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CRITICAL ANALYSIS OF SOLID WASTE MANAGEMENT IN INFORMAL SETTLEMENTS: A CASE STUDY OF LUSAKA'S SHANTY COMPOUNDS

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Abstract: Solid waste management is an essential part of sustainable urban development, especially in cities experiencing rapid urbanization and population growth, such as Lusaka, Zambia. Informal settlements, often referred to as slums, are home to a significant portion of Lusaka's population and are characterized by unplanned development, high population density, and inadequate infrastructure. These areas face serious challenges in solid waste management, including a lack of formal waste collection services, inadequate waste disposal facilities, and limited public awareness of good waste management practices. As a result, inappropriate waste disposal methods, such as open dumping, burning, and littering in public spaces, are common, contributing to widespread environmental degradation, public health risks, and socioeconomic inequalities.

This study aims to critically analyze the status of solid waste management in Lusaka slums, focusing on identifying key challenges, evaluating existing waste management practices, and proposing feasible solutions for sustainable development. Using a mixed-method research methodology, the study integrates qualitative data from interviews and focus group discussions with residents, community leaders, and municipal officials, as well as quantitative data on waste generation patterns, collection coverage, and the effectiveness of current waste management systems. The findings reveal a complex interplay of factors that hinder effective waste management in these enterprises. These include weak governance structures, limited municipal funding, inadequate waste collection infrastructure, and poor road networks that make many areas inaccessible to formal waste collection services.

The study also identifies critical socio-economic factors, such as high levels of poverty and unemployment, that limit residents' ability to pay for waste collection services, thereby exacerbating reliance on informal methods and unsustainable waste disposal. The health and environmental consequences of poor waste management are evident, with increased cases of vector-borne diseases such as malaria and cholera, contamination of water sources, and air pollution from waste burning. Furthermore, the accumulation of waste in public spaces and drainage systems leads to flooding during the rainy season, further exacerbating the vulnerability of these communities.

Despite these challenges, the study highlights several opportunities to improve waste management in Lusaka's slums. Community-based approaches, such as the formation of waste management committees and the employment of local residents to collect and recycle waste, offer a cost-effective and participatory solution. The potential for public-private partnerships is also significant, with private waste management companies playing a central role in complementing municipal efforts.

Technological solutions, including low-cost waste processing technologies such as composting and small-scale recycling, can address the unique needs of these slums while generating economic opportunities. Furthermore, the study highlights the importance of policy reforms to strengthen governance and accountability in waste management. Municipal authorities should prioritize informal settlements in their urban planning strategies and allocate adequate resources for waste collection and disposal. Public awareness campaigns that focus on waste segregation, recycling, and the health risks associated with improper waste disposal are essential to drive behavioral change at the community level.

This research concludes that addressing the challenges of solid waste management in Lusaka slums requires a comprehensive and multi-stakeholder approach. Collaborative efforts involving municipal authorities, community members, private businesses, and non-governmental organizations are essential to develop a comprehensive, efficient, and sustainable waste management system. By integrating policy reforms, community participation, and technological innovation, Lusaka can transform its approach to solid waste management, thereby improving the health, environment, and quality of life of residents in the most vulnerable areas. This study not only sheds light on the specific context of Lusaka, but also contributes to the broader debate on urban waste management in developing cities, providing lessons and strategies that can be adapted to similar contexts around the world.

Keywords: Solid Waste Management(SWM); Informal settlements; Environmental sustainability; Community participation; Urban governance

1 INTRODUCTION

Solid waste management is a fundamental part of urban planning, directly affecting environmental sustainability, public health and social equity. Globally, the challenges associated with solid waste management are increasing, driven by rapid urbanization, population growth and changing consumption patterns. According to the World Bank, urban areas produce an estimated 2.01 billion tonnes of solid waste annually, a figure that is expected to increase to 3.40 billion tone

by 2050 if current trends continue. The strain on existing waste management systems, particularly in low- and middle-income countries, has led to increased environmental degradation, public health crises and resource inefficiency. As cities address these challenges, effective solid waste management has become a critical indicator of sustainable urban development. In Zambia, the situation is no different. Lusaka, the country's capital and largest city, illustrates the complex dynamics of waste management in a context of rapid urban growth. With a population of over 3 million, Lusaka generates significant amounts of waste every day. However, the city's waste management infrastructure is struggling to keep up with the pace of population growth and economic activity. The challenges are particularly pronounced in Lusaka's informal settlements, locally known as slums, which house a significant portion of the city's residents. These areas are characterized by haphazard development, inadequate infrastructure, and limited access to basic services, including waste collection and disposal.

Lusaka's slums are home to some of the city's most vulnerable populations, living in precarious conditions with limited resources. Waste management in these areas is characterized by open dumping, waste burning, and the use of illegal landfills, practices that contribute to a number of environmental and health problems. Residents are exposed to contaminated water sources, air pollution from burning waste, and outbreaks of diseases such as cholera and typhoid. In addition, the accumulation of waste in drainage systems exacerbates flooding during the rainy season, displacing families and disrupting livelihoods. Despite these significant challenges, formal waste management systems are largely absent, forcing these communities to rely on informal and unsustainable practices.

This study aims to critically examine the state of solid waste management in the slums of Lusaka, highlighting the systemic issues that perpetuate poor waste management in these areas. It explores the socio-economic, environmental and institutional factors that contribute to waste management challenges, drawing attention to the intersection between urban poverty and environmental degradation. The research highlights the need for comprehensive and sustainable waste management solutions that address the unique needs of informal settlements while promoting broader urban sustainability.

The context of this study is particularly relevant given the global focus on achieving the United Nations Sustainable Development Goals (SDGs), particularly Goal 11 (Sustainable Cities and Communities) and Goal 12 (Responsible Consumption and Production). Effective waste management systems are essential to achieving these goals, as they play a key role in reducing pollution, conserving resources and improving public health. Focusing on the slums of Lusaka, this research aims to contribute to increasing understanding of urban waste management in developing cities, providing insights and practical advice for policymakers, urban planners and community stakeholders.

Using a combination of qualitative and quantitative research methods, the study analyses current waste management practices, identifies key challenges and proposes innovative, context-specific solutions. These include community-led waste management initiatives, public-private partnerships and low-cost technological interventions. The findings are intended to inform targeted policies and interventions that not only address the immediate challenges of waste management in informal settlements, but also contribute to the long-term sustainability of urban areas in Zambia and beyond.

2 LITERATURE REVIEW

Solid waste management (SWM) has become one of the most pressing urban challenges worldwide, with informal settlements facing unique and acute challenges. Despite advances in waste management technologies and practices, informal settlements remain underserved due to socio-economic, infrastructural and governance constraints. Lusaka, like many African cities, is experiencing rapid urbanization, with informal settlements growing faster than the provision of municipal services. This review critically examines global and local perspectives on SWM, highlighting theoretical frameworks, challenges, innovations and identified gaps.

Global Perspectives on Solid Waste Management in Informal Settlements

Globally, SWM has evolved from simple disposal practices to a more holistic approach that integrates waste reduction, reuse, recycling and assessment. According to Wilson et al. (2012) [1], the global waste generation rate is expected to increase by 70% by 2050, mainly due to urbanization and economic growth in developing regions. This has placed tremendous pressure on existing waste management systems, especially in informal settlements, which are often excluded from formal planning and service provision.

2.1 Socio-Economic Challenges

In informal settlements, poverty and unemployment are at the heart of waste management problems. According to Medina (2010) [2], waste in these areas is often seen as both a problem and a resource. Informal waste collectors play a crucial role in waste management by collecting, sorting and recycling materials. However, they work in hazardous conditions, without legal recognition or social protection. Research by Scheinberg et al. (2016) suggests that integrating informal waste collectors into formal systems can improve efficiency while providing socio-economic benefits.

2.2 Environmental and Health Impacts

The environmental consequences of poor waste management in informal settlements are serious. Dumping and open burning, common practices in these areas, lead to soil and water pollution, air pollution and greenhouse gas emissions. The health impacts are equally worrying, with studies linking poor waste management to outbreaks of diseases such as

cholera and malaria. For example, Ali et al. (2019) found that uncollected waste contributes significantly to public health crises in urban slums.

2.2.1 Innovative approach and community engagement

Community-based approaches have emerged as effective solutions for solid waste management in informal settlements. In Brazil, the Amaralina Cooperative project demonstrated the potential of cooperatives in sustainable waste management while providing livelihoods. Similarly, in India, community-led waste sorting initiatives in Pune improved recycling rates and reduced waste sent to landfills. These examples highlight the importance of involving local communities in the design and implementation of waste management programs.

2.2.2 Solid waste management in the African context

Africa's urban population is expected to double by 2050, with informal settlements accounting for most of this increase. This rapid urbanization poses significant challenges to waste management systems, which are often underfunded and poorly managed. Institutional and governance challenges

Weak governance is a recurring theme in solid waste management research in Africa. According to Boadi and Kuitunen (2003), corruption, lack of accountability and fragmentation of responsibilities among municipal authorities hinder effective waste management. Furthermore, policies often fail to address the specific needs of informal settlements, leaving residents without access to basic services.

In the Kibera slum of Nairobi, the lack of formal waste collection has led to widespread illegal dumping, affecting the environment and public health. Community-based organizations have stepped in to fill this gap, demonstrating the potential of local initiatives to address waste management challenges. Similarly, in Lagos, the introduction of public-private partnerships (PPPs) has improved waste collection rates, but issues of inequality persist as informal settlements are often excluded.

The role of informal waste collectors

Informal waste collectors, often referred to as "garbage pickers," play a central role in the solid waste management landscape in Africa. A study by Nzeadibe (2009) in Nigeria found that these workers contribute significantly to waste recycling and recovery, but remain marginalized in policy discussions. Integration into formal systems can improve recycling rates while improving their livelihoods.

2.2.3 Solid waste management in informal settlements in Lusaka

In Lusaka, Zambia, informal settlements, known locally as slums, are home to a significant portion of the city's population. These areas face serious challenges in solid waste management due to rapid urbanization, inadequate infrastructure, and limited municipal support.

(1) Current waste management practices

Formal waste collection services in Lusaka primarily target wealthy neighborhoods, leaving informal settlements unserved. Residents often resort to burning or dumping waste in open spaces, practices that have serious environmental and health consequences. The Lusaka City Council has made efforts to address these problems through partnerships with private waste management companies, but these initiatives have had limited reach in informal settlements.

(2) Community engagement and participation

Studies have shown that community participation is essential for effective solid waste management in informal settlements in Lusaka. Research by Banda et al. (2020) indicates that residents are willing to participate in waste management programs if they have the right support and resources. However, lack of awareness and education on waste sorting and recycling remains a significant barrier.

(3) Environmental and health impacts

The environmental impacts of poor waste management in Lusaka's informal settlements manifest themselves in the form of blocked drainage systems, flooding and pollution. The health risks are equally serious, with studies linking waste accumulation to outbreaks of cholera and other water-borne diseases [3]. These challenges highlight the need for integrated and specific waste management strategies.

2.2.4 Gap identified in existing research

Despite a growing body of literature on urban waste management, significant gaps remain. Many studies focus on urban waste management in general, neglecting the unique challenges faced by informal settlements. There is a need for more localized research that examines the socio-economic dynamics of waste management in slums, including residents' perceptions and behaviors.

Furthermore, research on the integration of informal waste collectors into formal systems in Lusaka is limited. While global case studies highlight the benefits of such integration, local studies are rare. Furthermore, data on waste generation patterns, collection rates, and disposal methods in informal settlements are insufficient, hindering the development of targeted interventions.

The literature on solid waste management (SWM) provides a multidimensional understanding of the challenges, opportunities and strategies for addressing waste problems in informal settlements. Globally, SWM has evolved from a primarily technical concern to a broader socio-economic and environmental issue, requiring multidisciplinary approaches and comprehensive policies. While the waste hierarchy and systems thinking frameworks provide theoretical foundations for sustainable waste management, their implementation in informal settlements is hampered by systemic inequities, limited resources and governance failures. Studies highlight that informal settlements are disproportionately affected by weak SWM, as these areas are often excluded from formal municipal waste management services, forcing residents to rely on unsafe and environmentally harmful waste disposal practices.

In the African context, rapid urban population growth and the expansion of informal settlements have exacerbated waste management challenges. Governance issues, such as corruption, inadequate funding, and fragmentation of responsibilities among municipal authorities, undermine the effectiveness of solid waste management systems. Furthermore, policies often fail to take into account the socio-economic realities of informal settlements, including the essential role played by informal waste collectors. Case studies from cities such as Nairobi and Lagos illustrate the challenges and potential of local and public-private initiatives, but also reveal persistent inequities in service delivery and resource allocation.

In the informal settlements of Lusaka, similar patterns emerge, with residents facing serious environmental and health risks due to inadequate waste management systems. Studies highlight the reliance on informal waste collectors, who contribute significantly to waste collection and recycling, but who operate without legal protection or official support. Community-based approaches have shown promise in addressing service gaps, but their scalability and sustainability remain limited without broader policy support and resource investment. Furthermore, localized research on waste generation patterns, disposal practices, and community engagement is scarce, making it difficult to design targeted interventions.

The gaps identified in existing research highlight the need for context-specific studies that address the unique challenges of solid waste management in Lusaka slums. These studies should explore the socioeconomic dynamics of waste management, including residents' perceptions, behaviors, and willingness to participate in sustainable programs. In addition, there is an urgent need to integrate informal waste pickers into formal systems, recognizing their contributions and providing them with safe working conditions, fair remuneration, and access to social protection. In conclusion, the literature highlights the importance of inclusive, participatory and multi-stakeholder approaches to waste management in informal settlements. By integrating ideas and contributions from marginalized communities, informal waste workers and local organizations, waste management systems can become more equitable and efficient. For Lusaka slums, addressing these challenges requires not only technical and financial investment, but also a commitment to social justice and environmental sustainability. This study aims to build on the existing literature, provide localized information and practical recommendations for improving waste management in informal settlements in Lusaka, thereby contributing to the academic discourse and practical solutions.

3 METHODOLOGY

This study uses a mixed methods approach to analyze solid waste management (SWM) in informal settlements in Lusaka, focusing specifically on slums. The methodology integrates qualitative and quantitative research techniques to provide a comprehensive understanding of waste management practices, challenges and potential solutions. This approach ensures that the study captures multidimensional aspects of MMN, ranging from technical and environmental issues to socio-economic and governance dynamics.

3.1 Research Design

The study was designed as an exploratory case study, focusing on selected slums in Lusaka. This design allows for an in-depth investigation of MMN in these areas, providing insights into the lived experiences of residents, the role of informal waste collectors and the effectiveness of existing waste management systems. The case study approach is particularly suited to understanding complex issues in specific contexts, as it allows the researcher to explore phenomena in their real-world context.

3.2 Study Area

The research focuses on the slums of Lusaka, which are characterized by high population density, inadequate infrastructure, and limited access to municipal services. These slums were selected because of their significant waste management challenges and their importance for understanding urban environmental issues in Zambia. Specific slums, such as Kanyama, Misisi, and Chawama, were selected as case study sites based on their size, waste generation patterns, and accessibility.

3.3 Data Collection Methods

The study uses several data collection methods to ensure a thorough understanding of the research problem:

3.3.1 Surveys

Structured questionnaires were administered to households in selected slums to collect quantitative data on waste generation, disposal practices and residents' perceptions of solid waste management services. The survey also included questions on socio-economic factors, such as income levels, education and family size, to analyze their influence on waste management behaviors. A sample of 300 households was determined using stratified random sampling to ensure representativeness.

3.3.2 Interviews

Semi-structured interviews were conducted with key stakeholders, including municipal officials, community leaders, informal waste collectors and representatives of non-governmental organizations (NGOs) involved in solid waste

management. These interviews provided qualitative information on the challenges, opportunities and gaps in waste management systems.

3.3.3 Focus group discussions

Focus group discussions were conducted with slum dwellers to encourage dialogue and gather diverse perspectives on waste management issues. Each focus group consisted of 8 to 10 participants, ensuring a balance in terms of gender, age and socio-economic background.

3.3.4 Field observations

Direct observations were conducted to document waste management practices, such as landfills, waste collection methods, and recycling activities. Photographs and field notes were used to record these observations, providing visual evidence and contextual knowledge.

3.3.5 Document analysis

Relevant documents, including municipal waste management plans, policy documents, and reports from NGOs and international organizations, were reviewed to understand the broader institutional and policy context of solid waste management in Lusaka.

3.4 Data Analysis

Data collected through surveys, interviews, focus groups, and field observations were analyzed using qualitative and quantitative techniques:

3.4.1 Quantitative analysis

Survey data were entered into statistical software (e.g. SPSS) for analysis. Descriptive statistics, such as frequencies, means, and percentages, were used to summarize waste generation rates, disposal practices, and socioeconomic characteristics. Inferential statistics, such as chi-square tests and regression analysis, were applied to identify relationships between variables.

3.4.2 Qualitative analysis

Interview transcripts and focus group discussions were analyzed using thematic analysis to identify recurring themes and patterns related to solid waste management challenges, community engagement, and potential solutions. NVivo software was used to code and organize the qualitative data, ensuring systematic analysis.

3.4.3 Triangulation

To improve the validity and reliability of the results, data from multiple sources were triangulated. For example, survey results on waste disposal practices were combined with field observations and interview responses.

3.5 Ethical Considerations

Ethical approval for the study was obtained from the relevant institutional review board. Participants were informed about the purpose of the study and informed consent was obtained prior to data collection. Anonymity and confidentiality were maintained by assigning unique codes to participants and storing data securely. Particular attention was paid to ensuring that vulnerable groups, such as informal waste pickers, were not exploited or stigmatized during the research process.

3.6 Study Limitations

The study acknowledges several limitations, particularly the risk of bias in self-reported data from the survey and interviews. Furthermore, the focus on specific slums may limit the generalizability of the findings to other informal settlements in Zambia or elsewhere. However, these limitations are mitigated by the use of multiple data collection methods and a robust analytical framework.

This methodology provides a rigorous framework for studying solid waste management in the slums of Lusaka. Combining quantitative and qualitative approaches, the study aims to capture the complexity of waste management issues and contribute to the development of sustainable, comprehensive and context-appropriate solutions. The inclusion of community voices and multi-stakeholder perspectives ensures that the findings are grounded in the realities of the study area and aligned with broader policy and academic discourses.

4 DISCUSSION

The findings of this study highlight the significant challenges associated with solid waste management (SWM) in Lusaka slums, emphasizing the interaction of socio-economic, environmental, and institutional factors. These challenges are not unique to Lusaka, but reflect broader trends in urban centers in developing countries, where rapid urbanization and population growth have outstripped the capacity of municipal waste management systems. The discussion summarizes these findings, connects them to existing literature, and explores their implications for policy and practice.

One of the critical observations of the study is the inadequate infrastructure and limited municipal services in Lusaka slums. Residents rely heavily on informal waste disposal methods, such as dumping and open burning, which contribute to environmental degradation and public health risks. These findings are consistent with those of Hoornweg and Bhada-Tata (2012), who found similar difficulties in informal settlements around the world. The lack of adequate waste

collection systems not only exacerbates pollution, but also disproportionately affects vulnerable populations, especially children and the elderly, who are more susceptible to diseases caused by poor waste management practices.

The role of informal waste collectors was an important theme of the study. These people play a crucial role in waste management, especially in areas that are poorly served by municipal services. However, their efforts are often underfunded and operate in dangerous conditions without recognition or legal support. This finding supports the findings of Scheinberg et al. (2016), who advocate integrating informal waste workers into formal systems to improve waste management efficiency and secure livelihoods. The study suggests that formalizing these workers can improve waste collection rates while addressing social equity issues.

Community participation has been identified as a key factor in effective waste management. The study found that residents are willing to engage in waste management initiatives if they have adequate resources and education. These findings echo those of Chaturvedi (2019), who highlighted the success of community-led waste sorting programmes in India. However, lack of awareness and financial constraints often hinder such initiatives in the slums of Lusaka. Overcoming these barriers requires targeted interventions, such as public awareness campaigns and subsidies for waste management tools and services.

The study also highlights the need to improve governance and institutional capacity. Fragmentation of responsibilities among municipal authorities, coupled with limited funding and corruption, has led to inefficiency in solid waste management. These findings are consistent with those of Boadi and Kuitunen (2003), who identified governance issues as a major obstacle to effective waste management in African cities.

Strengthening institutional frameworks and ensuring accountability are essential steps to address these challenges. Public-private partnerships, such as those seen in Lagos and Nairobi, offer a promising model for improving service delivery in informal settlements. Finally, the study highlights the environmental and health impacts of poor waste management. Uncollected waste contributes to flooding, land and water pollution, and greenhouse gas emissions. These results are consistent with those of UNEP (2018), which documented the global environmental consequences of inadequate waste management. In Lusaka, health risks associated with poor waste management, including cholera outbreaks and respiratory diseases, highlight the urgency of addressing this issue.

In conclusion, the discussion reveals that solid waste management in informal settlements in Lusaka is a complex problem that requires multi-stakeholder collaboration, community engagement and innovative solutions. Although the challenges are significant, the study identifies opportunities for improvement through the integration of informal waste collectors, increased community participation and strengthened governance. These findings contribute to the wider discourse on solid waste management in developing countries and provide actionable insight for policy makers and practitioners seeking to address the challenges of waste management in settlements informal urban.

5 THEORETICAL FLAMEWORK

The theoretical framework of this study is based on systems thinking and the waste management hierarchy, which together provide a comprehensive perspective for analyzing solid waste management (SWM) in informal settlements. These frameworks allow for the examination of SWM as an interconnected system influenced by social, economic, environmental and governance factors. This approach is particularly relevant in the context of Lusaka slums, where waste management issues are deeply rooted in broader urbanization and socio-economic challenges.

The waste management hierarchy, widely accepted as a fundamental model of SWM, emphasizes the priority of waste reduction, reuse and recycling over disposal. This hierarchy supports several global strategies aimed at achieving sustainable waste management. However, its practical implementation in informal settlements is often limited due to insufficient infrastructure, lack of public awareness and resource constraints. In these contexts, the model serves more as an aspirational framework, guiding the identification of gaps and opportunities for improvement, rather than prescribing specific interventions.

Complementing the hierarchy, systems thinking provides a holistic approach to understanding the complexity of waste management in informal settlements. Systems thinking recognizes that waste management is not an isolated problem, but is part of a broader urban ecosystem that includes social behaviors, economic activities, governance structures and environmental impacts [3]. For example, inadequate waste collection services in slums are linked to governance inefficiencies, which in turn affect residents' waste disposal practices and exacerbate environmental degradation. This interdependence highlights the importance of integrated, multi-stakeholder solutions that address root causes rather than symptoms.

The study is also informed by social capital theory, which emphasizes the role of community networks and collective action in addressing common challenges. In the context of solid waste management, social capital is evident in informal networks of waste collectors, community-led clean-up initiatives, and the willingness of residents to participate in waste management programs. The use of these networks can improve the effectiveness of solid waste management interventions by fostering trust, cooperation, and shared responsibilities among stakeholders [4].

