compares user patterns to known patterns, has a high false positive rate of detection, outdated signature-based intrusion detection systems (IDS) are unable to adapt to new attacks. However, an efficient classification technique can be used to resolve issue. Users' data security and privacy are seriously jeopardized by cybersecurity problems.

Because cloud systems are open, new security dangers and assaults require more clever and efficient responses [3]. Network intrusions are one of the biggest security threats that many organizations deal with nowadays. The importance of network security has grown as a result of the quick development of big data, cloud computing, related technologies, and information, as well as the growing dependence of our everyday communications on networked services [4]. Persistently complicated adversaries can assault traditional security mechanisms like encryption systems and fire barriers. Detective, deterrent, corrective, and preventative controls are the four types of security controls that are used in the cloud. These controls employ deterrence control, which lowers the attack level by warning the system. To make preventive measures and techniques more resilient to intruder attacks, preventive control is employed. The procedure of corrective control aids in identifying the threat and employs techniques to retrain the system to fend against future assaults [5]. In the cloud context, the IDS is a component of the detective control utilized for security control mechanisms . In the cloud context, the IDS is a component of the detective control utilized for security control mechanisms. IDS can be either a software system that uses identification and alerting to automatically monitor threats or a hardware system that uses physical devices to identify threats. IDS have been categorized according to their location, mode of operation, and action . In the literature, several Machine Learning (ML)-based models for network intrusion detection have been put out; some of these models are currently in use in the commercial sector. IDSs come in three varieties: hybrid, anomaly-based, and signature-based. According to machine learning approaches in anomaly-based intrusion detection systems can be used to mitigate the known threat. This method uses unidentified patterns or signatures to identify the packet that the hackers have targeted. Because it models host, user, and network behavior, it is also known as a behavior-based detection system. As a result, an alarm is triggered if the system's behavior deviates from its typical pattern. The signature of the last known threat or attack is stored in the database of a signature-based intrusion detection system. It is possible to identify packets from intruders using the signature and packet patterns. This method has a very high detection accuracy. . When the system does not have the arriving packet signature, this approach does not work. Although hybrid intrusion detection systems (IDS) combine the two previously mentioned techniques, they are rarely employed since they do not yield the required detection accuracy.

II. LITERATURE REVIEW

The growing reliance on cloud computing has brought significant advantages, such as scalability, flexibility, and cost-effectiveness. However, these benefits also come with an increased risk of cyberattacks. Intrusion detection in cloud environments has therefore become a critical research area. Traditional intrusion detection systems (IDS) are often not sufficient to handle the scale, complexity, and dynamic nature of cloud systems. As a result, there has been a surge in research on using machine learning (ML), deep learning (DL), and advanced mathematical techniques for building more effective and scalable intrusion detection solutions. Below is a review of the relevant literature on the subject. Kavitha, C., Gadekallu, T.R., K, et "Filter-based ensemble feature selection and deep learning model for intrusion detection in cloud computing", Electronics, vol.12, no.3, pp.556, 2023. Deep Learning Model (DLM) used. This method offered more robust feature selections, reduced the chances of including noisy or less informative features. The dependency on statistical tests failed to capture non-linear relationships that were crucial for intrusion detection.[1]

Aldallal, A., "Toward efficient intrusion detection system using hybrid deep learning approach", Symmetry, vol.14, no.9, pp.1916, 2022. Gated recurrent units (GRUs) and improved long short-term memory (LSTM) through a computing unit (Cu-LSTMGRU). It provided a high level of symmetry between cloud computing security and the detection of intrusions and malicious attacks. This technique did not consider both memory utilization and time complexity.[2]

Chakravarthi, S.S., Kannan, R.J.et "Deep Learning Based Intrusion Detection in Cloud Services for Resilience Management", Computers, Materials & Continua, vol.71, no.3, 2022.It used Auto-Encoder (AE). This model resolved the security concerns in cloud services for its application in manufacturing sector. Failed to detect more number of attacks by enhancing the features set with more optimal features.[3]

Sajid, M., Malik, K.R., Almogren, A. "Enhancing intrusion detection: a hybrid machine and deep learning approach", Journal of Cloud Computing, vol.13, no.1, pp.123, 2024. This system used XGBoost-LSTM Group-Artificial Bee Colony (G-ABC). It executed more effectively and operated at peak efficiency. Also, it had quick detection speed. This technique prevented overfitting and improved training efficiency. It required more training time due to its complexity. More attacks were not evaluated to further extend the effectiveness of IDS[4].

Gulia, N., Solanki, K., Dalal, S. "Intrusion Detection System Using the G-ABC with Deep Neural Network in Cloud Environment", Scientific Programming, vol.2023, no.1, pp.7210034, 2023. In this paper Group-Artificial Bee Colony (G-ABC) is used. This technique prevented overfitting and improved training efficiency. More attacks were not evaluated to further extend the effectiveness of IDS[5].

Basahel, A.M., Yamin, M."Enhanced coyote optimization with deep learning based cloud-intrusion detection system", Computers, Materials & Continua, vol.74, no.2, pp.4319-4336, 2023. In this paper Enhanced Coyote Optimization with Deep Learning based Intrusion Detection System for Cloud Security (ECODL-IDSCS) was used. It can be utilized as an effectual tool to achieve maximum security in the cloud platform. The performance of the model was not improvised by the use of advanced DL classifiers[6].