In addition, the study considers environmental justice theory, which emphasizes the equitable distribution of environmental benefits and burdens. Informal settlements such as those in Lusaka are often marginalized in terms of access to municipal services, including waste management, leading to disproportionate exposure to environmental hazards. This theoretical perspective emphasizes the need for comprehensive policies that address the systemic inequalities faced by slum dwellers [5].

By integrating these theoretical perspectives, the study provides a solid framework for analyzing the multidimensional challenges of waste management in informal settlements in Lusaka. This approach not only deepens our understanding of the dynamics of waste management, but also informs the development of targeted, sustainable, and equitable solutions [6].

6 RESEARCH GAP

Despite the growing recognition of the importance of solid waste management (SWM), significant gaps remain in understanding and addressing the unique challenges faced by informal settlements, particularly in sub-Saharan Africa. Most existing research focuses on urban waste management at the municipal or national level, often generalizing challenges without delving into the specific and localized problems of informal settlements. These areas, characterized by high population density, inadequate infrastructure and poverty, face unique waste management challenges that require tailored solutions.

However, there is a lack of detailed studies that explore the socio-economic, environmental and cultural factors that influence waste management behaviors and practices in such contexts.

This gap limits the development of interventions that correspond to the lived realities of informal settlement residents. Insufficient attention is paid to the informal waste sector. Informal waste collectors and recyclers play an important role in waste management in slums, often compensating for the inadequacy of formal municipal services [7]. However, their contribution remains undervalued and research on how their work can be formalized and integrated into structured solid waste management systems is limited. Studies rarely examine how their inclusion can improve the overall efficiency of waste management and bring social and economic benefits, such as job creation and improved livelihoods.

This lack of attention to the informal sector leaves an important part of the solid waste management process unexamined and unsupported. Community participation in solid waste management is another underexplored area. While many studies emphasize the importance of local community participation in waste management processes, little research has been conducted on the specific barriers to participation in informal settlements. Factors such as lack of awareness, financial constraints, and lack of trust in municipal authorities often hinder community engagement. Research rarely examines strategies to mobilize and sustain resident participation, particularly in contexts where resource constraints and competing priorities significantly impact their willingness and ability to engage in solid waste management initiatives. Furthermore, the intersection between governance and solid waste management in informal settlements has not been sufficiently addressed in the literature. Governance issues such as fragmentation of responsibilities, insufficient funding and lack of policy implementation compound the challenges of waste management [8]. However, little research has been conducted on how these systemic issues interact with the socio-economic dynamics of informal settlements to perpetuate inefficient waste management practices. Furthermore, innovative governance models, such as public-private partnerships and decentralized waste management systems, remain unexplored in the context of low-resource settings.

Finally, while the environmental and health impacts of poor waste management are widely recognized, the long-term implications for informal settlements have not been studied in depth. Most studies highlight immediate risks, such as pollution and disease outbreaks, but few examine how prolonged exposure to inadequate waste management practices affects the well-being of these communities over time. Furthermore, there is a lack of research on how emerging approaches, such as circular economy principles and climate-resilient waste management strategies, can be adapted to the specific needs and constraints of informal settlements.

These gaps highlight the need for comprehensive and localized research that bridges the gap between academic discourse and ground realities. By filling these gaps, future studies can contribute to the development of comprehensive, sustainable, and context-specific solutions for solid waste management in informal settlements, thereby improving environmental outcomes and the quality of life of marginalized urban populations.

7 CONCLUSION

Solid waste management (SWM) in informal settlements, particularly in rapidly urbanizing areas such as the slums of Lusaka, represents a fundamental challenge that requires multidimensional and localized solutions. These areas are disproportionately affected by inadequate waste management systems, leading to severe environmental degradation, public health risks and socio-economic inequality. This study has highlighted the complexity of SWM in such contexts, where the interplay of poverty, limited infrastructure, weak governance and cultural practices create unique barriers to effective waste management. Addressing these issues requires a comprehensive approach that prioritizes the needs and capacities of marginalized communities.

7.1 One of the Main Conclusions of This Study is the Important but Undervalued Role of the Informal Waste Sector

Informal waste collectors and recyclers play a vital role in the solid waste management process, often filling the gap left by inadequate municipal services. Their efforts contribute to waste collection and recycling, thereby reducing the overall burden on the environment. However, the lack of formal recognition and integration of these actors into official waste management systems limits their impact and sustainability. Formalizing their role through supportive policies,

training and access to resources can not only improve their efficiency, but also create economic opportunities and improve their livelihoods.

7.2 Community Participation has Emerged as Another Crucial Factor in Improving Solid Waste Management in Informal Settlements

The study highlighted that active participation of residents in waste management initiatives leads to better waste sorting, collection and disposal practices. However, barriers such as low levels of awareness, financial constraints and distrust of local authorities prevent sustainable participation. Overcoming these barriers requires targeted interventions, including community education programmes, awareness campaigns and the provision of affordable waste management solutions. Empowering communities to take ownership of solid waste management can foster collective responsibility and ensure the long-term success of interventions.

7.3 Governance and Institutional Capacity also Play a Central Role in Addressing the Challenges of Solid Waste Management in Informal Settlements

The study found that fragmentation of responsibilities across government agencies, insufficient funding and weak policy implementation exacerbate waste management problems. Strengthening governance structures and fostering cooperation among different stakeholders are essential to overcome these challenges. Innovative governance models, such as public-private partnerships and decentralized waste management systems, offer promising avenues for improving efficiency and accountability. These models can also facilitate resource mobilization and ensure that waste management efforts are tailored to the specific needs of informal settlements.

7.4 The Environmental and Health Consequences of Inadequate Waste Management in Informal Settlements Cannot be Overstated

Poor waste management contributes to pollution, the spread of disease and increased vulnerability to environmental hazards, disproportionately affecting already marginalized populations. Long-term strategies that integrate environmental sustainability and public health considerations are essential. Adopting circular economy principles, which focus on reducing waste and maximizing resource use, can provide sustainable solutions while mitigating environmental impacts.

7.5 This Study Highlights the Urgent Need for Comprehensive and Context-Specific Approaches to Waste Management in Informal Settlements

Effective solutions must integrate informal waste management actors, promote community participation, strengthen governance and adopt innovative and sustainable practices. Bridging the gap between research and practice, this study provides valuable insights into the broader debate on sustainable urban development and waste management. Policymakers, practitioners and stakeholders should prioritize inclusive and participatory strategies to transform solid waste management systems, ensuring environmental sustainability and improving the quality of life of the most vulnerable urban populations. Through collective efforts and targeted actions, it is possible to create resilient waste management systems that address the unique challenges of informal settlements.

COMPETING INTERESTS

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ETHICAL HRM IN THE ERA OF DIGITALIZATION- KEY CHALLENGES IN THE EVOLVING ROLES OF HRM

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Abstract: Challenges in ethical HRM practises are emerging due to the introduction of new technologies like automation, artificial intelligence, machine learning, Big Data, robotics and etc. HRM has transformed due to digital technologies like artificial intelligence which has the threat of leading to inequality. It is essential to discuss ethical HRM in the current era of digitalisation, because the HRM process itself has become data-based and digitalised which uses employee data for key processes like recruitment, selection, appraisal etc. This research will explore: what are the challenges presented to HRM to stay ethical in the era of digitalisation and how they can be overcome? There five identified findings, including the negative impact on the well-being of employees, the threat to autonomy and fairness, the threat to data protection and data privacy issues, ethical issues in gig economy and a lack of human touch and resistance from employees. Ethical issue of bias and discrimination might arise from the algorithms used in digital HRM tools and there is threat for data privacy and need for protecting sensitive employee data. Digital era business model, gig economy and its workers face many unethical issues which can be eliminated mainly by adherence to regulations and rules laid down by governments.
Keywords: HRM; Ethics; Digitalisation; AI

1 INTRODUCTION

Traditionally, Human Resource Management (HRM) and ethics focus on the moral treatment of workers or employees and a firm's stakeholders. Ethical HRM was perceived to be based on rights theory where the fundamental rights of stakeholders like liberty to negotiate or freedom of association, right for safety and appropriate salary, collective bargaining, equality in workplace and etc. Ethical HRM is not just about planning and acting in the welfare and interests of the organisation's employees and furthering their development and welfare, but also in engaging them in decision-making related to their needs and interests [1]. As stated by the authors, ethical HRM traditionally was about protecting the interests of the stakeholders. In the era of modern technologies and rapid digitalisation, HRM is practised based on 3Ds, namely, "distancing, depersonalising and dissembling". It has evolved to address the moral requirements of the organisation and its business [2]. It is essential to discuss ethical HRM in the current era of digitalisation, because the HRM process itself has become data-based and digitalised which uses employee data for key processes like recruitment, selection, appraisal etc. Ethics and HRM in a modern day highly digitalised organisation might face challenges related to ethical concerns [3]. Ethical HRM in modern day business environment has become a challenge as new types of work cultures have evolved such as remote working especially after Covid-19 pandemic.

This research will discuss the following research question: What are the challenges presented to HRM to stay ethical in the era of digitalisation and how they can be overcome?

Literatures from academic and research journals and real-time examples will be presented to discuss the topic. Significance of this research question is based on the current advancements in digital technologies and advent of remote working after the occurrence of Covid-19 pandemic.

The digitalisation of HRM processes is about implementing and utilising information technologies, AI, data technologies and etc. for speeding up and effective HRM processes, be more productive and reduce cost [4]. The digitalisation of HRM processes is used more effectively in recruitment process, training and development, appraisal, performance evaluation etc. For instance, Unilever has developed digitalised HRM process for recruiting employees which uses AI technology and has a digital platform providing training and development for its employees [5].

It has become important to discuss the challenges in ethical HRM practises because of the introduction of new technologies like automation, artificial intelligence, machine learning, Big Data, robotics and etc. These digitalisation technologies have ensured innovation, effective resource utilisation in HRM for better performance [6]. Varma et al. [7] also highlighted the need for analysing modern day HRM from ethical perspective as HRM has transformed due to digital technologies like artificial intelligence which has the threat of leading to inequality and there is a challenge for monitoring equality and fairness in HRM processes that are aided by artificial intelligence technologies. In modern day HRM practises, ethical and moral practises are questioned because many companies engage in surveillance of their employees using "bossware" which is also of ethical concern [8]. HRM in a virtual work environment and related ethical issues related to technology, people and culture must be analysed [9].

2 LITERATURE REVIEW ON THE DIGITALISATION OF HRM

The digitalisation of HRM became imperatively essential as information technologies rapidly transformed the way business was conducted and such technologies were also introduced into HRM. The digitalisation of HRM transformed the processes in HR management, its function and structure of HR departments and HR managers' activities. The digitalisation of HRM has provided the advantage of reducing HRM cost as use of technologies have reduced the need for more HRM personnel to manage employees. It helps organisations to respond quickly during challenges like pandemics. It can also provide more flexible and adaptive work cultures like remote working facilities to employees and ensure productivity and efficiency in HRM processes, as it can make use of employee data for data-based decision making, automate routine processes like data management, recruitment, remuneration system etc. The digitalisation of HRM processes is being practiced in the form of e-recruitment which involves online advertisement, pre-screening, application submission and processing and on-boarding of new recruitments etc [10]. It helps in access to information on time, tracking the applicants, e- payroll system, and e-performance management which includes turn-over report, score card, performance appraisal etc. It also provides e-training which includes skills inventory, training and skill development interventions, e-modules etc.

The digitalisation of HRM can save costs, as it can handle and manage employees of a global firm more efficiently [11-12]. Digitalisation enhances the efficiency of HRM personnel as it provides appropriate data for them to analyse resumes, select candidates based on data. The digitalisation of HRM lowers the interference in recruitment, selection or appraisal process by bureaucracy or favouritism. Digitalisation has allowed employees to feel connected with their company and has formed new channels of communication and interaction with the firm. Further, employees stay motivated as their performance is digitally monitored and they enhance their performance in projects they are involved. More importantly, the digitalisation of HRM has its advantage of simplifying HRM processes and making it faster. For instance, KPMG Belgium has implemented digital HRM process for employee on- boarding especially for young employees who are fresh to a job. This digital process of on-boarding sends practical and company related information on the first day of their job and contact details in their departments and HR. Employees expressed 4.45/5 score for digital hiring and on-boarding process. Similarly, UK's Anchor Group which is an NGO, has digitalised recruitment process and has developed a Chatbot in Facebook Messenger where they interact directly with the candidates. This has reduced the cost of recruitment by 65% and average candidates who apply to Anchor Group increased by 82% [13].

Prokopenko et al. [14] discussed the advantages and disadvantages of the digitization of HRM and how it impacts positively and negatively on personnel management. The authors analysed digitised HRM processes like applicant tracking system, online on-boarding, learning management system, social media platforms, performance management system, employee engagement system, HR analytics tools etc. The key advantages of digitalisation of HRM processes are time-saving, efficiency in management, wide reach of communication, cost-effectiveness, appropriate talent acquisition, scalability of training modules, skill development and exceptional training and learning experience for employees, data-driven performance assessment, enhanced and progressive work culture and rapid feedback for performance enhancement and strategic planning and predictive analysis of human resource management as shown in below Figure 1. Likewise, the authors listed out the disadvantages of digitalisation of HRM processes and they state that digitalisation might lead to possible discrimination and bias towards candidates and bias due to program algorithm. There will be over-reliance on technology for management of resources. There might be skill gap and time-consuming training and new skill development to work on new HR technologies. Employees may have scepticism over the HR tools used. This might even develop resistance among employees. Key challenges are digital fatigue, threat to data privacy, and technology integration issues.

The negative consequences of digitalisation of HRM might lead to ethical issues like data security or data leak of sensitive employee information [11]. It was found that employee's privacy might be impacted [15]. The digitalisation of HRM and the automation of process might lead to improper assessment of employees due to faulty algorithms [11]. Digitalisation involves high cost on software licences and cost on training employees. There might be lack of suitable skills to work on latest HRM software. The disadvantages of HRM digitalisation like high cost, threat of cyber-attack and data in-security might lead to employee confidentiality violation [16]. Digitalisation has lessened personal interaction among employees which might impact their team work or mental health or engagement with the firm [17].

3 CHALLENGES FOR ETHICAL HRM IN THE ERA OF DIGITALISATION

3.1 Negative Impact on the Well-being of Employees

The digitalisation of HRM has both positive and negative impact on the psychological and physical well-being of employees [12]. Employees have stated that while digitalisation of HRM has allowed convenience of remote working, flexible timing, effective communication etc., it has also impacted their health due to long hours of physical inactivity, psychological fear of being monitored, loss of data, cyber-attack etc. It can be inferred that employees have recognised the advantages of digitalisation of HRM and also the negative impacts on them personally due to digitalisation of HRM process. For instance, in Amazon, the digitalisation of HRM has allowed the management to constantly monitor their employees using surveillance system which has created paranoia among employees. While such digital HRM technologies to monitor help organisations to enhance employee productivity, ensure adherence or compliance with standards and ensure safe and secure work environment, it breaches the basic human rights of employees [18].

Self-determination theory will be appropriate to explain the ethical impact of the digitalisation of HRM. Self-determination theory proposed motivation of human being which determines their well-being. As per self-determination

theory, well-being of individuals emerges if they are able to satisfy their psychological needs, including 'need for competency, need for autonomy and need for social relatedness' [19]. Based on this theory, it can be stated that digitalisation of HRM will satisfy their needs for flexible work timing and place, which can enhance their competency and also provide work-life balance and allow them to transform their capability to be effective and competitive. But on the other hand, it might hamper their efficiency by putting more pressure on the employees regarding constant skill development, extended work timing, and the threat of possibility of being replaced. As per self- determination theory, the digitalisation of HRM has both positive and negative aspects on employees. It is critical to consider and address the negative impact on the staff well-being.

3.2 Threat to Autonomy and Fairness

The digitalisation in HRM process of talent acquisition has triggered ethical issues related to autonomy of employees, utility, and fairness [20]. Those emerging technologies in HRM has pressurised values like the privacy of employee data, autonomy, and balance of power [21]. Technologies in HRM has created tension between the benefits of using digital technologies in HRM and autonomy, because transparency of employees in making autonomous choices or decision making and control over the HRM process is lessened due to digitalisation. There is an ethical threat of instrumentalising employees which might result in dehumanisation and lack of social experiences and competences. For instance, employees might lose their autonomy when the organisation uses tools to track their activities and interactions on social media. People analytics which is digitalised HRM process to manage and control employees or workforce might help managers and employees to be knowledge intensive, adaptive, collaborate data to make decisions and be autonomous [22]. But in reality, digitalisation of HRM curtails autonomy of employees and employees lose their individuality and function without interaction with other fellow employees and less interaction with teams and collaborative activities [23]. Employees autonomy and cognitive learning becomes questionable as decision-making is replaced by technology.

Autonomy indicates 'the feeling of choice and concurrence with one's actions' (p. 2) [24]. In a work environment, autonomy will refer to 'the degree to which a job provides discretion over daily work decisions, such as when and how to do tasks' (p. 664) [25]. Based on rights-based ethical theory, basic human rights of employees must be honoured and one party must not over-power the other to cause dissatisfaction [1]. In the case of the digitalisation of HRM, threat to autonomy of employees to execute their decision without over involvement of a digital system can be seen as a threat to rights of individuals. Rights-based theory will also explain any threat to privacy, data theft, issue in data confidentiality etc [26]. The digitalisation of HRM will have positive impact on autonomy of employees and their performance by providing knowledge [27]. On the other hand, digitalisation technology in present era is also used for monitoring the employees [28-29]. Such surveillance impacts and decrease employees' autonomy of working freely and causes stress on them. Digitalisation has also elevated managerial control by emphasising adherence to work routines and procedures which again brings down employee autonomy. As employees are closely monitored and experience managerial control, their autonomy is impacted [30].

Ethical issues of unfairness might also emerge due to digitalization [20]. For instance, the use of new forms of user-interfaces on digital HRM platforms might be challenging for the candidate who is not familiar or unexperienced. While there are solutions to handle fairness through digital technologies and algorithms and software like HireVue to reduce bias and ensure fairness and diversity, unfair discrimination or unfair competition, unfair advantage to those who apply for a job through certain channels, unfair advantage to people who are familiar to digital HRM tools even though that technical skill is not needed for the job. Moreover, digital HRM tools like chatbots might also cause ethical issue of giving tension or poor experience or unpleasant interaction for candidates.

The use of technologies like AI in HRM is not unethical per se but such digital technologies like AI will rise ethical issues in autonomy, validity, privacy, discrimination and transparency [31]. The digitalisation of HRM might attract ethical issues such as the lack of social intelligence or empathy in the system, over-dependence on HRM system for decision-making which minimises autonomy and increases dehumanisation of processes in HRM, possibility of discrimination and bias due to the algorithms, lack of total data protection etc.

3.2.1 Algorithmic HRM and ethical issues

Algorithm in digital technologies like AI in HRM has been considered to increase fairness, transparency, and objectivity in HRM decision-making process [32]. But the ethical question of who will take responsibility for mistakes or failures increases the opacity of digitalisation of HRM because it paves way to asymmetry in information gathered, imbalanced power structures in the organisation and develop negative perception about the organisation's procedure and fairness in treating employees. More often miscalculations and poor interpretation of employee performance data will raise ethical questions [33]. As a waterfall effect, if employees perceive that the digitalised HRM and its algorithm treats them unfairly, they will also engage in unfair attitude and behaviour [34]. Further, digitalisation of HRM might make employees to feel powerless and legal uncertainty and incapacitated by digital technologies in HR management [35]. More importantly, considering employees as "quantifiable data objects" for HR management processes and not as social being is highly unethical [33].

Aalgorithmic HRM is increasingly being implemented in digitalised HRM activities like HR development and HR selection process [36]. It is an automated and data-based decision-making system. It is advantageous in identifying unrecognised talents within the organisation and also from outside. Many companies like SAP, Google, Microsoft etc. use AI supported with algorithm for HR processes. Algorithmic HR process has the threat of being unfair and

discrimination. Discrimination is explained as "unequal treatment" based on various factors [37]. If algorithmic HR system is fed with improper information or dataset, it might cause discrimination in selection process and biased decisions [38]. For instance, unfair and biased decision was taken by digitalised and AI-supported HRM system of Amazon. Amazon's HR system tracked performance of employees constantly and the algorithm of the HR system automatically fired employees [39]. This is an unethical HR decision which involved unfair treatment of employees by Amazon.

Digital HRM technologies and their algorithms might lead to discrimination towards specific racial groups and this is ethically debatable [40]. Opaque or unclear algorithms might exclude certain candidates which might be unethical. For example, Black employees in Facebook have brought racial discrimination in the global social media firm in many HRM practices like performance evaluation, remuneration and promotions [41]. Technologies like AI in HRM would be rigged and programmed to benefit certain groups or individuals which is gain highly unethical [7]. On the other hand, digitalisation will eliminate discrimination and will ensure that the HRM system adheres to HR regulations in providing minimal wages, employee safety, employee rights, health benefits etc [42]. The author also highlights the use of virtual reality technology in HR recruitment process which will help in minimising bias and extends opportunities to disadvantaged candidates. For instance, Jet.com and Deutsche Bahn use virtual reality technology in HRM for giving the candidates a view about the company and insight into their job role. Such technologies develop positive perception among the candidates about the company.

Algorithm-based decision-making in organisations for HRM is considered to reduce cost, minimise risks, enhance productivity. For instance, Deloitte has implemented algorithm-based HRM decision-making system which manages and evaluate every application based on certain requirements for every job and it is stated to aid in fair and unbiased decision-making in HRM [43]. But if the digital technologies like AI or machine learning are fed with inaccurate, biased, and unrepresentative datasets, it might give out biased suggestions to HR managers. An example for bias from digitalised HRM is of Amazon. Amazon's HRM system was biased and discriminatory towards female applicants and after criticisms Amazon erased the algorithm in hiring process [36].

The bias and discrimination caused due to algorithm in digital technologies like AI or Big Data and data analytics can be explained using Statistical Discrimination theory. Statistical discrimination theory is about "prejudice from assessment criteria that generalize group characteristics to individuals" (p. 2) [44]. The bias or prejudice might emerge due to the analysis technique used by the firm or constraints in financial resources or asymmetry between the job seekers and the employer. In a digitalised HRM environment which uses AI might make use of dataset which will result in discrimination in hiring based on race or gender etc.

Based on Kantian deontological ethical theory, individuals have to be judged or evaluated based on their actions and performance. Subjugating employees to the digital technologies and their algorithm can be considered to be unethical and undignified [7]. When digitalisation of HRM results in bias or discrimination, the ethics of the firm and their moral values become questionable. Further, based on Rawlsian Justice theory, fairness and equality are important in digitalisation technologies like Big Data and AI. This ethical theory proposes consideration for less-privileged groups of people. Thus, digitalisation of HRM has to ensure that it utilises data to eliminate social inequality in workplace [45].