Nazoksara, A.G. AutoIDS: A semantic autonomous intrusion detection system based on cellular deep learning and ontology for malware detection in cloud computing", 2024. Semantic autonomous intrusion detection system (SAutoIDS) was used in this paper. The autonomous nature and advanced detection capabilities allowed for quicker responses to attacks, thereby minimizing potential damage. It was capable to produce false positives or negatives, which led to unnecessary investigations or missed threats.[7]

Ogwara, N.O., Petrova, K. et "Towards the development of a cloud computing intrusion detection framework using an ensemble hybrid feature selection approach", Journal of Computer Networks and Communications, vol.2022, no.1, pp.5988567, 2022[8]. In this paper Cloud computing attack and intrusion detection (CCAID) system used. It was able to analyses heavy cloud computing network traffic in real time and detected attack packets with high detection accuracy and a low false alarm rate. It did not include validation of model with other network intrusion datasets.[9].

Challenges in Existing System

The challenges experienced by classical schemes that are collected regarding intrusion detection in cloud computing are described as follows.

DLM designed in [1] for intrusion detection in a cloud computing environment obtained effective results. How ever,this technique was failed to enhance performance and reduce over fitting.In[2], Cu-LSTMGRU model was introduced to improve IDS efficiency with low false alarm rate, though this approach did not address the data imbalance issues to achieve better results. To detect intrusion detection in cloud, XGBoost-LSTMwas presented in[4] with low test accuracy scores, but still it failed to detect a wide range of attack patterns as it did not use fusion methods. G-ABC [5] with the DNN model was used to select best features from the dataset. Nevertheless, this approach did not address the integration of a hybrid deep learning model, which was crucial for ensuring the model's scalability to handle large volumes of network traffic[10]. The increased adoption of cloud computing resources produces major loopholes in cloud computing for cybersecurity attacks. An IDS is one of the vital defenses against threats and attacks to cloud computing. Current IDSs encounter two challenges, namely, low accuracy and a high false alarm rate. Due to these challenges, additional efforts are required by network experts to respond to abnormal traffic alerts.[11]

Motivation

Primary motivation behind XKFHnet for cloud-based intrusion detection is to overcome the limitations of traditional IDS by leveraging the power of deep learning, advanced feature fusion techniques, and fractional networks. This approach aims to improve the detection of sophisticated and evolving cyberattacks, provide scalability for large cloud environments, and reduce false positives to ensure timely and accurate identification of threats in real-time. By incorporating models like Xception and Kronecker Forward Fractional Networks, XKFHnet promises to enhance the performance and reliability of intrusion detection systems in the ever-growing and complex cloud ecosystem.

III. PROPOSED SYSTEM

The **XKFHnet** project aims to develop a cutting-edge intrusion detection system tailored for the unique needs of cloud computing environments. The challenges associated with cloud-based IDS—such as handling large datasets, detecting evolving attacks, minimizing false positives, ensuring real-time performance, and addressing privacy concerns—define the scope of the project. By integrating Xception, Kronecker product fusion, and Forward Fractional Networks, the XKFHnet system offers a novel approach to overcoming these challenges and providing robust security solutions for cloud infrastructures.

The **XKFHnet** (Xception Kronecker Forward Fractional Net) is a deep learning-based model proposed for intrusion detection in cloud computing environments[12]. It combines state-of-the-art techniques from deep learning (Xception architecture), advanced mathematical feature fusion (Kronecker products), and fractional calculus to address the challenges of detecting sophisticated and evolving cyber threats in the cloud.