Algorithm-based HRM is said to impact personal integrity of employees where personal integrity refers to consistency in their words and reflection in their work [46]. The authors argue that algorithm-based digitalised HRM will alter the balance between integrity of employees and compliance and it will make them blindly adhere and trust the rules and processes fed in the digital HRM system. This will marginalise the employees' sense-making or creative thinking in critical decision-making situations. This is because there is lack of moral or creative dimensions in algorithms which might crowd-out integrity of employees and will adapt to just compliance with processes. There are many companies like Xerox, JP Morgan, IBM, SAS etc. who have benefitted from algorithm-based HRM. But, Uber's algorithm-based HRM has increased the imbalance among the drivers and management in sharing information and this has decreased the control over decision-making for the Uber drivers [47]. This has increased pessimistic feelings among the drivers and mistrust over the company. A case study on drivers of Ubers showed that algorithm-based digitalised HRM has decreased autonomy of Uber drivers in decision-making and they have shown resistance to such algorithms [48].

3.3 Threat to Data Protection and Data Privacy Issues

Digital technologies like AI and social media platforms have allowed firms to monitor on and off-duty communication of their employees [49]. AI can be used to perform wide swipe of multiple channels like social media to penetrate into their posts, likes and shares. While such intrusions might help in mitigating racist post or comments or conduct or harassment in workplaces and monitor sharing of sensitive and priceless business data by employee to competitors etc., but still, it shows intrusion into the privacy of employees. The digitalisation of HRM which paved way for flexible remote working environment for organisation eroded the boundaries between work and life [50]. While managers perceived that remote working employees are not under supervision, they tried electronic surveillance and monitoring of employee's activities. This is a serious ethical and legal issue, because such electronic surveillance can take screenshot of employee laptop, activate their cameras and record what they employee types on his laptop and also record their audio and visuals which is highly unethical. The digitalisation of HRM poses the challenge of maintaining confidentiality of employee data and in retaining workforce [51].

Breach of data related to employees and not protecting sensitive data of employees by firms will attract legal law suits. For instance, Barbara Dittman sued UMPC for not protecting 62,000 employees' data which was stolen from the servers

of UMPC [52]. As per Rights-based ethics theory, employees have the right to have their data protected in a digitalised environment and also have control over their personal and transaction data [45].

Technologies like AI, facial recognition, data mining, data analytics, automation etc. have redefined relationship among employees and the organisation [53]. It has to be noted that digital HRM operates based on the data of employees. So there raised an ethical question of how employee data is gathered and how it is used for enhancing performance and efficiency. An ethical doubt of who is responsible for the organisation's and its HRM's ethical decision raises. There is a doubt whether the outsourced partners who develop the HRM software or third-party HRM tool developer is responsible for data safety or the organisation. In a recent incident in 2022 in India, myrocket.co, a HR management company exposed thousands of candidates' personal information and sensitive data like payslips, tax filings, addresses etc. were leaked. This is an ethical challenge in digitalisation of HRM [54]. Similarly, US based company, Sequoia, disclosed unauthorised breach into their cloud data repository and huge data related to employees' and candidates' personal and sensitive information including social security number were taken by cyber-attack [55].

Companies like myrocket or Sequioa are third-parties which handle employee data and job information of many companies. This is where the issue of unethical data handling and lack of data protection becomes a challenge. Thus, ethical challenges like this demands compliance with data regulations in digitalised HRM systems. In EU, companies have to adhere to General Data Protection Regulation to ensure ethical use of employee or stakeholder or business data, maintain privacy, ensure transparency in use of data [40]. The introduction of AI in HRM has the challenge of ethical and regulatory concerns [56].

Organisations need to comply with regulations and monitor data protection, ensure data privacy, transparency, bias, or discrimination in algorithms. Organisations have to ensure ethical HRM processes by complying with ethical digital technology guidelines and implement best practices in using AI for HRM [57]. However, AI based HRM tools have increased stress on employees due to constant monitoring and evaluation and possibility of ethical issue of data privacy and biased or unfairness in recruitment or selection or appraisal due to algorithms [58].

3.4 Ethical Issues in Gig Economy

Digital technologies have brought in changes in traditional work culture and has transformed it into digital work framework which has in turn altered the relationship between employees and organisations [59]. Digitalisation of HRM has also aided in emergence of virtual work environment and gig economy [60]. Gig economy broadly refer to online platforms which provide flexible jobs like that of Uber, Deliveroo, TaskRabbit etc. [61]. Gig economy has paved way for redefining new work nature for contemporary economic conditions [62]. But it has certain ethical issues in managing the workforce. There are three kinds of ethical issues in gig economy HRM, including algorithmic control and managerial oversight; exploitative, precarious and dangerous labour; misclassification and discriminatory effects.

Gig economy are based on digital platforms relying on reputation system where the workers are given scores or ratings by customers, while these scores are used to monitor them and evaluate their quality of work and allocate further works [62]. This kind of system might lead to unequal job distribution. The digital platforms developed by third-parties are managed using algorithms which determines the quality of work of the gig economy workers. This indicates algorithmic control over the workers and exert pressure on them by constant monitoring and tracking of work. Another ethical issue noticed in gig economy HRM is the nature of work offered. Most often gig economy offers precarious or flexible and menial jobs which results in exploitation of gig economy workers. Misclassification of such employees happen and they are seen as "non- employees" and they have weak power and legal protection in the system. Gig economy has positively contribute to new kind of job generation with job flexibility [63]. Especially during and after the pandemic larger segment of people opted for gig works like food delivery, ride-sharing etc. to supplement income loss or job loss. Gig economy firms that have investors as ownerships tend to be more profit oriented and are exploitative of their employees, while collaborative model of business in gig economy are more equitable and promises quality work relations and HR practises [64].

Even though precarious work is not new to the market, gig economy which has seasonal, casual, or contract-based agreements, may face certain ethical issues. As the gig economy is highly based on scoring system, precarity of the job may become uncertain or precarious and commodification of labour is also possible. As they are seen as "human-as-service" and "just-in-time workforce," ethically the HRM system does not manage them equal to permanent workers [65]. Further, gig economy tends to deconstruct huge projects into smaller ones which can be catered by low-skilled workers for lower wages. For instance, Mechanical Turk splits large works like translation of books into small works to thousands of workers for low cost. This indicates exploitation of gig economy workers [66]. The next ethical debate in gig economy and its HRM is about the new status of such workers and how to differentiate such independent contractors from employees. Because of its precarity, gig economy workers are discriminated with low salary and low power and legal protection and regulatory ambiguity is also an ethical issue in HRM of gig economy. For instance, Uber consciously avoids social, legal, and ethical responsibilities as an employer [62]. In another incident, Uber faced legal lawsuit filed against its drivers in its gig economy business model. Unethically Uber considered its drivers as self-employed individuals who utilise their online platform or app and they tried to shed off their responsibilities and compliance with labour regulations and commitment to ensure their well-being, wages, and protection. But the court pronounced and instructed Uber to treat their drivers as their employees and not as self-employed individuals who associate with Uber for job opportunities and Uber drivers are entitled to have labour rights like minimum wages, paid leave etc. [67]. This indicates that digitalisation of HRM in contemporary business models like gig economy might lead

to unethical treatment of employees and neglect their basic labour rights. Even though gig economy has many positive impacts on the society and people's income, it has ethical challenges like marginalisation, commodification of workers, precarity and misclassification and exploitation of gig workers.

3.5 Lack of Human Touch and Resistance from Employees

Another ethical issue in digitalisation of HRM process is lack of human interaction and touch in the process. Digitalisation of HRM results in less human-to-human interaction and creates passive and impersonal space in the organisation and leads to gap between the employee and the firm [68].

HRM is founded on the concept of human interaction with employees but in the modern day digitalised HRM apps and online platforms play the role of "HR supervisors or managers" [69]. In traditional HRM, there was social and personal exchange of emotions, feelings and affect. Replacing humans with digital technologies will erase personal interaction and related emotions like empathy, trust etc. and will have negative impact on employees on a long-term basis.

Ethical and social risks of digitalisation of HRM are analysed and listed the challenges like structural changes in overall labour market, changes in skill demand, educational qualifications, possibility of "digital inequality" which might be a new form of discrimination, changing boundaries in privacy issues like allowing monitoring and tracking of employees' activities, their responsibilities etc [70]. The use of technologies like AI or big data or machine learning etc. have widened skills gap in the industry, because a) the digitalisation of HR activities like automation demands new skill sets to work in new platforms and b) there existing skills and capabilities like formal training or degrees are losing their value [71].

It has to be accepted that the 'new normal' which is remote or virtual working and related HRM delivers communications to employees without any emotions or empathy through digital channels like Whatsapp or Zoom [72].

The digitalisation of HRM system has attracted resistance from employees [73]. Even though during Covid-10 pandemic lockdowns and remote working, employees did not have any other choices but to adapt to digital HRM. They have the mindset of resisting new processes that might be introduced through digital and algorithm-driven HRM.

4 DISCUSSION

Based on Self-determination theory, well-being of employees has to be protected in a digitalised HRM environment. The digitalisation of HRM can eliminate ethical issues by developing clear strategy for designing the algorithm for the HR tools which will be unbiased and fair [14]. While using AI for HR processes, the organisation must ensure authenticity of data about employees or jobs which will determine the datasets based on which algorithm will be developed [74]. If the algorithm is not authentic, it might lead to unethical issues like bias and discrimination. Rights-based theory states the need for upholding employees' rights in protecting their data.

The democratisation of data and being transparent in handling data and in sharing information with employees will also ensure ethical practises in HRM. It is important for HR professionals to gain competence and skills in operating digital and data-based technologies in their daily work, because it will allow them to achieve the objective and goals of the organization, support employees to develop their performance and ensure ethical practises and in maintaining positive work culture [75]. As indicated by statistical discrimination theory, it is essential to ensure non-bias or no-discrimination based on faulty or biased algorithm or data analysis.

Future research can focus on developing ethical operations in digitalised HRM processes, it is essential to adhere to regulations and rules laid down by governments. While using digital technologies like Big Data or AI which handle sensitive data related to employees, it is important to follow regulations like "General Data Protection Regulation" in EU nations. HR Analytics activities need to protect the privacy of employees and protect their information as per this regulation [76]. Data integrity is a key ethical issue in digitalisation of HRM and use of data-driven technologies will pose threat of data leakage or data loss of sensitive and personal information of employees of an organisation and this ethical issue must be controlled by adhering to data regulations like POPIA (Protection of Personal Information Act) as in South Africa which will ensure information privacy and protection [77].

Future research can suggest organisations to develop clear ethical HR policies and guidelines for their digital operations and develop ethical charter and align it with the social norms of the nation in which operates because each country will have its own regulations and preferences in the way data is collected and protected. HR managers must develop and adhere to professional standards and follow ethical guidelines. Practical implications of this research suggest organisations to ensure ethical practices in HRM by maintaining data classification and inventory about the data types used in HR technological tools [78]. It is critical to compliant with regulations like GDPR and HIPPA (Health Insurance Portability and Accountability Act) to ensure ethical data collection and usage involving consent of employees and reporting of data breach. In the era of gig economy, in order to ensure ethical HRM practices, countries like UK have implemented National Minimum wages, statutory holiday, protection from discrimination etc. [79]. Existing acts like ERA (Employees Rights Act of 1996) is one of the regulations which organisations which have implemented digital HRM need to follow as it will ensure ethical HR practises like minimum wage provision to employees, unbiased and non-discriminatory HR processes like recruitment, selection, appraisal etc. and also give them the right to form union. Similarly, compliance with regulations like Equality Act 2020 will empower employees and also organisations to ensure ethical protection of labour rights, equal opportunity for employees without discrimination and bias [80].

Likewise, regulations like Data Protection Act of 1998 in UK have to be adhered which will prevent organisation to monitor or engage in digital surveillance of their employees which will prevent unethical HR practices [81].

5 CONCLUSION

New technologies and data-driven tools have transformed traditional human resource management and the current digital era has digitalised human resource management systems. Digitalised human resource management systems have proved to have positive impact on organisations like reducing cost and time, improving efficiency, eliminating bias etc. But on the other hand, digitalisation of human resource management has many ethical issues. It has impacted the well-being of employees as digital technologies might constantly monitor them resulting in psychological fear of being monitored, long working hours etc. Ethical issue of bias and discrimination might arise from the algorithms used in digital HRM tools and there is threat for data privacy and need for protecting sensitive employee data.
More importantly, digital era business model, gig economy and its workers face many unethical issues which can be eliminated mainly by adherence to regulations and rules laid down by governments. This research essay has presented and highlighted the ethical issues in digitalised HRM and how they can be overcome.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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IMPACT OF PERFORMANCE APPRAISAL ON EMPLOYEE MOTIVATION AND ENGAGEMENT: A CASE STUDY OF TAZARA IN MPIKA DISTRICT OF MUCHINGA PROVINCE

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Abstract: This study explores the impact of performance appraisal systems on employee motivation and engagement, focusing on the Tanzania-Zambia Railway Authority (TAZARA) in Mpika District, Muchinga Province. Performance appraisals are a cornerstone of human resource management, designed to evaluate employee performance, recognize achievements, address weaknesses, and align individual contributions with organizational objectives. Despite their widespread use, questions remain about their effectiveness in enhancing motivation and engagement, especially within public sector organizations where unique challenges such as bureaucratic inefficiencies and resource constraints exist.

Using a mixed-methods approach, the study combines qualitative and quantitative research methods, including surveys, semi-structured interviews, and analysis of organizational performance records. It examines critical components of TAZARA's performance appraisal system, such as goal-setting processes, feedback delivery, evaluation criteria, and reward mechanisms, to determine their impact on employee motivation and engagement. The study also explores the perceptions and attitudes of employees toward the appraisal process and its fairness, relevance, and contribution to their professional growth.

The findings indicate that performance appraisals can significantly influence employee motivation and engagement when effectively designed and implemented. At TAZARA, employees who experienced timely, fair, and constructive appraisals reported higher levels of motivation, job satisfaction, and a sense of belonging to the organization. These employees felt valued and were more likely to align their personal goals with the organization's strategic objectives, thereby increasing productivity. However, the study also identifies significant barriers to the effectiveness of performance appraisals at TAZARA. These include inconsistent implementation, lack of clear evaluation criteria, perceived biases, inadequate feedback, and the absence of actionable outcomes following appraisals.

Moreover, the study highlights the role of organizational culture and leadership in shaping the effectiveness of performance appraisal systems. A supportive leadership environment that prioritizes open communication and employee development can enhance the positive impact of appraisals. Conversely, poor communication and lack of management commitment to employee welfare undermine the potential benefits of appraisals, leading to dissatisfaction, disengagement, and reduced morale among employees.

The study concludes that performance appraisals are a powerful tool for enhancing employee motivation and engagement when aligned with organizational priorities and employee expectations. Recommendations for TAZARA include increasing the transparency and consistency of the appraisal process, improving communication channels, ensuring the alignment of appraisals with career development initiatives, and incorporating employee feedback into system redesign. These measures are expected to foster a more motivated and engaged workforce, ultimately improving organizational performance and service delivery.

By providing insights into the challenges and opportunities associated with performance appraisal systems, this study contributes to the broader discourse on human resource management in public sector organizations in Zambia and similar contexts. It underscores the need for adaptive and context-specific appraisal systems that not only evaluate performance but also serve as a strategic tool for employee engagement and organizational growth.

Keywords: Performance appraisals; Employee motivation; Employee engagement & organizational performance

1 INTRODUCTION

Performance appraisal systems have long been regarded as essential tools in human resource management (HRM), playing a pivotal role in assessing employee performance, fostering motivation, and driving organizational success. In its ideal form, the performance appraisal process is designed to assess individual contributions, provide constructive feedback, set developmental goals, and align personal achievements with organizational objectives. From a motivational perspective, well-structured performance appraisals are believed to enhance job satisfaction, increase employee engagement, and contribute to higher organizational productivity [1]. Despite this theoretical framework, the practical implications of performance appraisals, especially in public sector organizations, remain ambiguous and warrant further exploration [2].

The relationship between performance appraisals and employee motivation has been a subject of significant scholarly interest. According to Locke and Latham's Goal Setting Theory [3], the provision of clear, specific, and challenging goals through performance appraisals is crucial to motivating employees. By linking appraisal results to tangible rewards such as promotions, bonuses, or professional development opportunities, organizations can incentivize high performance. Additionally, feedback mechanisms embedded in the appraisal process can help employees recognize areas for improvement, thereby enhancing intrinsic motivation and promoting engagement with their roles [4]. In contrast, when performance appraisals are perceived as unfair, inconsistent, or disconnected from actual performance, they can lead to demotivation, frustration, and reduced commitment to organizational goals [5].

However, the effectiveness of performance appraisals in influencing employee motivation is contingent upon various factors, including the design and implementation of the system, organizational culture, and the broader context in which the appraisal is conducted. Research by Judge and Ferris [6] highlights that fairness, transparency, and the timeliness of feedback are crucial to the success of performance appraisals. Moreover, studies suggest that the traditional "top-down" appraisal approach, where managers evaluate subordinates' performance, can be less effective than more participatory approaches, such as 360-degree feedback systems, where employees are evaluated by peers, subordinates, and supervisors [7]. This shift towards more inclusive and multidimensional feedback models has been shown to increase employees' sense of fairness and accountability, which, in turn, boosts motivation and engagement [8].

The relationship between performance appraisals and employee engagement is equally complex. Engagement, as defined by Kahn [9], refers to the emotional and cognitive commitment that employees have towards their work roles. Engaged employees are more likely to go beyond their job descriptions and demonstrate discretionary effort, resulting in higher levels of organizational productivity. Performance appraisals can impact engagement by providing employees with the opportunity for personal growth and development, as well as a sense of accomplishment and recognition. When appraisals are structured to emphasize both recognition of achievements and development opportunities, employees are more likely to feel engaged with their work [10]. Conversely, poorly executed appraisals, characterized by vague criteria, lack of feedback, or favoritism, can lead to disengagement, as employees may feel that their efforts are unrecognized or undervalued [11].

In public sector organizations like the Tanzania-Zambia Railway Authority (TAZARA), the effectiveness of performance appraisal systems becomes even more critical, given the unique challenges faced by such institutions. Public sector organizations often struggle with resource constraints, rigid hierarchical structures, and limited opportunities for career advancement, which can undermine the potential positive effects of performance appraisals [12]. Furthermore, employees in public organizations may face lower extrinsic rewards compared to their counterparts in the private sector, which places greater emphasis on the intrinsic motivation facilitated through performance feedback, recognition, and career development opportunities. Kuvaas [13] argues that in environments where financial incentives are limited, the role of performance appraisals in fostering motivation becomes even more pronounced, as they provide the primary means of acknowledging employee contributions and fostering a sense of accomplishment.

While performance appraisals can contribute to employee motivation and engagement in any organizational context, their effectiveness in public sector institutions like TAZARA requires careful consideration of contextual factors, such as organizational culture, leadership style, and the specific challenges faced by the workforce. Scholars like Purcell and Hutchinson [14] emphasize the need for a more holistic approach to performance management in the public sector, where appraisals are linked not only to individual performance but also to broader goals such as public service delivery, transparency, and accountability. The study of TAZARA's performance appraisal system provides an opportunity to explore how these theoretical concepts play out in practice and how organizational factors can influence the success of performance appraisal systems in motivating and engaging employees.

This study aims to contribute to the body of knowledge on performance appraisals in public sector organizations, focusing specifically on TAZARA in Mpika District, Muchinga Province. By examining the implementation and impact of TAZARA's performance appraisal system, this research seeks to identify best practices, challenges, and opportunities for improving the effectiveness of performance appraisals in motivating and engaging employees. The findings are expected to provide valuable insights into the role of performance appraisals in public sector organizations in Zambia and similar contexts, ultimately guiding improvements in performance management systems that can lead to more motivated, engaged, and productive workforces.

2 LITERATURE REVIEW

This section presents a comprehensive review of the literature on performance appraisals, focusing on their impact on employee motivation and engagement. The review will cover various theoretical frameworks that support the use of performance appraisals, empirical studies on their effectiveness, the challenges encountered in their implementation, and best practices for improving their outcomes. This review specifically aims to highlight the broader understanding of performance appraisals in public sector organizations and how they can be leveraged to enhance employee motivation and engagement.

2.1 Theoretical Frameworks on Performance Appraisals

Performance appraisals are essential tools in human resource management, often designed to align individual employee goals with organizational objectives. One of the primary theoretical frameworks supporting performance appraisals is Goal Setting Theory (Locke & Latham, 1990), which posits that specific and challenging goals motivate individuals to exert higher levels of effort. In the context of performance appraisals, this suggests that when employees are provided with clear, measurable goals during appraisals, they are more likely to be motivated to achieve them, increasing overall organizational performance. Similarly, feedback provided during the appraisal process plays a critical role in goal achievement by reinforcing behavior and offering guidance on how to reach performance targets [1].

Another important theoretical perspective is Expectancy Theory (Vroom, 1964), which explains motivation as a function of the expected outcomes of certain behaviors. According to this theory, if employees believe that their performance appraisals will lead to desirable rewards such as promotions, salary increases, or professional development opportunities, they are more likely to be motivated to improve their performance. The expectancy of positive outcomes encourages effort and engagement. However, if employees perceive that appraisals are not linked to tangible rewards or development, motivation decreases, leading to disengagement [2].

The Equity Theory (Adams, 1963) also plays a crucial role in performance appraisals by emphasizing the importance of fairness. Employees are motivated when they perceive their treatment in the appraisal process as fair compared to their colleagues. If the appraisal process is seen as biased or discriminatory, employees may feel demotivated and disengaged. For this reason, transparency and fairness are critical components of an effective performance appraisal system, particularly in public organizations where perceptions of fairness are vital for maintaining employee morale and organizational stability [3].

2.2 Impact of Performance Appraisals on Employee Motivation

Empirical studies have consistently shown that well-designed performance appraisals have a positive impact on employee motivation. According to Armstrong (2017), performance appraisals provide an opportunity for employees to receive constructive feedback, which is essential for improving their skills and achieving career development goals. Regular feedback helps employees understand their strengths and weaknesses and offers clear directions for improvement, which can drive motivation. Furthermore, when appraisals highlight achievements and recognize hard work, employees feel valued and are more likely to stay motivated and committed to their work [4].

However, research by Kuvaas (2008) indicates that the benefits of performance appraisals on motivation are contingent upon the perceived fairness of the process. Employees who view the appraisal process as fair and transparent are more likely to experience increased motivation. On the other hand, if the process is perceived as unfair or biased, employees may feel frustrated and demotivated. For instance, if managers fail to provide clear criteria for performance evaluations or if the appraisals are influenced by personal biases, employees may lose trust in the system, leading to decreased motivation and engagement [5].Additionally, studies by DeNisi and Pritchard (2006) suggest that feedback, which is a critical component of performance appraisals, must be specific, timely, and constructive. General or vague feedback does not provide employees with clear insights into how to improve their performance. Specific feedback, on the other hand, helps employees understand exactly what behaviors to maintain and what needs to be changed. Therefore, the quality of feedback during the appraisal process has a direct bearing on its effectiveness in enhancing motivation [6].

2.3 Performance Appraisals and Employee Engagement

Employee engagement is a key outcome of effective performance appraisal systems. Engaged employees are emotionally and cognitively involved in their work, leading to higher levels of productivity, commitment, and satisfaction. According to Kahn (1990), employees are more likely to be engaged when they feel their work is meaningful and that their contributions are recognized and valued. Performance appraisals, when done properly, serve as a means of recognizing employees' efforts and accomplishments, thus enhancing their sense of purpose and engagement with their roles [7].