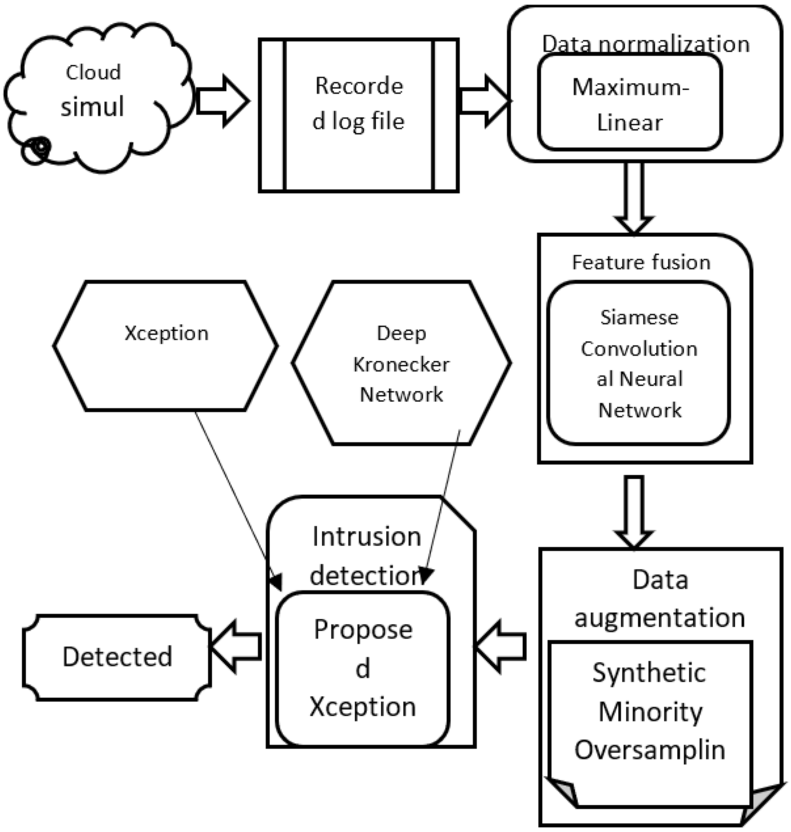

Fig.1.Block diagram of XKFHNet for intrusion detection in cloud

IV. WORKING

In Cloud Computing is the preferred choice of every IT organization since it provides flexible and pay-peruse based services to its users. Cloud Computing represents both a technology for using computing infrastructures in a more efficient way, and a business model for selling computing resources and services. On the other hand, such complex and distributed architectures become an attractive target for intruders. Moreover, the security and privacy are a major hurdle in its success because of its open and distributed architecture that is vulnerable to intruders. IDS is the most commonly used mechanism to detect attacks on cloud. The main aim of this research is to proposeXKFHNet for intrusion detection in cloud. Initially, cloud will be simulated and recorded log file will be taken from specific dataset [13],[14]. Then, data normalization will be carried out utilizing Maximum-Linear Normalization. After that, feature fusion will be conducted employing Siamese Convolutional Neural Network (SCNN) [15] with harmonic mean. Thereafter, data augmentation will be executed using SMOTE based oversampling [16] to enhance dimensionality of data. Next, intrusion detection will be performed employing XKFHNet. However, XKFHNet will be designed by combining Xception and Deep Kronecker Network (DKN) [17], where layers are modified based on Fractional calculus (FC) . Finally, attack mitigation will be conducted to reduce the impact or likelihood of attacks. The proposed XKFHNet will be implemented in PYTHON tool using data set mentioned in it. The performance of XKFHNet will be evaluated regarding metrics namely precision, recall and F1-score[18][19]. Additionally, designed XKFHNet will be compared with existing methods to prove its efficacy. Figure 1 demonstrates the block diagram of XKFHNet for intrusion detection in cloud.

V. APPLICATION

1.Network traffic analysis: IDS can analyze network traffic in real-time to detect threats and generate alerts.

2.Identifying known vulnerabilities: IDS can compare incoming packets against a database of known vulnerabilities to identify active instructions.

3.Threat detection: IDS can enhance threat detection and meet compliance mandates.

4. Threat prevention: IDS can help organizations stay ahead of the curve in threat prevention.

5. Network assurance and security: IDS can provide network assurance and security solutions.

VI. CONCLUSION

In this system we are using Xception Kronecker Forward Fractional Net (XKFHNet) for intrusion detection in cloud to improve detection rates of intrusions while managing the complexities of cloud-based network data. It will perform feature fusion, Siamese Convolutional Neural Network (SCNN)with harmonic mean is used for leveraging the strengths of different features while minimizing their weaknesses, leading to improved accuracy and robustness in predictive models .Also it will conduct data augmentation using Synthetic Minority Oversampling Technique (SMOTE) based over sampling to improve the dimensionality of data.

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Analyzing the Quality of Motorcycle Taxi Services in Agricultural Product Transportation: A Structural Equation Modeling (SEM) Approach

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***Abstract*— *Pinrang Regency is one of the largest rice producers in South Sulawesi Province, Indonesia, where the main occupation of the population is farming. The need for transportation of agricultural products is very much needed and what is used by the farming community is a modified vehicle, namely a motorcycle taxi. This research aims to determine the level of service quality based on characteristics. The research method uses descriptive quantitative based on a questionnaire survey of 130 respondents with the Structural Equation Model analysis model assisted by Analysis Moment of Structure software version 23. The results of the research analysis show that the Service Quality variable has a positive and significant effect on Customer Satisfaction, Service Quality has a positive and significant effect on Customer Loyalty, Price Fairness has a positive and significant effect on Customer Loyalty, Customer Satisfaction has a positive and significant effect on Customer Loyalty, because the Critical Ratio value shows value >1.960 and P-value <0.005 the hypothesis in this research can be accepted, while the Price Fairness variable has no significant effect on Customer Satisfaction because the P-value is 0.612.*

I. INTRODUCTION

Transportation is a supporter of human activities and has become one of the basic human needs that is inseparable from human life itself [1]. Transportation is the activity of moving goods and people from a place of origin to a destination [2] . There are three things related to transportation, namely there is a load to be transported, a vehicle is available as a means of transportation and there is a road that can be used [3]. Factors that influence the level of transportation growth in a region are geographical, economic, technological, social, political and environmental factors [4].

Transportation functions as a supporting and stimulating factor for development and as a service provider for economic development [5] . Rural transportation is transportation that functions to facilitate (reach) rural communities to distribute information and all services in rural areas [6]. Rural vehicles are needed to help productivity and mobilize agricultural products so as to encourage increased economic activity . Previous research showed that the transportation mode for transporting agricultural products, namely motorcycle people in South Sulawesi to transport agricultural products. Apart from that, taxi motorcycles are very good to use, especially during the harvest season so that people modify them or become operators as additional livelihoods apart from being farmers Motorcycle Taxi is an activity of transporting agricultural products using a modified motorcycle. farmers [7].