Research by Macey and Schneider (2008) supports this argument, showing that employees who perceive their performance appraisals as fair and developmental are more likely to exhibit higher levels of engagement. When appraisals focus not only on evaluating past performance but also on providing developmental feedback and career growth opportunities, they increase employees' sense of self-worth and commitment to their work. Moreover, engagement is positively influenced when employees believe their appraisals are linked to meaningful rewards, such as career advancement or opportunities for skill development [8].

In contrast, studies have shown that poorly executed appraisals can lead to disengagement. For instance, London (2003) found that employees who receive negative, non-constructive feedback or who feel that appraisals are used as a mere formality are more likely to disengage from their work. A lack of transparency, inconsistent criteria, and failure to address performance gaps during appraisals can lead employees to feel undervalued and disconnected from their organizational goals [9].

2.4 Challenges in Implementing Performance Appraisal Systems

Despite the potential benefits of performance appraisals, their implementation in public sector organizations such as TAZARA is often fraught with challenges. One of the primary challenges is the lack of resources and expertise to conduct effective appraisals. Public sector organizations frequently face resource constraints, and as a result, performance appraisals may be viewed as administrative burdens rather than valuable tools for employee development [10]. Moreover, hierarchical structures in public organizations often limit the effectiveness of appraisals, as managers may lack the authority or training to provide effective feedback, or employees may feel that their input is not valued in the appraisal process.

Another challenge is ensuring fairness and consistency in the appraisal process. Purcell and Hutchinson (2007) argue that for performance appraisals to be effective, they must be perceived as fair and consistent across the organization. In public sector organizations, where employees often experience limited career advancement opportunities, appraisals must be closely linked to tangible rewards and development opportunities to prevent dissatisfaction and disengagement. When appraisals are conducted infrequently or when feedback is not timely, employees may feel that their contributions are ignored, leading to low morale and reduced engagement [11].

2.5 Best Practices in Performance Appraisal Systems

To overcome the challenges associated with performance appraisals, best practices have been developed to enhance their effectiveness in motivating and engaging employees. One key practice is the adoption of 360-degree feedback systems, which involve gathering feedback from multiple sources, including peers, subordinates, and supervisors. This approach increases the accuracy and fairness of performance appraisals, as it provides a more holistic view of an employee's performance [12]. Bracken et al. (2001) emphasize that incorporating feedback from multiple perspectives fosters greater transparency and accountability, leading to higher employee satisfaction and motivation.

Another best practice is the integration of regular, ongoing feedback rather than relying solely on annual performance reviews. According to London (2003), frequent feedback allows employees to make adjustments to their performance in real time, which increases their sense of control and motivation. It also ensures that employees are consistently aligned with organizational goals and that any performance issues are addressed promptly, rather than waiting for an annual review [13].

Furthermore, incorporating career development and growth opportunities into the performance appraisal process can significantly enhance employee engagement. Kuvaas (2008) highlights that public sector organizations, which may have limited extrinsic rewards, can compensate for this by offering intrinsic rewards such as career development programs, skill-building opportunities, and pathways to promotion. These elements help employees feel that their contributions are being recognized and that they have a future within the organization, which can greatly enhance their engagement and motivation [14].

In conclusion, performance appraisals are a critical component of employee motivation and engagement in any organization. Their effectiveness is contingent upon several factors, including the fairness, consistency, and transparency of the appraisal process, as well as the quality of feedback provided to employees. While challenges exist, particularly in public sector organizations like TAZARA, adopting best practices such as 360-degree feedback and regular performance reviews can significantly enhance the outcomes of performance appraisal systems. By ensuring that appraisals are perceived as fair, developmental, and aligned with organizational goals, public sector organizations can foster higher levels of motivation, engagement, and organizational effectiveness.

3 METHODOLOGY

This section outlines the research approach, design, and data collection methods employed to investigate the impact of performance appraisals on employee motivation and engagement, using TAZARA in Mpika District as a case study. It also describes the target population, sampling techniques, data analysis methods, and ethical considerations adopted for this study.

3.1 Research Design

The study employs a mixed-methods research design, combining both quantitative and qualitative approaches to provide a comprehensive analysis of the topic. A quantitative approach was used to measure the relationships between performance appraisals, motivation, and engagement through structured surveys. The qualitative approach involved interviews and focus group discussions to gain deeper insights into employees' perceptions and experiences with the performance appraisal system at TAZARA. Mixed-methods research was chosen to integrate numerical data with rich contextual information, ensuring a holistic understanding of the phenomena under investigation [1][2].

3.2 Target Population

The target population for the study consisted of TAZARA employees in Mpika District, including both managerial and non-managerial staff. The organization was selected due to its strategic importance as a major public sector employer in the transportation industry, and its relevance to understanding performance management practices in Zambia's public sector.

The study targeted employees across different departments to capture a diverse range of perspectives on the impact of performance appraisals.

3.3 Sampling Technique and Sample Size

The study employed stratified random sampling to ensure representation across various employee categories (e.g., senior managers, supervisors, and junior staff). Stratification was necessary to capture the unique experiences and views of employees at different hierarchical levels within TAZARA. From a population of approximately 500 employees in Mpika District, a sample size of 150 participants was selected based on Cochran's formula for determining appropriate sample sizes in survey research [3].
Inclusion Criteria:
Employees who have been with TAZARA for at least one year (to ensure familiarity with the performance appraisal process).
Employees from all functional departments (to ensure diverse perspectives).

3.4 Data Collection Methods

3.4.1 Quantitative data collection
A structured questionnaire was designed to collect quantitative data on employees' perceptions of performance appraisals, their motivation levels, and engagement with their work. The questionnaire included closed-ended questions using a Likert scale (1 = strongly disagree, 5 = strongly agree) to measure the variables of interest. The questionnaire focused on:

- The fairness and transparency of the appraisal process.
- The effectiveness of feedback provided during appraisals.
- The linkage between appraisals and rewards or career development.
- Overall job satisfaction, motivation, and engagement levels.

3.4.2 Qualitative data collection
Semi-structured interviews and focus group discussions were used to collect qualitative data. Semi-structured interviews were conducted with 15 employees, including managers and supervisors, to gain insights into their experiences with performance appraisals and how these influence motivation and engagement. Focus group discussions with non-managerial staff provided additional perspectives on the challenges and benefits of the current appraisal system. These methods allowed for in-depth exploration of themes that could not be fully captured through the questionnaire alone [4].

3.5 Data Analysis

3.5.1 Quantitative analysis
Quantitative data collected from the questionnaires were analyzed using descriptive and inferential statistics. Descriptive statistics (e.g., means, frequencies, and percentages) provided an overview of employee perceptions, while inferential statistics (e.g., regression analysis) were used to determine the relationships between performance appraisals, motivation, and engagement. Statistical analysis was conducted using SPSS software, enabling the identification of significant predictors of employee motivation and engagement [5].
3.5.2 Qualitative analysis
Qualitative data from interviews and focus group discussions were analyzed using thematic analysis. Key themes related to performance appraisal practices, challenges, and their impact on motivation and engagement were identified through coding and categorization. This process involved identifying recurring patterns, unique insights, and contrasting views among participants, ensuring that the analysis captured both commonalities and divergences in employee experiences.

3.6 Validity and Reliability

To ensure the validity and reliability of the findings:
The questionnaire was pretested on a small sample of employees to ensure clarity and relevance.
Triangulation was employed by comparing findings from quantitative and qualitative data to enhance the credibility of the results.
Peer debriefing and member checks were conducted to validate the qualitative findings with participants.

3.7 Ethical Considerations

The study adhered to ethical research practices, including:
Informed Consent: Participants were informed about the study's purpose, procedures, and their right to withdraw at any time without penalty.
Confidentiality: Participant data were anonymized to protect their identities and ensure privacy.

Voluntary Participation: Participation was voluntary, with no coercion or incentives offered to influence responses.
Approval: The study was approved by the relevant institutional review board (IRB) and TAZARA management.

3.8 Limitations of the Methodology

While the mixed-methods approach enhances the comprehensiveness of the study, some limitations include:
Potential response bias, particularly in self-reported data from questionnaires.
Limited generalizability of findings, as the study focuses on a single organization in one district.
Challenges in ensuring the consistency of qualitative data interpretation due to subjective perspectives.
The methodology outlined above ensures a rigorous and balanced approach to investigating the impact of performance appraisals on employee motivation and engagement. By integrating quantitative and qualitative data, the study aims to provide actionable insights for improving performance appraisal practices at TAZARA and similar public sector organizations.

4 THEORETICAL FRAMEWORK

1. Goal-Setting Theory (Locke & Latham, 1990): Highlighted that clear, specific, and challenging goals communicated through appraisals enhanced employee motivation and alignment with organizational objectives.
2. Expectancy Theory (Vroom, 1964): Emphasized the importance of linking effort to performance (expectancy), performance to rewards (instrumentality), and ensuring that rewards were valued by employees (valence).
3. Equity Theory (Adams, 1963): Focused on fairness in appraisals and how perceptions of equity impacted motivation, with fair systems fostering trust and engagement.
4. Reinforcement Theory (Skinner, 1953): Advocated for using rewards and constructive feedback during appraisals to encourage positive behaviors and address performance gaps.
5. Employee Engagement Model (Kahn, 1990): Suggested that appraisals fostered engagement by recognizing employees, addressing concerns, and offering growth opportunities.
These theories collectively explained how appraisals influenced motivation and engagement by promoting goal clarity, fairness, reward alignment, and engagement, leading to improved performance and satisfaction.
The findings of this study reveal significant insights into the impact of performance appraisals on employee motivation and engagement within TAZARA, Mpika District. This discussion synthesizes the results with existing theoretical and empirical literature to highlight key themes, practical implications, and areas for improvement.

4.1 The Role of Performance Appraisals in Enhancing Motivation

The results showed that well-structured performance appraisals positively influenced employee motivation by aligning individual goals with organizational objectives. This finding supports Goal-Setting Theory (Locke & Latham, 1990), which emphasizes the motivational power of clear and challenging goals. Employees at TAZARA expressed increased clarity about their performance expectations, leading to greater commitment to their roles.
However, instances of dissatisfaction arose when employees perceived appraisals as subjective or inconsistent, aligning with Equity Theory (Adams, 1963), which posits that perceived unfairness demotivates employees. To address this, managers should ensure that appraisal criteria are transparent and consistently applied across all employees.

4.2 Linking Appraisals to Rewards and Career Growth

The study confirmed the importance of tying appraisal outcomes to tangible rewards and career development opportunities, as proposed by Expectancy Theory (Vroom, 1964). Employees who believed their performance would lead to valued rewards, such as promotions or salary increments, were more motivated and engaged. Conversely, employees who felt that appraisals did not translate into meaningful benefits exhibited reduced enthusiasm for the process.
This underscores the need for TAZARA's management to strengthen the connection between appraisal outcomes and organizational reward systems. Providing employees with timely feedback and clear paths for advancement can enhance the perceived value of appraisals and drive engagement.

4.3 The Role of Feedback in Employee Engagement

Feedback emerged as a critical element of the appraisal process. Consistent with Reinforcement Theory (Skinner, 1953), constructive feedback helped employees identify areas for improvement and reinforced positive behaviors. Additionally, timely feedback fostered a sense of recognition and value among employees, contributing to higher levels of engagement, as suggested by Kahn's Employee Engagement Model (1990).

However, some employees highlighted the lack of follow-up on appraisal feedback, which reduced its effectiveness. This indicates a need for a more robust feedback mechanism that includes actionable steps and periodic reviews to assess progress.

4.4 Perceptions of Fairness and Transparency

The study revealed that perceptions of fairness significantly influenced employees' acceptance of the appraisal process. Employees who felt the process was biased or lacked transparency were less motivated, corroborating findings from studies on fairness in performance management systems [1][2]. Ensuring fairness requires:

- Training managers to conduct objective evaluations.
- Establishing clear criteria and processes for appraisals.
- Involving employees in the design and review of appraisal frameworks.
- Improving these aspects can build trust in the system and enhance employee engagement.

4.5 Challenges in Performance Appraisals at TAZARA

The study identified several challenges in the appraisal process, including limited resources, inadequate training for appraisers, and inconsistencies in implementation. These challenges align with findings from other public sector organizations, where resource constraints often hinder the effectiveness of performance management systems [3]. Addressing these issues requires capacity building, such as providing appraiser training, and investing in appraisal tools to streamline the process.

4.6 Implications for Public Sector Organizations

The findings have broader implications for public sector organizations in Zambia and beyond. Public institutions like TAZARA face unique challenges, such as bureaucratic constraints and limited flexibility in reward systems, which can undermine the effectiveness of appraisals. Developing context-specific appraisal frameworks that prioritize fairness, employee development, and feedback can improve motivation and engagement in similar settings.

4.7 Limitations and Future Research

While the study provided valuable insights, its scope was limited to a single organization in Mpika District. Future research could:

- Expand to multiple public sector organizations for broader generalizability.
- Examine the long-term impact of appraisals on organizational performance.
- Investigate the role of cultural factors in shaping employee perceptions of appraisals.

The discussion highlights that effective performance appraisals significantly impact employee motivation and engagement, provided they are fair, transparent, and linked to meaningful outcomes. By addressing the identified challenges and leveraging feedback mechanisms, TAZARA and similar organizations can create appraisal systems that drive employee satisfaction and organizational success.

5 RESEARCH GAPS

While the study provided valuable insights into the impact of performance appraisals on employee motivation and engagement at TAZARA, several research gaps were identified, offering opportunities for further investigation:

5.1 Limited Generalizability

The study focused on a single organization (TAZARA) within Mpika District, limiting the applicability of the findings to other organizations, industries, or regions. The unique characteristics of public sector institutions and the local context may not fully represent performance appraisal systems in other settings. Future research could explore:

- Comparative studies across public and private sector organizations.
- Broader geographical coverage, including urban and rural areas.

5.2 Longitudinal Impact of Appraisals

This study captured a snapshot of employee perceptions but did not examine the long-term impact of performance appraisals on motivation, engagement, and overall organizational performance. Longitudinal studies are needed to understand:

- How sustained exposure to appraisal systems affects employee behavior.

- Whether improvements in engagement translate into measurable organizational outcomes over time.

5.3 Role of Cultural Factors

The influence of cultural norms and values on employee perceptions of performance appraisals was not extensively addressed. In Zambia, cultural dynamics, such as power distance, collectivism, and attitudes toward authority, could shape how employees perceive fairness and feedback. Further research could investigate:

- The interplay between cultural factors and appraisal effectiveness.
- Cross-cultural comparisons to identify universal and context-specific practices.

5.4 Digital Transformation in Appraisals

The study did not explore the potential role of technology in enhancing appraisal systems. As digital tools become increasingly integral to performance management, there is a need to examine:

- The adoption and effectiveness of digital appraisal platforms in public sector organizations.
- How technology can improve transparency, reduce bias, and enhance feedback mechanisms.

5.5 Managerial Competence in Appraisals

- The study highlighted issues of inconsistency and perceived bias in appraisals but did not deeply analyze the competency of appraisers.
- The skills and training required for managers to conduct fair and effective appraisals.
- The impact of managerial biases on employee motivation and engagement.

5.6 Psychological Factors and Employee Engagement

- While the study linked appraisals to motivation and engagement, it did not delve into the psychological mechanisms underlying these relationships.
- The role of emotional intelligence and psychological safety in appraisal systems.
- How appraisals influence employee well-being and job satisfaction.

5.7 Integration with Broader HR Practices

The study examined appraisals as a standalone process but did not investigate their integration with other human resource management practices, such as training, talent development, and succession planning. Future research could assess:
How appraisal systems complement broader HR strategies.
The alignment of performance appraisals with organizational culture and goals.

5.8 Employee Involvement in Appraisal Design

The study did not assess the extent of employee participation in designing appraisal frameworks. Research could focus on:
The benefits of involving employees in the development and refinement of appraisal systems.
How participatory approaches influence perceptions of fairness and engagement.
Addressing these research gaps will enhance the understanding of performance appraisal systems and their impact on employee motivation and engagement. By expanding the scope of inquiry, future studies can offer more comprehensive and actionable recommendations for improving performance management practices across diverse organizational and cultural contexts.

6 CONCLUSION

This study examines the impact of performance appraisals on employee motivation and engagement, focusing on TAZARA in Mpika District. It highlights how performance appraisals, when effectively implemented, serve as critical tools for aligning individual and organizational goals, fostering motivation, and enhancing engagement. Drawing on theories such as Goal-Setting, Expectancy, Equity, Reinforcement, and Employee Engagement, the study reveals that appraisals positively influence motivation when they clarify expectations, provide constructive feedback, and are linked to tangible rewards. However, challenges such as perceived bias, lack of transparency, and inconsistent implementation were found to undermine the system's effectiveness. The findings underscore the importance of fairness and transparency, the need for stronger linkages between appraisals and rewards, and the role of consistent feedback in sustaining employee motivation. Organizational challenges, including resource limitations and insufficient appraiser training, were also identified as areas requiring attention. The study calls for broader adoption of digital tools, enhanced managerial capacity, and integration of

appraisal systems with other HR practices. These insights provide a foundation for improving performance management frameworks in public sector organizations, fostering greater employee satisfaction and organizational success.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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MINE SAFETY MANAGEMENT AND CONTROL COUNTERMEASURES ON THE BASIS OF RISK ASSESSMENT

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Abstract: Based on modern intelligent concepts, smart mines deeply integrate technologies such as the Internet of Things (IoT), big data, artificial intelligence (AI), robotics, intelligent equipment, and 5G into modern coal development and utilization, creating an intelligent system with comprehensive perception, real-time connectivity, autonomous learning, dynamic prediction, and collaborative control. The intelligentization of mine production safety has become a core technological support for the high-quality development of the industry. This paper addresses the technological needs of smart mines, utilizes digital twin technology to achieve interconnectivity and intelligent application of mine management, and improves the overall effectiveness of the safety management system, risk assessment and control, accident analysis and prevention, and other fields. Based on digital twin and 5G technology, the company puts forward the concept of "prevention-oriented" safety management and formulates systematic solutions to effectively reduce the incidence of accidents. Combining Monte Carlo simulation, gray correlation analysis, GIS and remote sensing technology and other methods, it builds an innovative intelligent mine risk management system and proposes key technical paths to achieve high-quality development, including information network architecture, safety production control mode, intelligent decision-making and situational analysis mode. At the same time, the important role of management and personnel subsystems in mine safety risk management is emphasized to improve productivity and safety. Finally, the article puts forward countermeasure suggestions to promote the high-quality development of smart mines, the mining industry is moving towards the direction of intelligence and wisdom, and gradually realize the less manned or unmanned production mode, laying a solid foundation for the future development of smart mines.
Keywords: Intelligent mine; Internet of things; Digital twin; Safety management system; Risk assessment and control; Accident analysis and prevention

1 INTRODUCTION

Energy security is the cornerstone of national security and stable development, mines have long played a crucial role in China's energy security, is the stabilizer of energy supply and ballast, mine production safety is a multi-level, comprehensive integrated system, from management to technology, culture to regulations, personnel to the environment and other aspects of the core elements together. With the rapid development of the Internet of Things, artificial intelligence and big data technology, the smart mine will be a high degree of integration of informationization, automation and intelligence, and its ultimate goal is to realize the unmanned or less manned key production links in the mine, so as to improve production efficiency and safety [1].

China's mine safety problems are analyzed from several dimensions, which are usually divided into three major categories: accident types, accident causes, and accident consequences. In recent years, as the safety situation in mines has become increasingly serious, scholars have conducted in-depth research in this field, focusing mainly on the "prevention-oriented" approach to propose systematic solutions to reduce the incidence of accidents. The following three scholars' researches jointly promote an integrated mine safety risk management system: the studies of Wu Yongguang and Wang Guohui [2,3] laid a scientific theoretical foundation and management framework for the construction of the system, focusing on risk identification, assessment, and the development of emergency response plans; while Liu Wenhua's study [4] introduced intelligent and efficient means through technological innovation, providing the system with technical support and guarantee.In summary, the prevention of mine safety has shifted from the traditional "post-rescue" approach to "precautionary measures." In the future, the combination of intelligent technology and scientific management means will help realize the continuous improvement of mine safety. At the same time, all parties should strengthen cooperation to promote the construction of mine safety culture, enhance the safety awareness and sense of responsibility of all employees, and create a safer and healthier working environment for the mining industry.

The traditional safety management model has the shortcoming of "focusing on post-disposal, light on pre-prevention", and there is an urgent need to realize the forward movement of prevention and control through systematic risk assessment. This paper focuses on the application of risk assessment and control in mine safety management by combining the research results at home and abroad in the past decade. According to the previous discussion, the research objectives of this paper can be summarized as follows: 1) The research focuses on improving mine safety management and the construction of comprehensive safety systems to ensure effective hazard prevention and control; 2) This study explores advanced risk assessment techniques and control methods to identify potential dangers and mitigate risks in mining operations; 3) Through detailed accident analysis, the study proposes effective prevention countermeasures to reduce the occurrence of mining accidents and enhance overall safety.

2 MINE SAFETY MANAGEMENT SYSTEM

2.1 Construction and Challenges of Mine Safety Management System

With the increasingly stringent national requirements for mine safety production, the construction of mine safety management system has become a top priority. This system covers the entire life cycle of mine safety production [5], including geological exploration, mine construction, mine rescue and safety management and other business areas, with a special emphasis on building 5G network + platform intelligent production scenarios, artificial intelligence[6], internet of things [7], digital twins [8], intelligent equipment [6,7], etc. t The development and integration of modern mining technologies play a crucial role in achieving intelligent operations across all stages of a mine's life cycle. This includes risk management, production, transportation, safety, environmental protection, energy efficiency, and business management. By fully utilizing these advancements, it is possible to significantly enhance coal mine safety, effectively prevent and address major safety risks, and reduce the occurrence of serious production and safety accidents. This approach is of great importance in ensuring safer and more sustainable mining operations. At the same time, mining enterprises must adhere to relevant laws and regulations(https://www.mem.gov.cn/fw/flfgbz/), including the Mine Safety Law, the Work Safety Law, the Labor Law of the People's Republic of China, and the Regulations on Mine Safety Supervision. Compliance with these legal frameworks is essential for protecting the lives and safety of miners, improving productivity, promoting the high-quality development of the industry, fostering social harmony and stability, and enhancing international competitiveness.

Despite some progress in mine safety management at home and abroad, many problems remain [9]. Domestically, the main problems are institutional fragmentation, inadequate safety culture, lagging technical facilities and local protectionism; while abroad, the challenges are limited risk assessment, insufficient regulatory enforcement and inadequate implementation of laws. Based on this, we need to establish a new type of safety management system to further improve and strengthen mine safety management at home and abroad, enhance the level of safety production, ensure the safety of miners' lives and promote the sustainable development of the mining industry [7].