Choose to use motorcycle taxis because they are able to transport tens or even hundreds of sacks of grain per day depending on the distance and terrain conditions so that the farmer's grain is not damaged due to weeks of rain in the middle of the rice fields [8]. Service quality is a factor that determines the level of success in providing quality services to consumers and as a strategy to defend themselves and achieve success in facing competition [9]. The Servqual dimensions developed have become the basis for the development of service quality, namely tangibles, reliability, responsiveness, assurance and emphaty [10]. The basic meaning of service quality is all forms of activities carried out to meet consumer needs. Meanwhile, service is defined as the service provided by the owner in the form of convenience, speed, relationship, ability and friendliness as demonstrated by attitudes and traits in providing services for customer satisfaction [11]. Service quality is the suitability of product use to meet customer needs and satisfaction, where quality is used as a benchmark [12]

Satisfaction contains significant differences in the definition of satisfaction, all definitions have several elements in common. When examined as a whole, three general components can be identified: 1) customer satisfaction is a response (emotional or cognitive); 2) the response is related to a particular focus (expectations, product, consumption experience); and 3) the response occurs at a certain time (after consumption, after selection, based on accumulated experience) [13] . Customer responses follow a general pattern similar to the literature. Satisfaction consists of three basic components, a response related to a certain focus determined at a certain time. Customer satisfaction is a feeling of pleasure or disappointment that arises after comparing the performance of the product in question with the expected performance . From the definition of whether the service provided does not match the expectations of Go-Ride customers and if the expectations set are too low, then consumers will feel dissatisfied and disappointed, if performance matches expectations then customers will feel satisfied, what is provided exceeds expectations, then customers will feel happy and very satisfied.

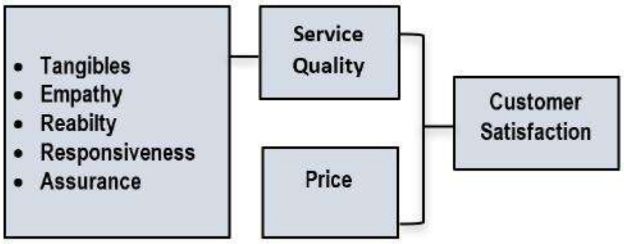

Fig.1. Indicators for measuring consumer satisfaction

There are five factors that cause customers to be loyal to the products/services they use: 1) Brand value; Customer perceptions that compare the costs or prices that must be borne with the benefits they receive. 2) Customer characteristics; In using a brand, each individual has different characteristics from other individuals. 3) Service Quality; [14] . If the customer's perception of the quality of service experienced is of high quality, it will have a positive effect. 4) Customer satisfaction; Related to the consumer's experience when making contact with the brand they use. This factor is very important, but customer satisfaction alone is not enough to cause a customer to remain loyal to a brand. 5) Trust; This concerns the extent of competitive rivalry between beliefs in a product or service category. It can be interpreted that customer loyalty is a strong commitment to repurchase a product or service consistently in the future [15].

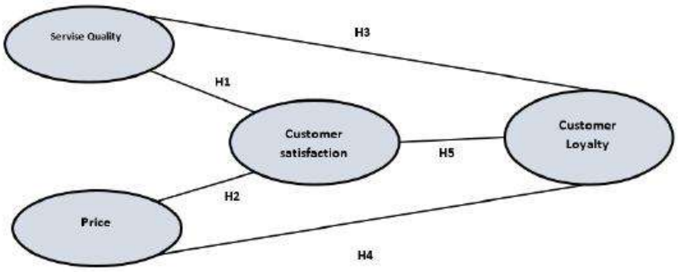

Fig.2. Frame of mind

The relationship between service quality and customer satisfaction : Service quality has a positive effect on customer satisfaction [15]. Customer satisfaction is an independent construct and is influenced by service quality, as well as customer loyalty is influenced by service quality. Pricing is directly related to the income received. Pricing must be appropriate so that consumers can be considered in making decisions when reusing [16]. The relationship between service quality and customer loyalty : Service quality has a positive influence on customer loyalty , stating that satisfaction has a positive influence on customer loyalty also expressed the same thing that satisfaction has a positive relationship with loyalty, however increasing satisfaction does not always result in increasing loyalty to the same degree. The relationship between price and customer loyalty has a positive effect on customer loyalty [17]. States that prices can also be regulated to prevent competitors from entering, to maintain customer loyalty, support repeat sales and so on. Apart from price, service quality also influences customer loyalty, where price has a significant influence on customer loyalty. The relationship between customer satisfaction and customer loyalty has a positive effect on customer loyalty [18] . That customer satisfaction is a factor that influences customer loyalty. where satisfaction has a significant influence on customer loyalty [19]. Customer satisfaction is an encouragement to individual desires which are directed at the goal of obtaining satisfaction [20]. Customers will be loyal to a product or service offered when they get satisfaction from the product or service. This research provides a clearer picture of the positive impacts felt by farmers. Initially modified motorcycles were used by farmers in what were known as taxi motorcycles, these motorcycles were designed for slippery and muddy terrain. Based on several studies that have been conducted in Sidenreng Rappang district, this research aims to find out the level of satisfaction and loyalty of farmers who use motorcycle taxis as a means of transporting agricultural products based on the characteristics of farmers, especially in Pinrang district using Sem Amos analysis.