2.2 Construction of a New Mine Safety Management System

In order to establish a new type of effective mine safety management system, this paper discusses the direction of safety production risk management in mining enterprises, focusing on analyzing the impact of various subsystems and safety inputs on overall safety management. Based on the dynamic reduction algorithm in rough set theory (RS), mine safety management is divided into five subsystems: personnel, material and equipment, technology, environment and management. On this basis, the comprehensive weights of each type of risk factors were calculated [9] and analyzed by combining the subjective and objective assignment method, the network analysis hierarchy method (AHP) [10] and the fuzzy comprehensive evaluation method [11]. The results of the study show that management and people subsystems have a significant impact in safety risk management in mining companies. Meanwhile, based on the resilience of the economic system, the difference between the target performance of the system and the interrupted performance is measured by reconfiguring the capacity of the subsystems to ensure that an acceptable growth path can be maintained in the long term in terms of production capacity, safety, and growth in wealth to further improve the overall economic performance of the enterprise.

Mine safety risk management is an important task to safeguard the health and safety of mine workers, especially in the whole life cycle of a mining enterprise, and the accident causation theory provides an important perspective to understand the mechanisms and causative factors of accidents. As the requirements for mine safety management become more stringent, risk management strategies are increasingly focused on addressing safety issues through preventive and protective measures. Using the fuzzy TOPSIS and PFVIKOR methods, mine safety risks can be divided into different levels, so as to build a dual prevention mechanism of risk classification and control and hidden danger investigation and management [11,12]. The establishment of a system dynamics (SD) model can effectively simulate the effect of safety risk management in mining enterprises under different safety input distributions, and help to formulate the optimal safety input program. The study again shows that the trend of mine safety improvement is most significant when safety funds are mainly invested in the management and personnel subsystems. This conclusion was simulated by Vensim PLE system dynamics software to analyze the interrelationships between factors within the system [13]. The study shows that the key influencing factors of the personnel subsystem, in order of importance, are: employee safety awareness, employee behavioral norms, employee technical level, managerial management level, physical and mental state of employees, and the basic quality of employees, which provide managers with a dynamic basis for safety risk management, and more comprehensively establish a mine safety management system.

However, this new safety risk system looks at the key system variables involved in the construction process and seeks to minimize the gap between the model and the actual mine while taking into account system integrity and applicability. Future research could further optimize the risk factors and associated data, and incorporate additional variables to refine the model. In addition to safety inputs, systematic objectives such as mine type and mining progress should be gradually incorporated into the research framework to improve the effectiveness and practicality of the mine safety management system. Through a series of exploration and research, the mine safety management system will gradually develop from a single safety input to a more comprehensive and integrated systematic management direction [12], helping mining enterprises to be more efficient and scientific in safety prevention and control in the face of a complex and changing

safety risk environment.

3 RISK ASSESSMENT AND CONTROL

3.1 Risk Dynamic Evolution Model

In order to enhance the scientific, real-time and adaptability of mine safety management and promote the development of mine safety management in the direction of modernization and intelligence, it is crucial to establish a risk dynamic evolution model. The model can not only provide more accurate decision-making support for mining enterprises, reduce the incidence of accidents, optimize resource allocation, but also comprehensively improve the overall level of mine safety management. Combined with the actual situation of mines in China, the whole life cycle of a mine [5] can be divided into the exploration and construction stage, the mine production stage, the mine reconstruction and expansion stage and the waste treatment stage.

In order to construct a dynamic evaluation model of safety risk in mining enterprises, the system dynamics (SD) method is introduced. System dynamics is a tool for synthesizing and analyzing social and economic problems and was first introduced by Professor J.W. Forrester of the Massachusetts Institute of Technology [14]. The method combines qualitative and quantitative analysis, is based on complex feedback theory and computer simulation technology, and is widely used in the fields of risk assessment and policy optimization. Especially in mine safety production, safety input is a comprehensive manifestation of human, material and financial resources of mines, which directly affects the safety level of the system. Based on the perspective of the whole life cycle of the mine, the dynamic evaluation of the safety risk of the mining enterprise is carried out by the improved system dynamics method, as shown in Figure 1, which is capable of clearly describing the system boundaries, the key variables and the safety production goals, and revealing the interactions between subsystems and their action paths [15]. With the increasing improvement of data mining, data processing capabilities and computer simulation technology, the system dynamics provide more scientific and accurate decision support for mine safety management and further enhance the overall safety management level.

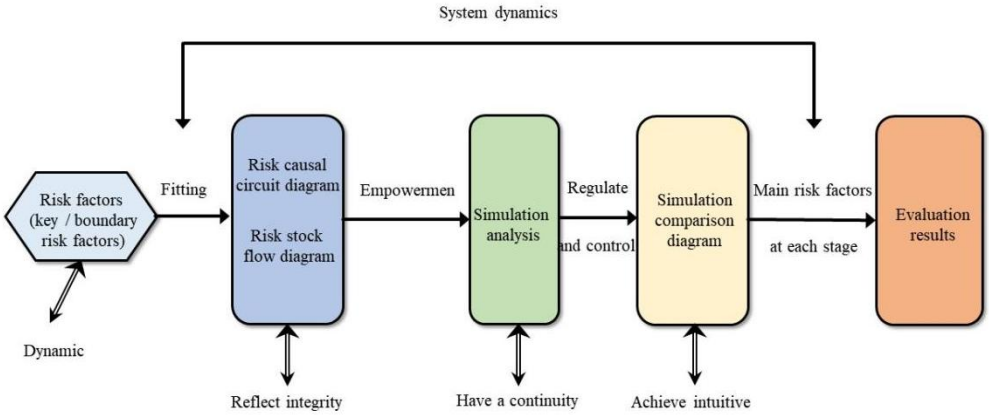

Figure 1 System Dynamics Flow Chart

As shown in Figure 1, by displaying the interrelationships and dynamic changes among the elements of the mining safety system, more targeted preventive measures and risk control strategies can be developed, ultimately optimizing the management of mine safety.

With the help of causal equations R_j , the system is divided into several subsystems P ,whose descriptive relations are expressed in the form[5]:

$$S = (P, R_j); P = \{P_i \mid i \in 1-5\} \tag{1}$$

In formula (1), S is the total system, P is the subsystem, and R_j is the relationship matrix used to describe the relationship between variables, which is generally an equation or a table function. In the SD model, the subsystem is composed of several fow level variables, velocity variables, time functions, and auxiliary variables. According to the characteristics of SD model, the following mathematical description is given [14]:

$$V = TR, \begin{bmatrix} R \\ A \end{bmatrix} = \begin{bmatrix} L \\ A \end{bmatrix} \tag{2}$$

In formula (2), T is the transfer matrix, V is the relationship matrix, L , R , and A are the level variable, fow rate variable, and auxiliary variable, respectively.

Based on formula (1–2), Vensim PLE is used to construct the system dynamic causality diagram of the fve subsystems of human–machine-technology-environment management of mining enterprises.

Currently, the State Administration of Work Safety (now part of the Ministry of Emergency Management) has introduced a series of new risk assessment indicators specifically for the mining industry, based on the current situation in the sector.

Table 1 New Indicators for Risk Assessment

Targets	Elements
Assessment of safety culture	Employee safety awareness, training and education, etc.
Equipment safety assessment	Level of automation, emergency equipment and facilities, etc.
Evaluation of risk control measures	Safety capital investment, safety technology measures, etc.
Social and Legal Risk Assessment	Compliance with laws and regulations, fulfillment of social responsibilities, etc.
Risk assessment of the work environment	Ventilation systems, geologic hazards, etc.
Risk assessment of operational processes	Operating procedures and standards, hazard identification, etc.

As shown in Table 1, these new indicators aim to more scientifically and accurately assess the various safety risks that may arise during the mining process, thus providing a more reliable basis for decision-making in mining safety management.

3.2 Innovations In Risk Assessment Methodologies

Mine safety production is a highly complex and dynamically changing system involving interactions between multiple risk factors. Traditional risk assessment methods usually focus on the analysis of a single factor, making it difficult to comprehensively reflect the complex interaction and feedback relationships between various parts of the system. This makes traditional methods often lack sufficient precision and comprehensiveness in identifying and addressing potential risks to mine safety production [3,13]. With the progress of science and technology, new assessment methods have emerged, gradually making up for the shortcomings of traditional methods. Modern risk assessment techniques can not only effectively identify and quantify potential risks in mine safety production, but also dynamically simulate and predict the evolution of risks. The following are some advanced assessment methods: fuzzy logic methods, artificial intelligence and machine learning [6], Monte Carlo simulation, geographic information system (GIS) and remote sensing technology, etc. These technologies not only improve the accuracy and efficiency of assessment, but also better predict and respond to unexpected risks in dynamic and complex environments, thus helping to improve the management of mine production safety, ensure the safety of miners' lives, and promote the sustainable development of society.

In recent years, Bayesian Network (BN) as a graphical model based on probabilistic inference, where each node represents a random variable and directed edges between nodes represent conditional dependencies between random variables. Using Bayes' theorem, the probability distribution of other unknown variables is inferred with partial information known [16]. With the unique advantages in dealing with uncertainty and complex causality, it has gradually become an important tool for mine safety risk assessment, effectively revealing the correlation between various types of factors in mine safety accidents, and providing more scientific and precise decision support for mine safety management. In mine safety risk assessment, Bayesian network can effectively capture the interrelationships between various types of risk factors in mines, and through probabilistic reasoning, Bayesian network can predict the safety status of the mine system, identify potential risks, and provide a basis for risk control and countermeasures [17]. Some scholars have proposed a Bayesian network model that integrates different risk factors of mines (geological conditions, equipment status and human errors) and applied it to mine risk management. The study validates the effectiveness of the method in the field of mine safety by analyzing data from a variety of mine safety accidents and shows that the method can provide a reliable basis for the assessment of mine safety risks. Similarly, Some researchers have proposed a mine safety risk assessment method based on Bayesian networks. By modeling multiple risk factors involved in mine safety management, a Bayesian network model was constructed so as to effectively assess potential safety risks and propose countermeasures to improve mine safety management [16]. By introducing the time factor, the dynamic Bayesian network can significantly improve the accuracy and predictive ability of mine safety assessment to better cope with the ever-changing mine operation environment [18]. These research results demonstrate the wide application of Bayesian networks in mine safety risk assessment and further promote the in-depth development of innovative Bayesian network-based approaches in the field of mine safety. By flexibly modeling complex causal relationships in mines and considering the effects of multiple factors, Bayesian networks provide more refined and comprehensive risk prediction and decision support for mine safety management.

3.3 Application of Intelligent Control Technology

Intelligent mine is based on the original digital construction, integration of perception technology, transmission technology and information processing and other advanced technologies and modern mining technology, so that the perception and monitoring of the mine can be realized. By doing so, people and people, people and things, things and

things of a mine can be closely connected to the network. Through this network, the whole process of mine safety production and operation can be dynamically and comprehensively monitored and controlled, covering all aspects of mine development, extraction, transportation, safety management, production and operation, and ultimately realizing intelligent less manned or unmanned mine operation [19]. As a key technology to solve the problems of mine safety, management and efficiency, smart mine is a cutting-edge research field of multidisciplinary cross-fertilization with broad development potential.

Mining Internet of Things (IoT) technology realizes the intelligent connection of mining equipment and facilities, and can efficiently gather "human-machine-environment" sensory information. With the emergence of various mine big data platforms, it solves the problem of efficient management and storage of mine "human-machine-environment" sensory data. Through the virtual-reality fusion and knowledge generation mechanism, digital twin technology organically combines the existing mine mechanism model, empirical knowledge and mine "human-machine-environment" big data, which provides effective knowledge service for the state identification and intelligent cooperative control of the mine [1,14]. The mine digital twin model and its related intelligent data analysis algorithms will become a key technological breakthrough point for the future development of smart mines.

As a new generation of information technology dedicated to deconstructing, describing and cognizing the physical world, digital twin technology has become a new focus of global information technology development, directly serving key areas such as advanced manufacturing and energy industry in the national strategy of artificial intelligence. With the continuous innovation of information technology, the deep integration of smart mines with digital twin, 5G communication, cloud computing, big data, industrial Internet of Things (IoT), artificial intelligence (AI) and other technologies will provide an important technological support for the intelligent development of coal mines, realize the safe, green, efficient and intelligent mining of coal, and provide new ideas for the exploration of the sustainable development of smart mines [7,13,19]. By proposing the knowledge modeling method of physical entity, virtual space modeling and virtual-reality fusion interaction mechanism, it can effectively solve the problems of accurate control and disaster warning prevention and control in the process of mine production. Mine production scenarios are complex and variable, involving a variety of equipment and facing the coupling problem of the mining environment [8]. Combined with the digital twin five-dimensional model, the construction of a twin model for mine production data requires the integration of cross-domain knowledge, including the deep combination of theories and technologies such as mine operation mechanism, mine safety, CPS, big data analysis and automation control.

4 ACCIDENT ANALYSIS AND PREVENTION

4.1 Analyzing the Causes of Accidents

Accident-Causing Theory (Accident-Causing Theory) is to extract information from a large number of accidents, to analyze the variables and determine and diagnose the causes of accidents, to explore the pattern of events, and to provide a scientific and detailed basis for the prevention of accidents and the improvement of safety management work from the theoretical point of view. The common methods used in causal analysis research are game theory-TOPSIS method, hierarchical analysis (AHP) [10], gray system theory, and explanatory structural model (SIM) [20]. Human factors and the validity and reliability of safety science methods are important criteria for assessing their applicability to accident analysis, but these criteria often lack systematic evaluation. Therefore, the aim of this study is to compare two systematic accident analysis methods, the Accident Map Method (Accimap) and the System Theoretical Accident Model (STAMP), and analyze their performances in four aspects: procedure, level of detail, causal factors, and suggestions for improvement [5], and take the gas explosion accident in the coal mine of Daqing, Heilongjiang, China, as a case study to The validity and reliability of these two methods are discussed in depth. These systematic accident analysis (SAA) methods are based on socio-technical systems, control theory, and resilience engineering [12], and the validity and reliability of the results generated are often considered key criteria for judging their applicability. According to the China Coal Mine Safety Production Network (CMSPN) Accident Express and official data released by provincial coal mine safety supervision bureaus, roof accidents and transportation accidents occur more frequently and cause more fatalities, while the number of gas accidents is much lower than that of transportation accidents, but the number of fatalities is higher than that of transportation accidents, indicating that gas accidents are more dangerous. At present, roof accidents, transportation accidents and gas accidents are still the main causes of mine safety production accidents in China.

On May 23, 2021, a coal mine gas explosion occurred in Daqing City, Heilongjiang Province, China, at the Daqing Longfeng Coal Mine. A large amount of gas leaked from the mine and started a fire (https://www.chinamine-safety.gov.cn/). Investigations showed that about 20 miners were carrying out operations underground at the time of the incident, and that some mine leaders and safety managers failed to perform their duties of emergency warning and ventilation management when the gas explosion occurred, resulting in 24 deaths and 52 injuries. Gas build-up and inadequate ventilation systems were the main causes of the explosion. To this end, we use systems theory applied to accident causation models and identify a range of causal factors. In contrast to related studies such as Underwood and Waterson and Waterson, this study provides a systematic comparative analysis of the results and analytical procedures of four different studies on the same accident through quantitative and qualitative methods. Comparison of the causal factors showed that the reliability based on the STAMP approach (63%) was significantly higher than the Accimap approach (36%), but its validity was lower at 8%. In terms of recommendations for improvement, the STAMP analysis

provides broader and covers multiple system levels, whereas the Accimap analysis focuses more on recommendations related to the system as a whole [20]. These findings suggest that the use of more structured analytical methods such as STAMP can help to reveal the nonlinear and coupling relationships in major accidents, and thus have important theoretical significance and practical value for the prevention and control of major accidents in coal mines.

4.2 Measures for the Prevention of Accidents

Preventive measures for mine safety accidents are crucial, not only to maximize the safety of miners' lives, but also to work to reduce the occurrence of mine disasters and ensure the safety and stability of mine operations. Effective preventive measures can greatly reduce the risk of accidents, improve the safety of mine production, and create a safer working environment for miners. Below are some common and critical mine safety accident prevention measures:

1.In order to strengthen the new safety management system, it is necessary to improve the ventilation system and strictly implement the mine safety production responsibility system. Regular safety inspections and hidden dangers are carried out to identify potential risks and take effective preventive and control measures in a timely manner. In underground mining operations such as coal mines, it is necessary to ensure sufficient ventilation to prevent the accumulation of gas and other harmful gases, so as to avoid the occurrence of explosions and other major safety accidents, and at the same time, it is necessary to strengthen the safety training of miners and the construction of a safety culture [21], the miners are the first line of defense for mine safety, so they should be organized regularly to carry out safety training, to improve their safety awareness and emergency response capabilities, and to create a safe, healthy and positive working atmosphere, and encourage employees to take the initiative to participate in safety management.

2.A risk matrix (high risk, medium risk, low risk) is used for hierarchical management based on a comprehensive assessment of the probability and consequences of risks, and appropriate control measures are taken based on the results of the assessment, prioritizing high-risk areas to ensure safe production. At the same time, detailed emergency plans for mining disasters are formulated and emergency drills are organized regularly [13] to ensure that mine staff can react quickly and take effective rescue measures when disasters occur.

3.Scientific geological investigation is carried out to assess the stability of the mine, especially during the extraction process, to ensure the structural safety of the mine and prevent the occurrence of geological disasters such as landslides and landslides. At the same time, the introduction and application of advanced safety technology equipment, such as gas monitoring instruments, explosion-proof equipment and automated control systems [22], real-time monitoring of environmental changes in the mine through technical means, timely warning of potential dangers, to ensure that mining operations are carried out safely.

5 CONCLUSIONS AND OUTLOOK

Aiming at the model construction of smart mines, mine production safety problems and solutions, this paper analyzes the current status of smart mine research and development, and points out that digital twin technology is the inevitable trend of the future evolution of smart mine technology. From the perspective of system architecture, smart mines need to realize their optimization and enhancement by deriving and constructing physical entities and smart twin digital bodies. On the basis of applying the actual needs, this paper discusses how to solve the key objectives of safety management system, risk assessment and control, and accident analysis and prevention in the process of realizing smart mine technology. Based on the current research status and existing gaps, this paper puts forward the following suggestions: 1) the establishment of an intelligent control system based on dynamic risk assessment as the core guarantee of mine safety, 2) increasing R&D investment in cutting-edge technologies, such as AI and digital twin, to promote technological innovation and application, and 3) the application of deep learning in mine risk assessment and accident prediction, to further improve mine safety management's Intelligent level. In the future, the mine safety management system will make more significant progress with the help of intelligent, digital and automation technology, which is no longer limited to static monitoring and after-the-fact response, but will be transformed to dynamic, real-time intelligent management. Through big data analytics, IoT, digital twins and other means, risk prediction and control in mines will be more accurate, and accident prevention and emergency response will be more efficient. With the in-depth promotion of safety culture and the continuous improvement of industry standardization, the overall safety management level of mines is expected to be steadily improved and the frequency of accidents gradually reduced, creating a safer working environment for miners. Overall, the core development direction of mine safety management in the future should focus on intelligent, data-based management methods, while strengthening the cultivation of safety awareness of the whole staff and cultural construction, so as to realize the transformation from post-response to forward-looking prevention.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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BUILDING A DIGITAL CLOUD PLATFORM FOR TAX COLLECTION AND MANAGEMENT OF ANCHOR REWARD INCOME BASED ON BIG DATA ANALYSIS AND CLOUD COMPUTING

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Abstract: This study uses big data analysis, cloud computing, artificial intelligence and other technologies to build a digital cloud platform for tax collection and management of anchor reward income, and provides full-process intelligent 'cloud' tax services. By analysing the current situation of the development of the network broadcasting industry and the problems of tax collection and management. A detailed design and implementation of the digital cloud platform for tax collection and management of anchor reward income is carried out, including the hybrid cloud module, data sharing module, and cloud service module for tax collection and management policies. It achieves full digital tracking and monitoring of anchor income, real-time collection and integration of data, accurate calculation and analysis, timely warning of abnormal situations, identification of potential tax avoidance, and accurate prevention and control of the risk of tax payment by anchors; it achieves the goals of fairness, compliance, efficiency, intelligence, and digitalisation of tax collection and administration of anchor bounty income, prevents tax source loss, helps coordinate the scheduling of tax policies, resources, information, and data, and provides intelligent decision support for the taxation It provides intelligent decision-making support for the tax department, and realises the standard tax collection and efficient control of anchor reward income.
Keywords: Anchor bounty income; Tax administration cloud platform; Risk warning; Big data analysis

1 INTRODUCTION

In recent years, China's webcasting industry has experienced a blowout development. According to the '2023 China network performance (live) industry development report', as of the end of 2023, China's live broadcasting user scale reached 617 million, the anchor account accumulated more than 130 million, the average daily peak of new anchors for 43,000 people, 2023 industry market scale reached 193.03 billion yuan. Behind this prosperity gradually bounty income expenditure, levy and management problems are increasingly prominent, such as imperfect tax system, taxpayers main body and other issues. Become a key factor restricting the healthy development of the industry. Scholars at home and abroad have carried out some research on the tax collection and management of the Internet economy. Meijer R.(2015) believes that the government should intervene in the regulation of network live broadcasting platforms and should focus on the three aspects of freedom of expression on the platform, the protection of information, and the protection of intellectual property rights. Scholars such as Franziska Zimme(2017) have analysed the necessity of the regulation of network social media such as Periscope, YouNow and other online social media regulation of the need to analyse, that the new social media there are data and user privacy leakage, platform illegal retransmission and other problems, should strengthen the regulation of online social media platforms and the protection of user information security [1]. Wilson (2017) from the point of view of technological regulation believes that based on the distributed network, the regulator can use algorithms to platforms of data to monitor and innovate the regulation [2]. Elise Thorburn (2017) conducts a case study on live webcasting APPs and argues that live webcasting should be researched from a variety of disciplinary fields such as jurisprudence and sociology [3]. Wang Huoliang (2021) believes that the income from webcasting rewards should be taxed, and he believes that the premise of taxation lies in whether it is taxable, which should be judged from the three aspects of the subject of taxation, the object and the tax benefits, and webcasting rewards are fully in line with the three elements of taxation [4]. Xing Lu (2022) believes that China's network live broadcasting industry is still in the primary stage of development, the industry's entry threshold is low, the speed of profit is fast, the quality of practitioners is uneven, and at the same time, due to the temporary absence of relevant tax norms, there are problems in the management of the collection of personal income tax in the network live broadcasting industry that can't be ignored [5]. Sun Meichen (2024) believes that it should be clear that the tax items of the network live streaming reward as a breakthrough, and at the same time clarify the live streaming reward personal income tax withholding obligation, to provide a basis for the live streaming reward personal income tax collection and management, in the way of collection of personal income tax to distinguish between the approved levy and the checking of accounts for levy of the applicable circumstances, and finally in the tax penalties to apply the penalty decision and the range of penalties prudently [6].
Although the above scholars have studied the tax collection and management of the Internet economy, there is insufficient systematic research on the cloud platform for tax management of anchor bounty income tax, and the related

branch research is also insufficient. There is a lack of research on the technical systematisation of the digital platform for tax collection and administration and the real-time and automated monitoring of the tax collection process through digital technology, cloud computing and other emerging technological means to monitor, identify, calculate and collect taxes in real time and accurately. There are no comprehensive and feasible proposals for the improvement of the tax penalty and compliance management system. In summary, this study refines this deficiency by using digital technology to construct a tax collection and management cloud platform to solve the difficult problem of tax collection and management issues in the webcasting industry.