II. METHODOLOGY

Research Method

This research uses a descriptive quantitative method, namely by looking for information about existing symptoms. Data such as service quality, rates, satisfaction and loyalty were collected through observation, interviews and questionnaire surveys with 130 respondents directly and randomly in the field for 3 to 6 months and then analyzed using Analysis Moment of Structure (Amos) version 23 software. Respondents answered each question variable based on the answer choices given using a Likert scale (Strongly agree, agree, disagree, disagree and strongly disagree [21]

Analysis Techniques

The steps for conducting Sem analysis using the Amos program according to [22] are as follows: 1.) Create a model specification based on theory, then determine how to measure the construct, collect data and then enter the data into the Amos program. 2.) Amos will fit the data into the specified model, then provide results that include all model fit statistics and parameter estimates. 3.) Enter the data which is usually in the form of a covariance matrix of the variables being measured, for example the value of the question items used. Other forms of input can be correlation matrices and averages. Data can be raw data and then converted into covariance and average. 4.) Make estimates according to research needs. 5.) Match the data with the model that has been created.

Fig.3. Motorcycle Taxi Activities

III. RESULT AND DISCUSSION

Respondent Characteristics

Table 1. Respondent Characteristic

Characteristics	Indikator	Percent (%)
Gender	Male	100
	Female	0
Age	< 35	6.9
	36-45	33.8
	46-55	55.4
	> 56	6.9
last education	Elementary school	63.0
	Junior High School	28.5
	Senior High School	6.2
	College	2.3
Job status	Main	73.1
	Side	26.9
Marital status	Married	100
	Single	0
Land area	> 1 Ha	31.4
	< 1 Ha	68.6
Price per-trip	< IDR15.000	79.2
	> IDR 15.000	20.8

Note: US$ 1= IDR15.100 (Indonesian exchange rate 2023)

Based on table 1, the results of the analysis of respondents' characteristics are based on gender, male with a percentage of 100% and female 0%. The age range of 56–65 years with a percentage of 6.9%, 36–45 years 33.8%, 46–55 years 55.4% and 27–35 years 6.9% indicates that the age of farmers is predominantly quite old and only a small percentage is old. still young. The final education level is elementary school with a percentage of 63.0%, junior high school 28.5%, high school 6.2% and College education 2.3% indicating that farmers generally have low education which cannot be absorbed into the formal sector and very few have a bachelor's degree and the farmer sector is used as side jobs other than as a civil servant/private employee. Based on the main job status as a farmer with a percentage of 73.1% and secondary 26.91%. Marital status is married with a percentage of 100% and unmarried 0%. The average area of cultivated rice fields is <1 Ha with a percentage of 68.6% and >1 Ha is 31.4%. Based on the transportation costs for agricultural products per transport <IDR. 15,000, the percentage is 79.2%, > IDR. 15,000 20.8% indicates that the price or transportation costs are still tentative or can change according to the agreement between the farmer and the operator based on the transportation distance and the work carried out individually. group or individual wholesale.

Normality Test

Structural Equation Modeling (SEM) which uses *Maximum Likelihood Estimation* (MLE) assumes that the data is normally distributed. This normality test uses the Multivariate critical ratio criterion of ± 2.58 [23].

Table 2. Normality test

Variable	min	Max	Skew	c.r.	kurtosis	c.r.
CL5	4.000	7.000	,419	-1949	,134	,334
CL4	4.000	7.000	,219	1,019	-,175	-,407
CL3	4.000	7.000	-,287	-1,336	-,692	-1,611
CL2	4.000	6.000	-,134	-,626	-1,088	-2,532
CL1	4.000	6.000	-,618	-2,876	-,776	-1,805
CS1	4.000	6.000	-,293	-1,363	-1,508	-3,509
CS2	4.000	7.000	-,143	-,666	-,972	-2,262
CS3	4.000	6.000	-,453	-2,107	-1,378	-3,208
PF2	4.000	7.000	-,453	,692	-,156	-,363
PF2	4.000	7.000	-,149	,169	-,217	-,505
SQ12	4.000	6.000	,036	,090	-1,283	-2,986
SQ13	4.000	6.000	,019	,492	-1,567	-3,646
SQ9	4.000	7.000	,106	1,035	-,875	-2,038
SQ10	4.000	7.000	,222	,154	-,782	-1,820
SQ11	5.000	6.000	,033	2,208	-1,775	-4,131
SQ7	5.000	7.000	,474	1,657	-1,464	-3,407
SQ8	4.000	6.000	,356	-,501	-1,582	-3,682
SQ3	4.000	6.000	-,108	-,597	-,930	-2,164
SQ4	4.000	6.000	-,128	,845	-,924	-2,151
SQ5	4.000	7.000	,182	,726	-,531	-1,237
-1,950	5.000	6.000	,156	,287	-1,996	-4,646
,765	4.000	7.000	,062	,139	-,286	-,666
SQ2	5.000	6.000	,030	1,302	-1,922	-4,473
Multivariate			,280		13,099	2,202

Based on table 2, the analysis results show that the multivariate c.r value is 2.202. This value is not greater than 2.58 and not less than -2.58, so it can be concluded that the data distribution used meets the normality criteria.