2 MATERIALS AND METHODS

2.1 Logical Architecture of the Anchor Reward Income Tax Collection and Management Cloud Platform

The authentication, the financial personnel will make corrections after clarifying the reasons for the failure, and then carry out the authentication again. The financial personnel make remote tax declaration through the cloud platform for tax administration of anchor reward income, and the system automatically reads the tax declaration data, then transmits it to the tax department to automatically complete the business processing of tax declaration, and finally feeds back to the anchor through the module. The cloud platform for tax collection and management of anchor reward income comprehensively collects invoice detail data and automatically generates tax return forms and other invoices, tax-paid vouchers, and lists of deduction vouchers for submission. The financial personnel make tax payments according to the tax return, and the module sends tax completion certificates to the anchors upon completion. The overall framework of the cloud platform for tax collection and management of anchor reward income is shown in Figure 1 below.

2.2 Logical Architecture of Anchor Reward Income Tax Collection and Management Cloud Platform

The anchor reward income tax collection and management cloud platform built based on digital technology consists of five dimensions, which are the basic resource layer, data storage layer, collection and management application layer, user service layer, and risk identification management layer [7].

2.2.1 Basic resource layer

The basic resource layer mainly covers two parts: software resource layer and hardware resource layer [8]. Among them, the hardware resource layer includes servers, storage devices, and network devices; the software resource layer consists of two parts: the computing resource layer and the storage resource layer. As the foundation of the anchor reward income tax collection and management cloud platform, it can meet the basic needs of the platform at all levels.

2.2.2 Data storage layer

It mainly includes a data sharing platform, a data storage platform, and a data mining platform. Among them, the data storage platform is the foundation of the data storage layer, and the data mining platform is the pillar of the data storage layer. Tax authorities can carry out in-depth mining of a large amount of tax data through the data mining platform. At the same time, tax authorities can realise real-time exchange of internal and external data through the data sharing platform, creating an economic and efficient information exchange environment for the cloud platform.

2.2.3 Levy Management Application Layer

It consists of four parts: tax-related information sharing, tax source management, tax service and tax inspection. With the help of cloud computing technology, the levy management application layer adopts switches to connect with server nodes, and the levy management application layer can install network cards for servers to enable servers to perform their routing and forwarding functions, thus establishing a network structure that can be applied to specific scenarios.

2.2.4 User Service Layer

The cloud platform for tax collection and management of anchor reward income is managed by the tax authorities, while the participants of the cloud platform for tax collection and management of anchor reward income are taxpayers and various government departments. According to the different characteristics or needs of taxpayers, the Host Reward Revenue Tax Administration Cloud Platform provides different tax services for them, and the Host Reward Revenue Tax Administration Cloud Platform also has the advantages of high efficiency and low cost.

2.2.5 Risk identification management module

The risk identification management module carries out in-depth risk analysis on the tax administration data of anchor reward income through the built-in model library, algorithm library, knowledge library and expert library, identifies potential risks and provides countermeasures to help enterprises carry out effective tax administration planning and reduce the probability of risk occurrence. The module also includes a risk assessment system, which allows financial staff to regularly study and take exams to improve their risk-handling ability, and tax authorities to assess the tax collection and management system of enterprises to promote the establishment of a tax collection and management supervision system for enterprises before, during and after the tax collection and management, and to improve their risk-handling ability.

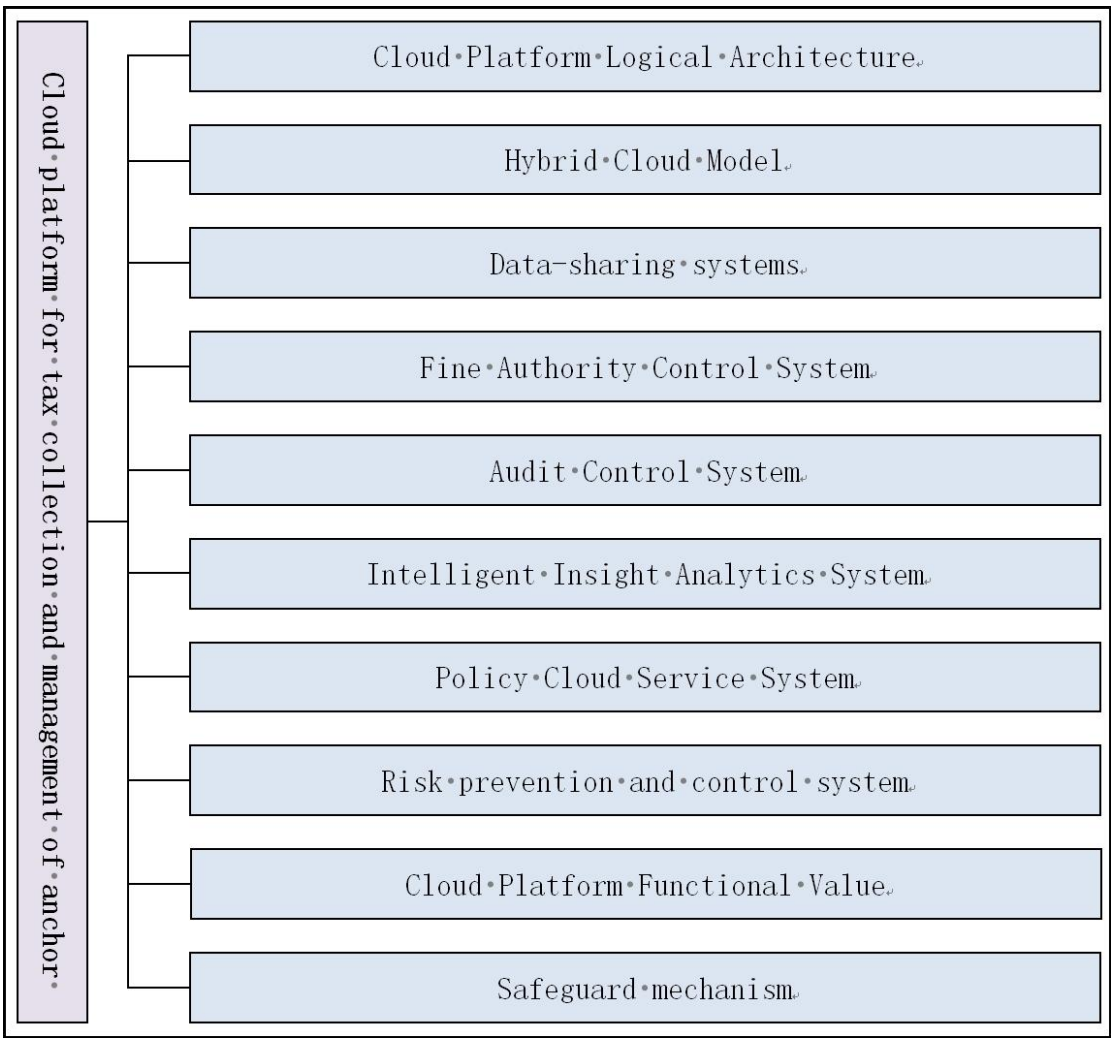

Figure 1 Overall framework of the Cloud Platform for Tax Collection and Management of Anchor Reward Income

2.3 Hybrid Cloud Model for Tax Collection and Management of Anchor Bounty Income

The hybrid cloud model is a cloud computing deployment model that combines private and public clouds to meet the security and flexibility needs of the webcast reward tax system by flexibly deploying and migrating applications and data between private and public clouds. The webcast reward tax management system can store and manage sensitive taxpayer data in the private cloud to ensure data security, while non-sensitive data and computing tasks can be processed using the elastic resources of the public cloud to improve the system's computing power and performance.

3 MODELLING AND SOLVING

3.1 Host Reward Income Tax Collection and Inspection Control System

In view of the characteristics of tax inspection work, the anchor reward income tax collection and management cloud platform integrates artificial intelligence technology in depth to create an intelligent tax inspection office platform in line with the reality of work. It makes full use of artificial intelligence algorithms to develop the tax collection and inspection control system in depth, and upgrades the existing electronic checking software combined with tax big data in an intelligent way; on the basis of summarising the problems of tax collection and management of anchor reward income, it constantly enriches the case data model to simulate manual checking; through the intelligent inspection platform, it automatically obtains all kinds of operational data information of the subject of investigation, automatically analyses and matches the case data model, and automatically judge tax suspicions, and issue a brief report on the analysis of tax-related situations of enterprises with one click; and establish a module for automatically checking the accuracy of the applied legal provisions to assist the adjudicators in the adjudication work, which can also strengthen the supervision of the adjudicators of the audit cases and improve the adjudication mechanism of the audit cases.

3.2 Intelligent Insight Analysis System for Tax Administration of Host Reward Income

Relying on the underlying data centre, the cloud platform for tax collection and management of anchor bounty income is embedded with a multi-dimensional analysis engine, which enables tax analysts to flexibly switch analysis

dimensions and carry out an all-round analysis mode. At the same time, it uses visualisation technology to conduct rapid information exchange with users through multi-terminal data dashboards to enhance the ability of agile strategic decision-making. The anchor reward income tax collection and management cloud platform makes full use of tax-related data, builds business analysis scenarios, applies statistical methods from quantitative analysis to qualitative analysis, quickly locates industry finance and taxation problems, provides a digital foundation for intelligent tax decision-making, and realises the creation of finance and taxation value with data [9].

3.2.1 Statistical analysis portal

Establish tax data cockpit, effectively monitor the tax operation of the anchor, achieve multi-dimensional statistical analysis (including regional tax, tax types, tax concessions, filing progress, etc.), to help users quickly capture the data analysis results that need to be focused on, to assist the anchor to make efficient and accurate tax decisions.

3.2.2 Tax data centre

Integrate all tax data scattered inside and outside the system through the underlying technology to establish a complete tax data set, helping users to grasp the tax payment reality of the whole group in order to support the overall planning of tax work. Using the standard report analysis mode of the full-scenario intelligent tax management platform, it allows users to define their own data sources and statistical dimensions to maximally meet the needs of diverse scenarios. At the same time, the application has a built-in automatic tax liability rate calculation model to help users quickly grasp the tax liability situation.

3.2.3 Multi-dimensional tax insight

Through the in-depth extraction of tax data, multi-dimensional analysis is carried out for two major themes: tax types and management areas, and personalised charts are used to display the results, so as to quickly grasp the dynamics of tax. Real-time refreshing of total tax payment and tax exemption ranking, timely grasp of work performance, and abnormal changes at a glance. All insight results support layer-by-layer penetration and provide traceability paths to help tax staff identify key conflicts and solve problems efficiently.

3.2.4 Declaration progress monitoring

Tax statistical analysis provides comprehensive declaration and payment monitoring, and the progress status meets the dynamic management of key tax nodes, greatly improving the efficiency of supervision and reminding business personnel to complete the relevant declaration and payment work in a timely manner.

3.2.5 Enterprise credit level enquiry

Tax credit level is a key part of the social credit system, which affects the enterprise tax payment environment and preferential tax treatment. The full-scene intelligent tax management platform supports tax credit level enquiry, provides one-click enquiry on downgrading status, visualised Kanban boards and other functions, and assists users in identifying credit crises so as to deploy and avoid relevant tax risks in advance.

3.3 Cloud-based service system for anchor reward income tax collection policy

The complexity of tax calculation for anchor reward income makes it difficult for anchors to file tax returns. For this reason, we design a cloud-based tax administration policy service system to provide accurate tax calculation and policy services. The system is pre-set with rich tax scenarios, declaration forms, professional drafts and algorithms, covering various industries and regions, and setting a large number of risk checking points. Anchors can access preferential policies and compliance requirements in real time to reduce application costs [10].

3.4 Anchor Reward Income Tax Administration Risk Prevention and Control System

In order to control the impact of the risk of tax administration of anchor reward income on the development of anchors, the system actively uses the risk identification management module to carry out tax risk management and control, standardise the tax activities of enterprises, and reduce the chances of the occurrence of enterprise tax risks. The system makes use of the risk identification management module to comprehensively collate enterprise tax data, thoroughly examine the impact of business activities on tax payment, clarify whether the capital expenditure is for public use, whether the expense presentation is in line with the enterprise accounting standards, and whether the division of costs and expenses is standardised, etc., so as to effectively avoid the situation where the shareholders are reimbursed illegally by using the enterprise's costs and expenses; and review whether the payment of employees' salaries is in line with the list of social security, and whether the costs and expenses of the period are tax adjustments are carried out in compliance, whether the period expenses are accrued in accordance with regulations, whether the input tax amount is transferred out in time for processing, etc., so as to avoid the risks related to value-added tax in a timely manner; verify the composition of the anchor income in time, make clear whether the payment of personal income tax is in compliance, and determine whether the enterprise's taxable income is accurate, so as to effectively circumvent the risk of income tax [11].

On the basis of clarifying the time of occurrence of risks, the scope of occurrence, risk triggers, the degree of harm and solution measures, etc., the risk identification management module is designed to generate a risk heat map, which is used to formulate a risk response strategy, carry out tax planning in a reasonable manner, determine the risk matters and allow all parties to make enquiries, so as to achieve the purpose of controlling the probability of the occurrence of risks and reducing the harms of risks, and safeguarding the long-term development of the enterprise.

The anchor reward income tax levy management risk control application scenario helps the anchor to improve the ability to prevent risks beforehand, and helps the anchor to check themselves in advance and prevent and control them in time. Based on the industry finance and tax data, relying on the platform's leading technical architecture advantages, the risk monitoring model set up through the business, intelligent scanning and locking the potential risks that may exist, and timely warning, tax personnel can be prompted to timely carry out risk research and judgement, investigate and deal with; at the same time, the anchor reward income tax collection and management of risk control application scenarios can be the indicators of risk models. At the same time, the anchor reward income tax risk management application scenario can evaluate the usability of the indicator risk model and iteratively improve the indicator library. In addition, the application scenario of risk management and control of tax collection and management of anchor reward income can monitor the changes of tax policies and regulations in real time, update the tax risk assessment of enterprises in a timely manner, and provide corresponding countermeasures.

4 DISCUSSION

4.1 Improve the Efficiency of Tax Collection and Verification of Anchor Reward Income

The banking and tax system opens up the capital chain for sharing, and the tax bureau networks data and information with various ministries, the People's Bank of China, commercial banks and other organisations to give full play to the supportive function of big data technology in information sharing, so as to timely, accurately and in a multi-dimensional manner monitor and verify taxpayers‘ basic information, tax payment status, personnel information, etc. (e.g., information on the enterprise's registration, information on the enterprise's relevant personnel, etc.), in order to verify the authenticity of taxpayers’ declarations It can also realise information sharing and multi-dimensional, all-round and full-process tax co-administration.

4.2 Accurate Monitoring of Tax Liability

This anchor bounty income tax collection and management cloud platform system verifies whether there are any anomalies by supervising the data declared, and it also checks and compares the data of taxpayers' bank accounts and enterprise-related ledgers. This tax control system constantly monitors the enterprise's tax liability rate, whether it is too high or too low there is a risk of being interviewed and audited by the tax bureau. In practice, although an enterprise's tax liability rate may be affected by a number of factors, generally the fluctuation of the tax liability rate of an enterprise within a certain period of time will not be very large. The level of VAT and income tax and changes in the tax burden of each industry under the tax system are recorded in greater detail in the local tax system, which is more sensitive to the percentage of fluctuation in the tax burden rate of enterprises, and the tax authorities will assess the tax payment of enterprises and investigate the reasons for fluctuations in the tax burden rate of some enterprises.

4.3 Centralisation and Easy Access to Tax-Related Information of Anchors

The cloud platform for tax collection and management of anchor reward income concentrates the tax-related information of all anchor reward income in the sharing platform, and it is necessary to require the Internet live broadcasting platform not only to record and share the personal information of the network anchor for registration and authentication, but also to record and update in real time and in the peer-to-peer sharing platform with the tax authorities the legal relationship between the network anchor and the platform and the guilds, the way of settlement of the transaction, the ‘reward’ share ratio, and the data of the ‘reward’ actually received by the anchor. The ‘reward’ share ratio and the actual ‘reward’ data received by the anchor should be recorded and updated in real time and shared on the peer-to-peer sharing platform with the tax authorities.

5 CONCLUSION

This study has successfully constructed a digital cloud platform for tax collection and management of anchor reward income, describing the logical structure of the cloud platform for tax collection and management of anchor reward income, as well as the related tax collection and management audit control system, tax collection and management intelligent insight and analysis system, tax collection and management policy cloud service system, and income tax collection and management risk prevention and control system, etc. Based on this this paper also proposes to put forward the following relevant recommendations. Increase the penalty for illegal and irregular behaviour such as tax evasion and tax evasion on the reward income of anchors, and also establish integrity files to incorporate their behaviour into the management of the credit system. At the same time, through the establishment of a more stringent access audit mechanism, to ensure that the new anchor has a legitimate identity background and stable economic sources. Live broadcast platform as the anchor income payment and management, should also bear the responsibility of supervision. During the access audit process, the platform should strictly review the tax status of the anchor and assist the tax department to complete the daily tax monitoring work. The tax department should establish a regular assessment mechanism for the tax compliance of the anchor's income, and link it to the anchor's credit rating and the platform's incentive policy.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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HONOR AND LEADERSHIP IN HENRY IV, PART 2: A COMPARATIVE ANALYSIS OF HOTSPUR, PRINCE HENRY, AND FALSTAFF

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Abstract: In *Henry IV, Part 2*, Shakespeare intricately explores the concept of honor, presenting contrasting perspectives through the characters of Hotspur, Prince Henry, and Falstaff. Each character embodies a different conception of honor, offering a critique of its role in leadership and personal identity. Hotspur's impulsive valor is driven by a desire for personal recognition, ultimately leading to his downfall. Prince Henry, on the other hand, evolves throughout the play, moving from a self-centered pursuit of glory to a more pragmatic understanding of leadership that prioritizes national stability over personal pride. Falstaff, with his cynical view, mocks traditional notions of honor, exposing the contradictions in a society that glorifies war while neglecting its human cost. Through these contrasting figures, Shakespeare presents a nuanced examination of honor as both a burden and a guiding force, ultimately suggesting that true honor lies not in individual acclaim but in the long-term welfare of a kingdom. The play thus offers a profound commentary on the responsibilities of leadership, the complexity of honor, and the moral growth necessary to wield power effectively.
Keywords: Honor; Leadership; Moral growth; Effective power wielding

1 INTRODUCTION

Honor is not merely a demonstration of bravery but a test of moral fortitude—an ability to maintain grace under pressure, even when personal ambition urges otherwise. This idea, often romanticized in literature and history, carries deep implications for both individuals and societies. In Shakespeare's *Henry IV, Part 2*, the theme of honor is explored with complexity, revealing how it is perceived, pursued, and ultimately achieved by different characters in the play. Shakespeare uses the contrasting views of honor held by Hotspur, Prince Henry, and Falstaff to present a multifaceted examination of leadership, valor, and the personal cost of maintaining honor.

At the core of the play is the tension between different understandings of what it means to be honorable. On the one hand, there is the militant honor exemplified by Hotspur, the young and fiery nobleman whose sense of honor is grounded in battle, reputation, and a deep-seated need for recognition. His honor is impulsive and uncompromising, driven by an internalized need to uphold his family's name and defend his personal dignity, often through rash actions. On the other hand, Prince Henry's concept of honor evolves throughout the play, transitioning from a youthful desire for personal glory to a more nuanced understanding of leadership that encompasses responsibility, duty, and the welfare of the people he will eventually rule. In this sense, honor for Henry is not simply a matter of individual achievement but a means to secure the stability of the kingdom and fulfill his obligations as a future monarch.

Shakespeare's juxtaposition of these two characters—Hotspur and Henry—serves to highlight the multifaceted nature of honor and leadership. While Hotspur's actions are motivated by an intense desire for personal recognition, Prince Henry's path to honor is marked by a careful balancing of personal ambition with the demands of political reality. Through the unfolding events of the play, Shakespeare provides a powerful commentary on how honor, in its most genuine form, can transcend individual ego and become a tool for governance and social stability.

2 REDEFINING HONOR: LEADERSHIP, VALOR, AND MORAL GROWTH IN HENRY IV, PART 2

2.1 The Honor of Hotspur: Impulsive Valor and Tragic Downfall

Hotspur's understanding of honor is deeply rooted in his sense of personal glory and battlefield prowess [1]. He views honor as a tangible, almost material commodity, something to be gained through acts of heroism and bravery. To Hotspur, honor is synonymous with victory in combat and the public recognition that accompanies it. This perception of honor is closely tied to his impulsive nature—his tendency to act without reflection or foresight, driven by a burning desire to be seen as a hero.

From the very beginning of the play, Hotspur's commitment to honor is evident in his behavior. His refusal to ransom prisoners after the battle is a clear indication of his belief that honor cannot be bought or compromised. He sees the act of capturing and executing enemies as an essential part of maintaining his honor. This uncompromising stance leads him into conflict with King Henry IV, who views Hotspur's actions as reckless and counterproductive to the stability of the kingdom. For Hotspur, however, the pursuit of honor is not about the well-being of the kingdom but about the affirmation of his personal identity as a warrior and nobleman [2].

Hotspur's tragic flaw lies in his inability to see beyond his narrow conception of honor. His obsession with personal glory blinds him to the larger political realities of the time. This is particularly evident in his rebellion against King Henry IV, where his pursuit of honor leads him into a deadly conflict that ultimately results in his demise. Hotspur's refusal to negotiate or compromise, coupled with his constant need for recognition, leads him to make rash decisions that alienate potential allies and seal his fate. His death on the battlefield is not just a physical defeat but a symbolic one—Hotspur's understanding of honor, based on impulsive valor and unchecked ambition, ultimately leads to his downfall.

2.2 Prince Henry: A Journey from Personal Glory to Political Responsibility

In contrast to Hotspur's reckless pursuit of honor, Prince Henry's journey is marked by an evolving understanding of leadership and duty. At the start of the play, Henry is seen as a wayward prince, spending much of his time in the taverns with Falstaff and his companions, engaging in escapism and youthful indulgence. His behavior contrasts sharply with the more serious, military-minded Hotspur [3], and his father, King Henry IV, is openly disappointed in him. The king's expectations for his son are clear—he wants Henry to embody the traditional ideals of honor through military achievement, much as his predecessor, Henry III, had done. However, Henry's approach to honor is more pragmatic, grounded in his awareness of his eventual role as king and the political responsibilities that come with it.

At the heart of Henry's development is his shifting conception of honor. In the early acts of the play, Henry appears indifferent to the traditional notion of honor, choosing instead to live a life of disrepute. However, as the pressures of kingship and the need to secure his throne begin to weigh on him, Henry undergoes a transformation. The turning point occurs after Hotspur's death, when Henry steps into the role of a leader who must not only command troops but also govern a kingdom.

The battle with Hotspur marks a pivotal moment in Henry's evolution as a leader. In the final confrontation, Henry defeats Hotspur [4], fulfilling the expectations imposed upon him by his father and the court. However, the aftermath of this victory reveals the complexities of Henry's understanding of honor. When Falstaff falsely claims to have killed Hotspur and Henry remains silent, allowing the lie to stand, it is a moment of profound significance. Rather than reacting with indignation or correcting Falstaff's falsehood, Henry allows the charlatan to take credit for the kill. This moment of restraint signals a significant shift in Henry's understanding of honor—he begins to realize that true leadership is not about claiming individual glory but about securing the stability and welfare of the realm.