Test the validity of the Price Fairness variable

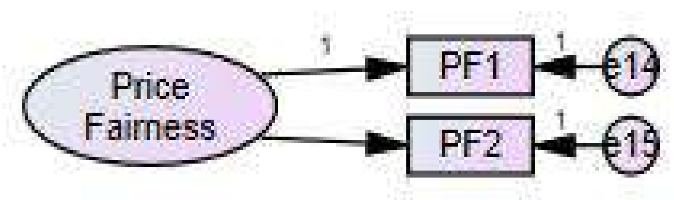

Fig.4. CFA Variable Price Fairness

Table 3. CFA Price Fairness Results

Variabel		Estimate	S.E.	C.R.	P	Label
PF1 <--	Price fairness	1,000				
PF2 <--	Price fairness	,644	,305	2,110	,035	P < 0,05 significant

Based on Figure 4 and the output results shown in Table 3, it is known that the two indicators used to measure the Price Fairness variable have significant P values So it can be explained that all significant indicators are used to measure the Price Fairness variable.

Test the validity of the Customer Satisfaction variable

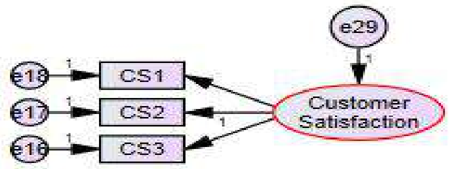

Fig.5. CFA Variable Customer Satisfaction

Table 4. CFA Customer Satisfaction Results

Variabel			Estimate	S.E.	C.R.	P	Label
CS3	<--	CS	1,000				P< 0,05 significant
CS2	<--	CS	1,283	,148	8,672	***	P< 0,05 significant
CS1	<--	CS	,938	,130	7,210	***	P < 0,05 significant

Based on Figure 5 and Table 4, it can be seen that the three indicators used to measure the customer satisfaction variable have a p-value <0.05, so they can be declared significant, so it can be explained that all significant indicators are used to measure the customer satisfaction variable.

Validity test of service quality variables.

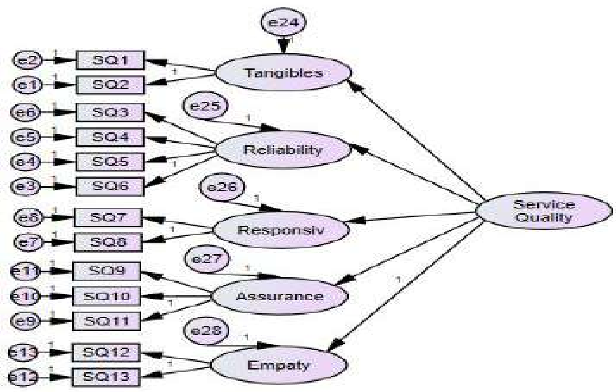

Fig.6. CFA Service Quality Variables

Table 5. CFA Service Quality Result

Variabel			Estimate	S.E.	C.R.	P	Label
SQ2	<--	Tangibles	1,000				
SQ1	<--	Tangibles	,533	,243	2,200	,028	P < 0,05 significant
SQ6	<--	Reliability	1,000				
SQ5	<--	Reliability	1,718	,515	3,336	***	P < 0,05 significant
SQ4	<--	Reliability	1,799	,574	3,135	,002	P < 0,05 significant
SQ3	<--	Reliability	1,897	,594	3,193	,001	P < 0,05 significant
SQ8	<--	Responsiv	1,000				
SQ7	<--	Responsiv	,619	,137	4,532	***	P < 0,05 significant
SQ11	<--	Assurance	1,000				
SQ10	<--	Assurance	1,237	,244	5,076	***	P < 0,05 significant
SQ9	<--	Assurance	1,124	,256	4,385	***	P < 0,05 significant
SQ13	<--	Empaty	1,000				
SQ12	<--	Empaty	,998	,178	5,592	***	P < 0,05 Significant

Based on Figure 6 and Table 5, it can be seen that the thirteen indicators are used to measure service quality variables. Having a p-value <0.05, it can be declared significant, so it can be explained that all significant indicators are used to measure the service quality variable.

Test the validity of the Customer Loyalty variable

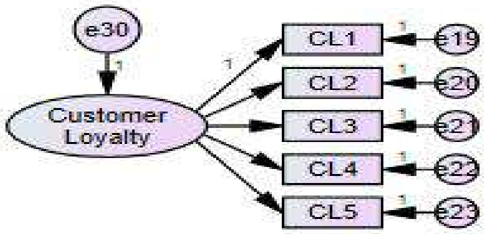

Fig.7. CFA Customer Loyalty Variable

Table 6. CFA Customer Loyalty Results

Variabel			Estimate	S.E.	C.R.	P	Label
CL1	<--	CL	1,000				P < 0,05 significant
CL2	<--	CL	1,378	,376	3,664	***	P < 0,05 significant
CL3	<--	CL	2,353	,667	3,526	***	P < 0,05 significant
CL4	<--	CL	2,368	,699	3,389	***	P < 0,05 significant
CL5	<--	CL	1,770	,545	3,249	,001	P < 0,05 significant

Based on Figure 7 and Table 6, it can be seen that the five indicators used to measure the customer loyalty variable have a p-value <0.05, so they can be declared significant, so it can be explained that all significant indicators are used to measure the customer loyalty variable.

Reliability Test

Table 7. Reliability Test Results

Variable	Indicator	SFL	SFL Kuadrat	Error	Construct Reliability	Variance Extracted
Price Fairness	PF1	0.709	0.502	0.497	0.753	0.604
	PF2	0.745	0.555	0.444		
Service Quality	SQ2	0.962	0.925	0.074	0.926	0.504
	SQ1	0.412	0.169	0.830		
	SQ6	0.382	0.145	0.854		
	SQ5	0.591	0.349	0.650		
	SQ4	0.661	0.436	0.563		
	SQ3	0.661	0.436	0.563		
	SQ8	0.793	0.628	0.371		
	SQ7	0.492	0.242	0.757		
	SQ11	0.561	0.314	0.685		
	SQ10	0.611	0.373	0.626		
	SQ9	0.572	0.327	0.672		
	SQ13	0.724	0.524	0.475		
	SQ12	0.705	0.497	0.502		
Customer Satisfaction	CS3	0.741	0.549	0.450	0.867	0.594
	CS2	0.869	0.755	0.244		
	CS1	0.69	0.476	0.523		
Customer Loyalty	CL1	0.401	0.160	0.839	0.747	0.519
	CL2	0.555	0.308	0.691		
	CL3	0.759	0.576	0.423		
	CL4	0.717	0.514	0.485		
	CL5	0.594	0.352	0.647		

Based on table 7, the recommended values for construct reliability and extracted variance are above 0.70 and 0.50. (Yusuf Haji-Othman et al., 2022). Based on table 8, it can be seen that the reliability testing results show reliable results because the construct reliability value is ≥ 0.70 and the variance extracted value is also ≥ 0.5.

Model Fit Test

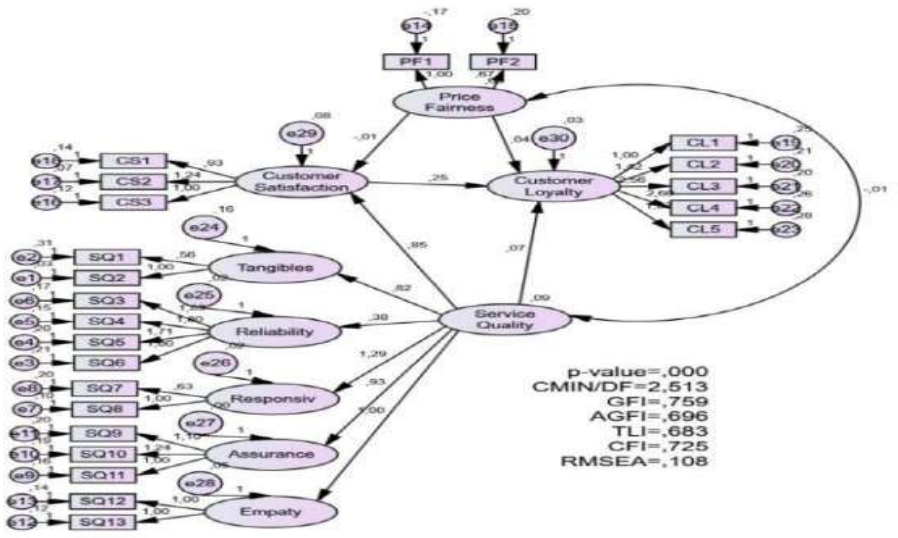

Fig.8. Fit Models

Table 8. Goodness of fit results

Goodness of Fit Index.	Cut off value.	Result	Mode Evaluation
Chi-Square	Expected tobe small	559.6	Good fit
Probability	≥ 0,05	0.000	Marginal fit
CMIN/DF	≤ 2,00	2.555	Marginal fit
GFI	≥ 0,90	0.953	Good fit
AGFI	≥ 0,90	0.908	Good fit
TLI	≥ 0,95	0.676	Poor fit
CFI	> 0,95	0.720	Poor fit
RMSEA	≤ 0,08	0.110	Marginal Fit

Testing the suitability of the model in figure 8 and table 8 shows that the Chi-Square, GFI and AGFI indices meet the cut off value. This can be interpreted as meaning that the model in the figure above has been confirmed by the data or in other words the model is fit. The data used in this research is able to describe the phenomena that exist in the field. In contrast to the probability value of 0.000 which is smaller than 0.05, CMIN/DF of 2.555 which is greater than 2.00, RMSEA of 0.08 which is greater than 0.110, it can be said to be marginal fit. Meanwhile, TLI is 0.676, CFI is 0.720, each of which does not meet the cut off value or is in the poor fit ratio. However, it can be concluded that if there are one or more results from the goodness of fit criteria that meet the cut off value, then the model can be declared fit as a whole. [24].