This development is further reinforced by Henry's interactions with his father. The king's traditional view of honor, grounded in military valor and aristocratic dignity, is at odds with Henry's more pragmatic approach. The king criticizes his son for failing to embody the kind of honor he admires, which leads to a sense of tension between the two. However, by the end of the play, Henry has surpassed his father's narrow definition of honor, recognizing that true greatness as a leader lies in the ability to put the needs of the kingdom above personal pride.

2.3 Falstaff: Honor as a Hollow Pursuit

In addition to the figures of Hotspur and Prince Henry, Shakespeare introduces Falstaff, a character who offers a cynical, self-serving view of honor. Falstaff's perspective on honor is shaped by his pragmatic and opportunistic nature. He openly mocks the concept of honor, dismissing it as an empty, superficial ideal that serves no practical purpose. To Falstaff, honor is a mere "scutcheon"—a piece of insignia or decoration that holds no intrinsic value [5]. His view of honor is driven by self-preservation and the pursuit of comfort, rather than any noble pursuit of glory or duty.

Falstaff's mockery of honor exposes the contradictions of a society that glorifies war and violence while disregarding the human cost. Throughout the play, Falstaff engages in a series of escapades, dodging responsibility and avoiding conflict whenever possible. His approach to life is one of survival rather than honor, and he is willing to go to great lengths to avoid danger, including lying, cheating, and deceiving others. However, while Falstaff's view of honor may seem cynical, it also highlights the human desire for self-preservation and the need to navigate a world fraught with uncertainty and danger.

Despite his dismissal of honor, Falstaff plays a crucial role in Prince Henry's development. Through his interactions with Falstaff, Henry is able to explore the limits of traditional honor and develop a more nuanced understanding of leadership. Falstaff's antics serve as a foil to the seriousness of Hotspur's honor and the more pragmatic approach of Henry. In this way, Falstaff's character serves as a reminder that honor is not always as straightforward or as admirable as it is often portrayed [6]. His survivalist philosophy challenges the traditional notions of chivalry, exposing the contradictions and limitations of a system that values martial prowess over human dignity.

2.4 The Evolution of Honor: Leadership and Responsibility

Ultimately, Shakespeare presents honor as both a burden and a guiding force, shaping the trajectory of Henry's transformation into a capable ruler. Honor, in *Henry IV, Part 2*, is not a simple ideal to be pursued at any cost, but rather a complex concept that must be understood in the context of leadership and responsibility. While Hotspur's reckless pursuit of honor leads him to his tragic end, and Falstaff's dismissal of honor leaves him a man of no true consequence, Henry learns to wield honor as a tool of governance [7]. His ability to relinquish personal credit for Hotspur's death demonstrates that true honor lies not in public recognition or battlefield achievement but in the ability to prioritize the

greater good and secure the long-term welfare of the kingdom [8].
Through his evolving understanding of honor, Henry emerges as a leader who transcends the narrow views of honor held by both his father and Hotspur [9]. By choosing national stability over personal pride, he proves that greatness is not achieved through reckless valor or self-aggrandizement but through wisdom, restraint, and an unwavering commitment to the responsibilities of leadership. In doing so, he rises to the challenge of kingship, demonstrating that honor, when properly understood, is not a mere decoration or title but a guiding force that shapes the destiny of a ruler and the future of a nation [10].

3 CONCLUSION

In the end, Shakespeare's exploration of honor in *Henry IV, Part 2* serves as a powerful reminder that true leadership is not defined by the pursuit of personal glory but by the ability to navigate the complexities of power, responsibility, and moral integrity.

3.1 The Nature of Leadership

True leadership, as depicted in Shakespeare's *Henry IV, Part 2*, is not merely a quest for personal glory or recognition; rather, it is fundamentally about confronting and navigating the intricate interplay of power, responsibility, and moral integrity. This notion is powerfully illustrated through the contrasting journeys of key characters like Hotspur, Prince Henry, and Falstaff, each of whom embodies a distinct approach to honor and leadership.
Hotspur, with his impulsive valor and unyielding pursuit of martial glory, exemplifies a narrow and self-centered conception of honor. His actions are driven by a deep-seated need for personal recognition and the upholding of his family's name, often at the expense of broader considerations. While his bravery on the battlefield is undeniable, his reckless approach ultimately leads to his downfall, highlighting the limitations of a leadership style that prioritizes personal acclaim over the welfare of others.
In contrast, Prince Henry's evolution throughout the play offers a more nuanced and sophisticated understanding of leadership. Initially portrayed as a wayward youth more interested in personal indulgence than in his royal duties, Henry undergoes a profound transformation. He learns to balance his personal ambitions with the responsibilities that come with his position, recognizing that true honor lies in serving the greater good of the kingdom. His journey is marked by a growing awareness of the complexities of power and the moral demands of leadership, culminating in his emergence as a capable and compassionate ruler.
Falstaff, with his cynical and opportunistic worldview, provides a counterpoint to both Hotspur's idealism and Henry's evolving pragmatism. His irreverent attitude towards traditional notions of honor serves to expose the contradictions and hypocrisies inherent in societal expectations. Through Falstaff, Shakespeare critiques the superficial glorification of war and the pursuit of honor at all costs, suggesting that true leadership must transcend such narrow and self-serving motivations.
Ultimately, Shakespeare's portrayal of these characters underscores the idea that true leadership is not about the pursuit of personal glory, but about the ability to navigate the complexities of power and responsibility with moral integrity. It requires a deep commitment to the welfare of others, a willingness to make difficult choices, and the wisdom to balance personal ambition with the greater good. Prince Henry's transformation serves as a powerful testament to this ideal, demonstrating that true leadership is not a static achievement but a dynamic process of growth, self-awareness, and ethical decision-making.

3.2 Character Contrast and the Impact of Honor

In his exploration of honor within *Henry IV, Part 2*, Shakespeare masterfully employs the contrasting characters of Hotspur, Prince Henry, and Falstaff to illustrate the multifaceted and often paradoxical nature of honor in the context of leadership. Hotspur, with his fiery and impulsive nature, embodies a traditional yet narrow view of honor, one that is deeply rooted in martial valor and personal recognition. His honor is defined by the battlefield, where he seeks to uphold his family's name and earn the respect of his peers through acts of bravery and defiance. However, this intense focus on personal glory often blinds him to the broader consequences of his actions, leading to reckless decisions that ultimately contribute to his downfall.
Prince Henry, on the other hand, begins the play with a seemingly carefree and self-indulgent attitude, which initially masks his true potential. As the story unfolds, he undergoes a significant transformation, moving from a youthful pursuit of personal amusement to a profound understanding of his responsibilities as a future king. His evolving concept of honor is marked by a growing recognition that true leadership requires a balance of personal ambition with the greater good of the kingdom. Henry learns to prioritize national stability and the welfare of his subjects over the fleeting rewards of individual acclaim, demonstrating a nuanced and selfless vision of honor that is both pragmatic and morally upright.
Falstaff, the play's comedic and cynical foil, offers a stark contrast to the more conventional views of honor held by Hotspur and Prince Henry. His irreverent and opportunistic nature mocks the very idea of honor, treating it as a malleable and often hypocritical concept used by society to justify its most base actions. Falstaff's perspective serves to highlight the absurdities and contradictions inherent in the glorification of war and the pursuit of honor at all costs.

Through his interactions with Falstaff, Prince Henry is exposed to a worldview that challenges the traditional notions of honor, prompting him to question and ultimately redefine his own understanding of what it means to be honorable in a position of power.

Through these contrasting figures, Shakespeare presents a vivid and complex tapestry of honor and leadership. He shows how honor can both elevate and distort the path to leadership, depending on how it is understood and pursued. Hotspur's reckless bravery and Falstaff's cynical opportunism represent two extremes, while Prince Henry's journey towards a more balanced and selfless conception of honor offers a compelling example of moral growth and effective leadership. In the end, Shakespeare suggests that true honor lies not in the pursuit of personal glory or the rejection of societal expectations, but in the ability to navigate the complexities of power and responsibility with integrity, wisdom, and a deep commitment to the welfare of the kingdom.

3.3 Prince Henry's Growth

Prince Henry's journey in *Henry IV, Part 2* is marked by a profound transformation that sets him apart from both Hotspur's impulsive valor and Falstaff's cynical pragmatism. Unlike Hotspur, who is driven by a reckless desire for personal glory and recognition, often engaging in actions that are as dangerous as they are self-serving, Prince Henry evolves to embrace a more sophisticated and selfless conception of honor. He recognizes that true leadership requires a deeper commitment to the welfare of the kingdom rather than the pursuit of individual accolades. This shift is not merely a change in perspective but a fundamental redefinition of what it means to be honorable in a position of power.

Falstaff, on the other hand, represents the antithesis of traditional honor. His opportunistic and cynical approach to life mocks the very notion of honor, viewing it as a hollow concept used by society to justify its most brutal actions. Yet, through his interactions with Falstaff, Prince Henry learns to see beyond the superficial allure of glory and the cynical dismissal of honor. He begins to understand that honor is not about grand gestures or fleeting fame, but about the consistent and selfless dedication to the greater good.

Prince Henry's growth is evident in his actions and decisions throughout the play. He moves from a youthful focus on personal achievement to a mature understanding of his responsibilities as a future monarch. This transformation is not without its challenges, as he must navigate the complexities of political intrigue, familial expectations, and personal desires. However, his ability to prioritize the well-being of the kingdom over his own acclaim demonstrates a level of moral integrity and leadership that is both rare and commendable.

In transcending the extremes represented by Hotspur and Falstaff, Prince Henry embodies a vision of honor that is rooted in service, duty, and a genuine concern for the people he will rule. His journey is a testament to the power of moral growth and the capacity for individuals to redefine their values in the face of adversity. By the end of the play, Prince Henry emerges not just as a capable ruler, but as a leader who understands that true honor lies in the long-term welfare of his kingdom, rather than in the short-lived rewards of personal glory. This nuanced understanding of honor sets him apart as a leader who is both principled and pragmatic, capable of guiding his kingdom through the complexities of power and responsibility with wisdom and compassion.

3.4 The True Value of Honor

Through this process, he not only grows into a capable ruler, but also demonstrates the enduring power of honor as a force that can guide, shape, and change the course of history.

Through the contrasting characters of Hotspur, Prince Henry, and Falstaff, Shakespeare paints a vivid portrait of the ways in which honor can shape, and sometimes distort, the path of leadership. By transcending both the reckless valor of Hotspur and the cynical opportunism of Falstaff, Henry learns to embody a more nuanced and selfless vision of honor, one that prioritizes the welfare of the kingdom over the fleeting rewards of individual acclaim. Through this process, he not only grows into a capable ruler but also demonstrates the enduring power of honor as a force that can guide, shape, and transform the course of history.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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PREDICTION STUDY OF 2028 OLYMPIC MEDAL TABLE BASED ON WEIGHTED FUSION MODELING

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Abstract: The purpose of this paper is to construct a weighted fusion model to predict the 2028 Olympic medal table with greater accuracy. Firstly, the data is cleansed and a relevant evaluation system is established using the K-Means clustering method. Then, a weighted fusion model integrated with a regression model and a time series model is adopted to predict the medal table of the 2028 Olympic Games. The results are as follows: the United United States is predicted to increase both the number of gold medals and the total number of medals, due to the home field advantage; China's number of gold medals may decrease, due to the abolition of the dominant events; and Japan's number of medals is expected to decrease, due to the loss of home field advantage. The study demonstrates the efficacy of the model in predicting the medal table, thereby providing a reference for countries to formulate their participation strategies and optimise the allocation of resources.
Keywords: Weighted fusion model; K-Means clustering; Olympic Games; Medal prediction

1 INTRODUCTION

The Olympic medal table is of significant global interest, as it serves as a barometer for the sporting prowess of nations worldwide. It offers insight into the effectiveness of national sports policies, the calibre of athlete training programmes, and the allocation of national resources towards sports. The number of gold medals attained is frequently regarded as a metric for evaluating a nation's sporting achievements. Given the growing importance countries attribute to sports events and the influence of a number of factors, the Olympic medal table has become more difficult to predict, and accurate prediction of the Olympic medal standings is therefore important.

In previous studies, scholars have utilised various methodologies to predict the medals. Based on the interpretable machine perspective, Shi Huimin et al. employed a random forest model to assess the predictability of medals in different sports, thereby demonstrating the feasibility of Olympic medal prediction[1]. Tian Hui et al. selected the host country of the 14th-23rd Winter Olympics as the research object, systematically studying the host country's dominant characteristics, such as the number of gold medals The ranking in the medal table, and the number of medals in different sports sub-items. The advantageous characteristics of the host country were then studied from the perspective of national competitive sports development policies and funding inputs. The dominant effect of the host country of the Winter Olympics was analysed, and logistic regression models were established to predict the number of medals of our athletes in the 202 2 Beijing Winter Olympics will be the best in the history of Winter Olympics participation[2]. Wang Fang used the non-linear method of neural network to fit and predict the per capita GDP data, and based on the prediction model proposed by Bernard and Busse, we made a prediction of the medals of the 2020 Tokyo Olympics, and then made a prediction for the 2020 Tokyo Olympics. 2020 Tokyo Olympic Games medals were predicted[3]. However, these models are not without their limitations. Neural networks require a substantial amount of data and are susceptible to quality issues. They also have a high computational demand and are less robust to outliers. PSO and multiple linear regression analysis models become more complex and may introduce greater uncertainty, affecting the stability and reliability of the model. Logistic regression Logistic regression models are sensitive to linearly divisible data and have a weak ability to deal with feature interactions. Time series analysis is suitable for simple, stable and cyclical data. In order to more fully and efficiently predict the Olympiad scores, it is necessary to comprehensively consider the phasic factors and use a combination of multiple analysis methods.

The objective of this paper is to accurately predict the medal list of the 2028 Olympic Games by combining a weighted fusion model integrated with a regression model and a time series model. This will take into account historical medal data, athletes' situations, and Olympic events, as well as analysing the related factors in depth. The aim is to provide references for countries to formulate their participation strategies and optimise the allocation of resources.

2 MATERIALS AND RESEARCH METHODS

2.1 Data Preprocessing

Data from the official International Olympic Committee website used in this article.

The initial phase of the study involves detecting missing values and visualising the missing values in the dataset using heatmaps. In the event that the dataset contains missing values, the heatmap will visibly highlight the missing areas, thus helping to identify problematic parts of the data. If duplicate records are found, appropriate measures such as deletion or merging will be taken to ensure the accuracy and reliability of the data.

2.2 Research Methods

In this paper, three models are proposed for predicting the number of gold, silver and bronze medals won by countries with well-developed sports systems and countries with developing sports, respectively. For time series variables, such as the number of medals in previous years, it is customary to employ time series models. For continuous and sub-type variables, including quantitative ratings of athletes' abilities and the number of gold, silver and bronze medals, regression models are utilised to predict the number of medals in the current Olympics. Consequently, a weighted fusion model combining the regression model and the time series model was employed in constructing the prediction model for the number of medals in future Olympic Games, as illustrated in Figure 1 Flow chart.

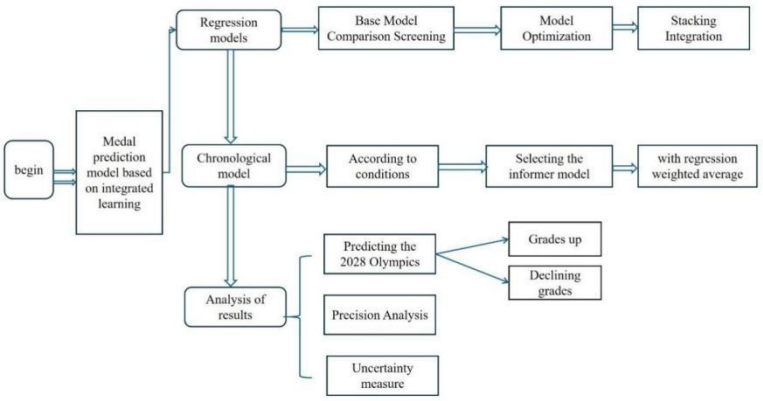

Figure 1 Flow Chart

In the context of selecting a nonlinear model, the tree model has been observed to exhibit an overfitting problem on the dataset due to the tree model itself. To address this challenge, this paper proposes a stacking method for integrating multiple tree models. The proposed model involves the utilisation of several tree models, with a meta-model being implemented to merge their predictions. Examples of such models include the GBDT model[4], XG-Boost model[5], Cat-Boost model [6]and Extra Trees model[7]. This integration approach effectively solves the overfitting problem inherent in individual tree models, thus improving the generalisation and performance of the models on unseen data, as illustrated in Table 1.

Table 1 Plot of Optimal Parameters for Each Base Model

Mould	GBDT	ExtraTrees	XGBoost	Cat-boost
optimal parameter 1	learning rate=0.1	profundity=14	learning rate=0.05	profundity=6
optimal parameter 2	profundity=10	Node ratio=0.7	profundity=10	learning rate=0.1
optimal parameter 3	Number of decision trees=200	Number of decision trees=300	Number of decision trees=200	Number of iterations=200

3 MODEL CONSTRUCTION

Initially, the number of medals won by each country at each Olympic Games was enumerated. Thereafter, these data were visually represented and analysed, as demonstrated in Figure 2.

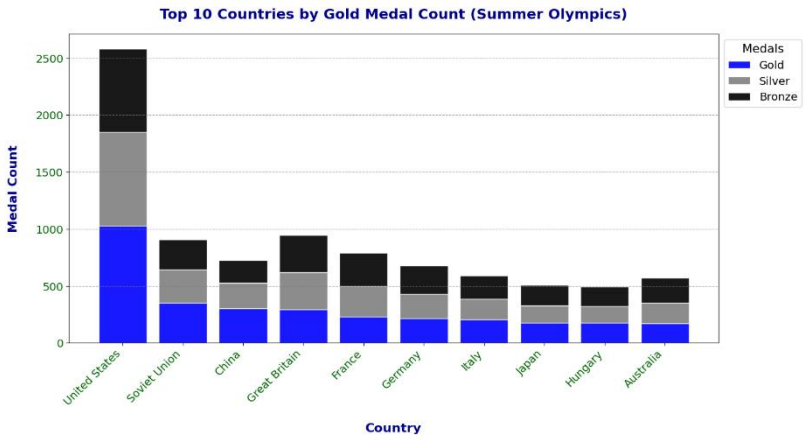

Figure 2 Top 10 Countries in Terms of Gold Medals

As demonstrated in the accompanying visualisation chart, there exists a considerable disparity in the level of sports development between nations, a discrepancy that has the potential to exert an adverse influence on the subsequent prediction model if not effectively addressed. Data discrepancies have the capacity to engender model prediction bias, resulting in imbalanced data comparisons between sports powerhouses and developing countries. Furthermore, such discrepancies can lead to the distortion of training data, an occurrence that has the capacity to compromise the accuracy of the model. Additionally, the presence of oscillatory behaviour in the model can impede its ability to converge stably during the training process. This, in turn, gives rise to a flattening of the objective function, changes in the direction of the gradient, and unstable results, which in turn adversely affects prediction accuracy and generalizability.

In order to address these issues and to enhance the predictive validity of the subsequent model, this paper proposes a categorisation of countries according to their level of sports development. Specifically, the paper proposes a two-category classification system, namely 'mature sports system countries' and 'emerging sports countries'. Mature sports system countries refer to those countries that already have a perfect sports system, and have a high level of sports competition and stable medal output, such as the United States, China and so on. These countries have accumulated substantial resources and advantages over time in the domains of training, infrastructure development, and financial investment in sports programs. In contrast, emerging sports countries are those that are in the process of establishing or progressively enhancing their sports systems. Although their sports resources and infrastructure may not be optimal, these countries have demonstrated potential in certain sports programs and are anticipated to enhance their sports standards over time.

In order to realise this classification, this paper adopts the K-Means clustering algorithm. The number of gold, silver and bronze medals won by each country in different Olympic years is input as the features in the data set. The clustering algorithm then divides these countries into different groups. By employing this method, this paper can automatically identify which countries have strong sports competitiveness and which countries are gradually developing their sports potential. The clustering results are shown in Figure 3.

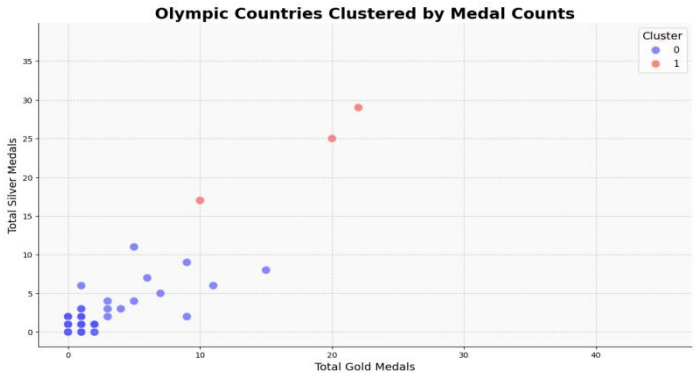

Figure 3 Graph of Clustering Results

The objective of this paper is to use clustering analysis to identify two categories of countries: those with a mature sports system and those with an emerging sports system. The results of this categorisation will facilitate the subsequent construction of a more accurate prediction model. The model will focus on the strengths and experiences of the former category in multiple sports, while the model will pay more attention to the potential and development trends of the latter in specific sports. The development of distinct prediction models for these two categories is expected to mitigate the impact of potential differences in data, thereby enhancing the accuracy and reliability of the model. This study will also establish an evaluation system to quantify the abilities of athletes.

3.1 Establishment of Evaluation Indicators

3.1.1 Comprehensive national competitiveness

(1) Obtaining the athletes of the target country who are competing in a particular sport.
(2) Calculation of athlete scores
(3) We begin by clarifying the rules for allocating points, as shown in Table 2.

Table 2 Points Allocation Table

Awards	Gold	Silver	Bronze	None
Score	10	6	3	1

In this paper, time-decreasing weights are assigned to the athletes' historical performances, and decreasing weight factors are set for each Olympics. The kth Olympics is weighted as w_k, $w_k = 1 - 0.2(k-1)$, $k = \{1,2,3,4,5\}$ and S_{t_k,A_i} is the athletes' scores in the kth Olympics. The following formula is used to calculate the athletes' total weighted scores P_{A_i}:

$$P_{A_i} = \sum_{i=1}^{5} S_{t_k,A_i} \cdot w_k \# \quad (1)$$

(4) Country's total score in a given minor event: assuming that all the country's athletes (NOC) participating in minor event E are A_i, the country's total score $T_{NOC,E}$ in this minor event is the sum of the scores of all the participating athletes.

$$T_{NOC,E} = \sum_{i=1}^{n} P_{A_i} \# \quad (2)$$

(5) Normalisation of overall scores: In order to quantify the competitiveness of each national team in the sub-event, we normalised the scores in each sub-event.

$$N_{NOC,E} = \frac{T_{NOC,E}}{\max T_{NOC',E}} \# \quad (3)$$

(6) The normalised score $N_{NOC,E}$ takes values in the range [0,1], with higher normalised scores indicating greater competitiveness for that country in that subprogramme.