Table 9. Hypothesis testing

Connection	Estimate	S.E	C.R	P- value	Keterangan
CS <-- SQ	0.848	0.178	4.769	***	Significant
CS <-- PF	-0.014	0.028	-0.507	0.612	Unsignificant
CL <-- SQ	0.554	0.115	2.469	0.039	Significant
CL <-- PF	0.341	0.148	3.095	0.011	Significant
CL <-- CS	0.293	0.136	2.152	0.031	Significant

Based on table 9, hypothesis testing shows that the Service Quality variable has a positive and significant effect on Customer Satisfaction, Service Quality has a positive and significant effect on Customer Loyalty, Price Fairness has a positive and significant effect on Customer Loyalty, because the Critical Ratio value shows a value of >1.960 and the P-value value <0.005 so the hypothesis in this research can be accepted [25]. while the Price Fairness variable has no significant effect on Customer Satisfaction because the P-value is 0.612.

IV. CONCLUSION

Motorcycle taxi transportation is a means that supports successful development in supporting the activities of the farming community in Pinrang Regency, South Sulawesi Province, especially in the agricultural products sector. The use of motorcycle taxi services is the community's main choice to help productivity and mobilize agricultural products. Based on the research results, motorcycle taxi customer loyalty is influenced by the level of satisfaction. Therefore, service quality greatly influences customer satisfaction based on tangibles, reliability, responsiveness, assurance, especially on price or prices perceived by farmers using motorcycle taxis which are adjusted to the services provided such as conditions and distance traveled by the operator.

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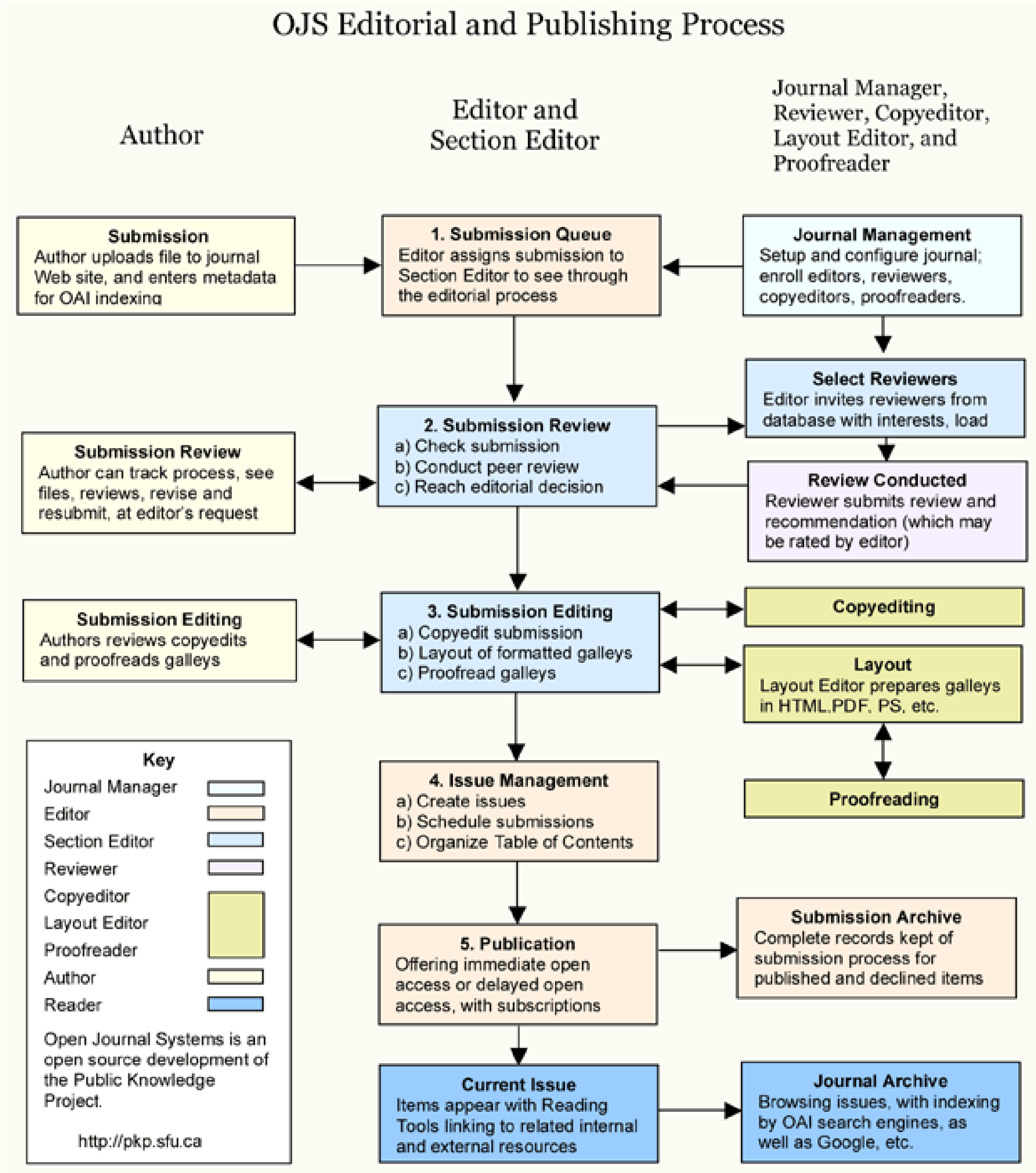

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