(7) Calculation of the country's combined competitiveness in all small projects

$$C_{NOC} = \sum_{i=1}^{m} N_{NOC,E} \# \quad (4)$$

3.1.2 Country highlights competitiveness

A country's outstanding competitiveness is an important indicator for assessing its excellence and ability to win gold, silver and bronze medals in small events. By analysing the historical results of the athletes competing in each minor event, the competitiveness of each country for gold, silver and bronze medals can be calculated and provide data support for subsequent forecasting and analysis, and the steps for constructing the indicator are as follows:

(1) Access to all athletes competing in a specific minor sport in a target year.

(2) Calculate each athlete's score using the Historical Performance Score formula.

$$P_{A_i} = \sum_{i=1}^{5} S_{t_k,A_i} \cdot w_k \# \quad (5)$$

(3) Identify the top three scoring athletes in a minor event: After calculating the scores of all participating athletes, rank the athletes according to the size of their scores, and write down the results of the ranking as:

$$P_{A(1)} \geq P_{A(2)} \geq P_{A(3)} \geq \cdots P_{A(n)} \# \quad (6)$$

Calculation of Gold, Silver and Bronze Medal Indicators For each sub-item E, the countries that will receive gold, silver and bronze medals will be determined by ranking their scores in the following order；

$$\begin{cases} G_{NOC,E} = \begin{cases} 1, & \text{if } NOC = NOC_{(1)} \\ 0, & otherwise \end{cases} \\ S_{NOC,E} = \begin{cases} 1, & if\ NOC = NOC_{(2)} \\ 0, & otherwise \end{cases} \# \\ B_{NOC,E} = \begin{cases} 1, & if\ NOC = NOC_{(3)} \\ 0, & otherwise \end{cases} \end{cases} \quad (7)$$

(4) Aggregate gold, silver and bronze medal metrics for each sub-event: For a given country (NOC), sum the gold, silver and bronze medal metrics for all sub-events to obtain the total gold, silver and bronze medal metrics for that country.

$$\begin{cases} G_{total,NOC} = \sum_{i=1}^{m} G_{NOC,E_i} \\ S_{total,\ NOC} = \sum_{i=1}^{m} S_{NOC,E_i} \# \\ B_{total,NOC} = \sum_{i=1}^{m} B_{NOC,E_i} \end{cases} \quad (8)$$

(8) Evaluating the outstanding competitiveness of countries: The $G_{total,NOC}$, $S_{total,\ NOC}$, $B_{total,NOC}$ calculated above can be used to systematically evaluate the outstanding competitiveness of countries. These indicators reflect the country's performance at the level of elite athletes and also provide a quantitative basis for the subsequent prediction of the Olympic gold, silver and bronze medal lists.

3.2 Fusion of Regression and Time Series Models

Regression models and time series models[8] have very different architectures, but both have their own advantages in solving specific problems. Although they give close results, an integrated model with better performance can be obtained by model fusion. For the fusion, this paper uses a simple weighted average method and uses sklearn for auto-tuning the coefficients to obtain the optimal fused model. The final integrated model combines the strengths of both the tree model and the linear regression model and can therefore achieve a higher performance score than the individual models. Although the score of the integrated tree model is higher than that of the linear regression model, the structure of the optimal output allows the two models to complement each other's strengths, further improving the overall performance. Figure 4 illustrates the fusion architecture of the integrated model:

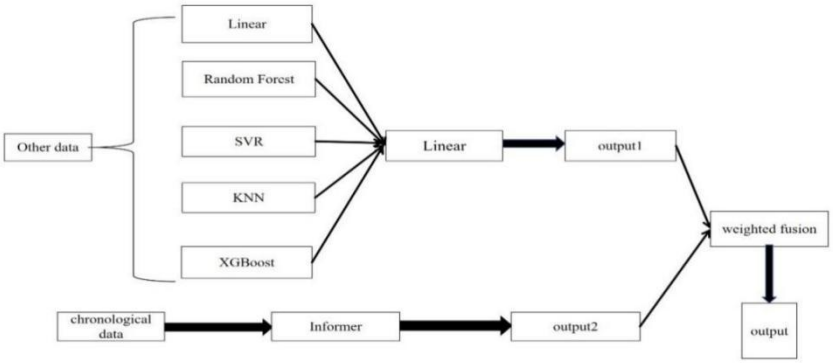

Figure 4 Weighted Fusion Model Structure

After the weighted fusion of the models, this paper validates their performance and finds that their performance on the dataset will indeed be stronger than any single model, and can effectively mitigate the overfitting phenomenon, and more accurate predictions are obtained on the validation set, and the performance graphs of their fusion models are shown in Table 3 :

Table 3 Fusion Model Performance Graph

	MSE	MAE
fusion model	3.875	0.9680

3.3 Calculate the Uncertainty

In the stacking integration model, in this paper we can calculate the prediction uncertainty of the model by analysing the prediction results of each base learner. Specifically, in this paper, we can obtain the prediction values of each base learner for the test set and calculate the variance of these predictions. With the variance, in this paper we can derive the standard deviation and then calculate the confidence interval for each prediction. In this paper, we choose the 95% confidence interval: $Y \pm 1{,}96\delta$, and draw a visualisation to show the stability and instability of the prediction values, as shown in Figure 5 :

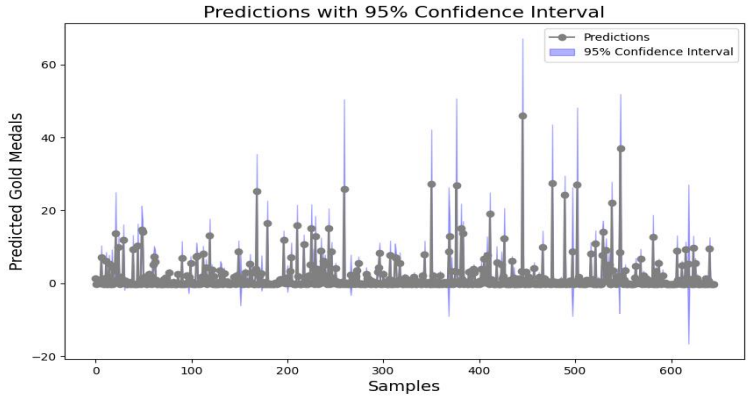

Figure 5 Visualization of Predicted Values

The model's predictions for some of the samples have large uncertainties, as evidenced by large standard deviations and even an excessively wide range of confidence intervals for some of the samples, with negative values and unusually large upper bounds. This may indicate that the model is unstable with certain data, possibly due to noise, overfitting or problems with the data itself.

To improve the stability of the model, consider analysing the characteristics of the high uncertainty samples, adding regularisation to prevent overfitting, and tuning the hyperparameters of the model. In addition, using more robust models and increasing the granularity of data processing will help to reduce prediction uncertainty and increase model confidence.

3.4 Predicted Results of the 2028 Olympics Medal Table

By analysing information on the 2028 Summer Olympics in Los Angeles, the Los Angeles Organising Committee has decided to drop traditional sports such as weightlifting and boxing and to add five new major sports: baseball and softball, racquet tennis, cricket, squash and flag football. Based on these changes, and assuming that the list of

participants does not change significantly from 2024, the predictive model in this paper gives only a large bonus to the performance of the United States, with no significant change in the number of medals for other countries. Incorporating this information into the previously constructed medal prediction model, the following conclusions can be drawn - the United States, as the host, will benefit from home advantage and its performance at the 2028 Summer Olympics in Los Angeles will be significantly improved, with the number of gold medals and total medals expected to increase significantly. In contrast, the performances of China and Japan are likely to decline. While China is a strong competitor in many events, the elimination of traditionally dominant Chinese sports such as weightlifting and boxing in 2028 could lead to a decline in its gold medal tally, while Japan, which shone at the 2024 Games, is expected to see a decline in its medal tally as a participant in the 2028 Olympic Games due to the loss of its home advantage, as shown in the results in Table 4 .

Table 4 Olympic Medal Prediction Table

NOC	Gold medal	Total medals
United States	51	151
China	31	86
Japan	19	45
Australia	18	52
France	17	62
Netherlands	16	38
Great Britain	14	64
South Korea	11	35

According to this forecast, the United States is expected to improve its performance at the Olympics due to its strength and home advantage, while China and Japan are likely to see their medal tally decline. Such a change highlights the importance of home advantage and the far-reaching impact of changes to the programme of events on the performance of different countries. In addition, the addition of new events may provide new opportunities for other countries, particularly the United States, to capitalise on their local culture and spectator support to excel in these new events.

4 CONCLUSION

In this paper, the participating countries are categorized by cluster analysis, and then the weighted fusion model is successfully constructed to predict the medal table of the 2028 Olympic Games by constructing feature engineering, establishing the relevant evaluation index system, and integrating time series and regression models. There are many factors that affect the performance of the Olympic Games, in addition to the pattern that can be found from historical data, other factors such as comprehensive national power and host effect should be comprehensively considered, and intelligent methods such as neural networks should be used to make more perfect predictions, and more factors will be incorporated in the future.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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THE IMPACT OF GREEN SUPPLY CHAIN MANAGEMENT ON THE VALUE OF NEW ENERGY VEHICLE ENTERPRISES: A CASE STUDY OF BYD

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Abstract: With the increasing environmental pollution and climate deterioration, the new energy vehicle industry plays a vital role in coping with the challenges of emission pollution and resource depletion brought by the traditional automobile industry.As an environmentally friendly and sustainable business practice, green supply chain management has a profound impact on the value of new energy vehicle enterprises.This paper takes BYD as the research subject, measures the degree of green supply chain management using the green supply chain management evaluation index published by the Ministry of Industry and Information Technology, collects and normalizes the enterprise value represented by the return on net assets, and finally employs the gray correlation analysis method to explore the relationship between the two, thereby confirming that BYD's green supply chain management has a positive impact on its enterprise value and provides corresponding suggestions. The research in this paper provides some guidance for new energy vehicle enterprises to formulate and implement green supply chain management strategies, and helps enterprises achieve a win-win situation of environmental and economic benefits.
Keywords: Green supply chain management; New energy vehicle; Corporate value; Grey relevance

1 INTRODUCTION

In the context of climate change and environmental problems, governments and enterprises are gradually recognizing the urgency and importance of addressing climate change, and there is a broad global consensus on the development of a "low-carbon economy", which emphasizes reducing energy consumption, reducing environmental pollution and controlling greenhouse gas emissions. China has also responded positively, adhered to the path of green and sustainable development, and integrated green supply chain management into the development strategy of enterprises [1].

In order to mitigate the negative impact of corporate activities on the atmospheric environment, renewable energy solutions such as solar, hydro and wind are being actively sought in addition to traditional energy sources. These emerging industries will gradually become the dominant force in China's economy, and among these industries, the new energy field has been identified as one of the seven strategic emerging industries for China's future development [2]. In order to build a clean, safe and reliable energy system and reduce carbon emissions, many companies have begun to set foot in the new energy industry, especially in the field of new energy vehicles, and the development momentum of related enterprises is particularly rapid. As a global leader in the field of new energy vehicles, BYD actively responds to the national goal of "carbon peak before 2030 and carbon neutrality before 2060", and promotes carbon emission reduction through technological innovation and green supply chain management.

Green supply chain management is a modern management method that integrates the concepts of green manufacturing and supply chain technology, which emphasizes the integration of environmental protection and sustainability principles into supply chain operations to achieve energy conservation, emission reduction and pollution reduction. Corporate value encompasses the resources and capabilities of the company, as well as the beliefs, philosophies and goals behind it, while reflecting the company's social responsibility, environmental impact and impact on various stakeholders.Fadhel found that green supply chain management practices can not only improve the environmental performance of enterprises [3], but also indirectly affect financial performance, improve operational efficiency and enhance corporate image by enhancing competitive advantage, and bring competitive advantages to enterprises. Zhang Lingfu et al. found that the green supply chain affects the improvement of enterprise value through the level of risk-taking, and the technological innovation ability and supply chain concentration further regulate this process [4].

The three traditional methods of asset valuation are divided into the cost approach, the market approach and the income approach. On the basis of these three methods, many scholars use a variety of evaluation methods to analyze the performance or value of enterprises. Sujit et al. used the balanced scorecard theory to divide enterprise performance into four dimensions [5]: finance, customer, internal process, and learning and growth, and comprehensively evaluated the performance of small and medium-sized manufacturing enterprises through questionnaire survey and data analysis. Arjuna et al. comprehensively used tools such as analytic hierarchy process [6], target matrix, and traffic light system to construct an evaluation system for green supply chain management for an agricultural product marketing company, and carried out a quantitative analysis of the environmental impact and performance of the enterprise's operation process.

The above relevant literature shows that green supply chain management can significantly improve enterprise value. Current research on green supply chain management mainly focuses on manufacturing, retail, food and beverage, and chemical and pharmaceutical industries, while the new energy vehicle industry is far from paying enough attention [7].

Therefore, this paper selects BYD enterprises in the new energy vehicle industry as the research object, and uses the gray correlation method to study the correlation degree of green supply chain to its enterprise value, so as to provide guidance for new energy vehicle enterprises to formulate and implement green supply chain management strategies. In addition, the practice of green supply chain management can not only enhance corporate value, but also promote the sustainable development of the new energy vehicle industry, and achieve the dual benefits of environmental protection and economic benefits.

2 ANALYSIS OF THE CURRENT SITUATION OF THE NEW ENERGY VEHICLE INDUSTRY AND THE RELEVANT GENERAL SITUATION OF BYD

2.1 Analysis of the current situation of the new energy vehicle industry

As a pioneer in the innovation of the automotive industry, the new energy vehicle industry not only brings together cutting-edge technologies in many fields such as energy, transportation and computers, but also provides new development opportunities for China's transformation from imitation to transcendence, from a "big automobile manufacturing country" to a "strong automobile manufacturing country".

In terms of production capacity, China's annual output of new energy vehicles has climbed from 84,000 units in 2014 to 9.587 million units in 2023, ranking first in the world for nine consecutive years. China's rapid growth in the field of new energy vehicles, the significant increase in technology patents, and the leading position in battery manufacturing clearly demonstrate the significant progress that China has made in the transformation of the automotive industry to green and electrification [8]. The following table shows the top 10 retail sales of China's new energy vehicle manufacturers from January to November 2024:

Table 1 From January to November 2024, China's New Energy Vehicle Manufacturers will be Ranked TOP10 in Retail Sales

Rank	The name of the business	Sales volume (10,000 units)	Year-on-year growth	Market share
1	BYD Auto	331.52	37.80%	34.50%
2	Geely Automobile	75.41	94.30%	7.90%
3	Tesla China	57.42	8.80%	6.00%
4	SAIC GM-Wuling	55.71	42.60%	5.80%
5	Changan Automobile	55.03	60.60%	5.70%
6	Ideal car	44.20	35.70%	4.60%
7	Cialis Motors	35.58	379.20%	3.70%
8	Chery Automobile	35.39	252.30%	3.70%
9	GAC Aion	33.08	-24.80%	3.40%
10	Great Wall Motors	25.33	21.30%	2.60%

From Table 1, it can be seen that BYD, as the new energy vehicle manufacturer with the highest sales volume and market share, has great reference value for other car companies in the same industry when studying its corporate value. Moreover, BYD has repeatedly obtained A-level ESG ratings over the years, indicating that BYD has performed well in promoting sustainable development strategies. So we take BYD as the research object to explore the impact of green supply chain on the value of new energy vehicle enterprises.

2.2 BYD Green Supply Chain Management

BYD Co., Ltd., abbreviated as "BYD", was established in February 1995. After more than 20 years of rapid development, it has established more than 30 industrial parks worldwide, and its business scope includes multiple fields such as electronics, automobiles, new energy, and rail transit.

BYD is committed to ecological innovation, implementing climate commitments with leading green solutions and practical actions, advocating for "cooling the earth by 1 ℃". In 2022, BYD announced the discontinuation of fuel vehicles and focused on pure electric and plug-in hybrid vehicle businesses, becoming the world's first car company to officially announce the discontinuation of fuel vehicles. In terms of green supply chain management practices, BYD actively promotes green transformation through innovative practices in four areas: green suppliers, green products,

green logistics, and green packaging. The company requires suppliers to fully consider environmental impacts in product design and production processes, and take continuous improvement measures to reduce these impacts [9].
In addition, BYD has strengthened the transparency and compliance management of its supply chain, signed a "Green Supply Chain Management Contract" with suppliers, requiring them to comply with national environmental regulations, reduce emissions, improve processes and production methods, and provide necessary environmental certificates. BYD has established a supply chain supervision mechanism to conduct regular audits and on-site inspections of its cooperative suppliers, ensuring the fulfillment of its environmental commitments.

3 INDICATOR SYSTEM AND EVALUATION METHODS

3.1 Evaluation Index System for Green Supply Chain Management Enterprises in the Automotive Industry

This article uses the "Evaluation Index System for Green Supply Chain Enterprises in the Automotive Industry" released by the Ministry of Industry and Information Technology to score BYD's green supply chain management from 2019 to 2023, in order to measure the impact of green supply chain management on the performance of automotive enterprises. The evaluation index system for green supply chain management enterprises in the automotive industry is shown in Table 2:

Table 2 Evaluation Index System for Green Supply Chain Management Enterprises in the Automotive Industry

Primary indicator	Secondary indicator	Index Properties
Management Strategy X1(20 points)	X11 The concept of green development should be proposed in the enterprise management policy (4 points)	Qualitative
	X12 Develop green supply chain management goals and implementation plans annually (4 points)	Qualitative
	X13 Establish a green supply chain management system and standard system (4 points)	Qualitative
	X14 Has personnel or institutions dedicated to managing the supply chain (4 points)	Qualitative
	X15 Establish education and training mechanisms (4 points)	Qualitative
Green Procurement and Supplier Management X2(25 points)	X21 The existing supplier admission standards and management should clearly specify the requirements for providing material data, and issue and effectively implement green procurement guidelines (6 points)	Qualitative
	X22 Proportion of suppliers certified with ISO14001 or GB/T24001 (3 points)	Quantitative
	X23 Proportion of suppliers using energy-saving and environmentally friendly processes/equipment (4 points)	Quantitative
	X24 Has an upstream supplier performance evaluation mechanism, awarding green suppliers to suppliers whose evaluation results meet certain standards, and carrying out environmental performance improvement for those with poor results (6 points)	Quantitative
	X25 Supplier Regular Audit (2 points)	Qualitative
	X26 Conducts green supply chain training for supplier organizations (4 points)	Qualitative
Green Production X3(15 points)	X31 Automotive Green Design Requirements (4 points)	Qualitative
	X32 Uses advanced technology and intelligent equipment (2 points)	Qualitative
	X33 Requirements for the use of toxic and harmful substances (3 points)	Quantitative
	X34 Passed the clean production audit (2 points)	Qualitative
	X35 Recycled material usage ratio (2 points)	Quantitative
Green consumption and recycling X4(20 points)	X36 Promotes green logistics (2 points)	Qualitative
	X41 Green Marketing (1 point)	Qualitative
	X42 Packaging material recycling rate (1 point)	Quantitative
	X43 Recycling System Construction (8 points)	Quantitative/Qualitative

	X44 Standardized recycling rate of scrapped cars/products (4 points)	Quantitative
	X45 Guides downstream enterprises in recycling and dismantling (2 points)	Qualitative
	X46 Carries out automobile remanufacturing (2 points)	Qualitative
	X47 Actual recycling rate of automobiles or parts (2 points)	Quantitative
Green Information Platform Construction and Information Disclosure X5(20 points)	X51 Has a green supply chain management information platform that enables the collection of automotive material data, energy consumption, and other information throughout the entire industry chain (10 points)	Qualitative
	X52 Disclosing Enterprise Energy Conservation and Emission Reduction Information to the Public (2 Points)	Qualitative
	X53 Disclosing information on recycling outlets to the public (2 points)	Qualitative
	X54 Discloses the proportion of green suppliers to the public (2 points)	Qualitative
	X55 Discloses to the public the measures and implementation results of jointly carrying out environmental performance improvement with suppliers (2 points)	Qualitative
	X56 Releases corporate social responsibility report to the public (2 points)	Qualitative

The evaluation index system for green supply chain enterprises in the automotive industry includes five primary indicators and thirty secondary indicators. This includes twenty-one qualitative indicators, eight quantitative indicators, and one indicator that is both qualitative and quantitative. All indicators comply with industry regulations and relevant policies. The specific calculation formula for the overall score of green supply chain management in the automotive industry is as follows:

$$AGSCI = X11 + X12 + X13 + X14 + X15 + X21 + X22 + X23 + X24 + X25 + X26 + X31 + X32 + X33 + X34 + X35 + X36 + X41 + X42 + X43 + X44 + X45 + X46 + X47 + X51 + X52 + X53 + X54 + X55 + X56 \quad (1)$$

In the formula, AGSCI stands for the evaluation index of green supply chain management enterprises in the automotive industry.

3.2 Grey Correlation Analysis Method

Grey correlation analysis is suitable for research contexts with small sample sizes and unclear data patterns, and its analysis results are generally consistent with qualitative analysis. The core of this method is to evaluate the geometric relationship between two sequence curves in order to determine the degree of correlation between them, that is, the grey correlation degree. In short, the smaller the difference between two sequences, the stronger their correlation; The greater the difference, the weaker the correlation.

Grey correlation analysis has two main functions: system analysis and comprehensive evaluation. Many studies focus on the evaluation of indicators for a certain system, but the focus of this article is to use the grey relational analysis method to analyze the degree of correlation between BYD's enterprise value and green supply chain, and conduct analysis.

In the initial stage of conducting grey relational analysis, it is necessary to dimensionless the parent sequence and sub sequences, where the parent sequence is the dependent variable and the sub sequence is the independent variable [10]. This article adopts a standardized approach to the evaluation indicators of green supply chain management and the dimensionless processing of ROE.

The second step is to calculate the grey correlation coefficient between the parameters of the parent sequence and the sub sequence, using the following formula to calculate the grey correlation coefficient:

$$\gamma = \frac{\Delta\min + \rho\Delta\max}{\Delta t(i,0) + \rho\Delta\max} \quad (2)$$

Among them, $\Delta\min$ is the minimum absolute value of the difference between two sequence values, $\Delta\max$ is the maximum value, and $\Delta t(i,0)$ is the difference at the t-th data point (i=1,2,3,4,5,6). ρ is the resolution coefficient between [0,1], and usually takes 0.5 to obtain the most accurate correlation. Therefore, 0.5 is used for calculation in this section.

4 EMPIRICAL ANALYSIS

4.1 Quality Analysis of BYD Green Supply Chain Index

According to the "Evaluation Index System for Green Supply Chain Management Enterprises in the Automotive Industry" mentioned above, score BYD's annual reports and corporate social responsibility reports from 2018 to 2023,

and calculate its green supply chain management index. Due to space limitations, a detailed index calculation table will not be presented. Table 3 shows the scoring details of green supply chain management based on primary indicators:

Table 3 BYD Green Supply Chain Management Index Detail Table

Indicator/Year	2019	2020	2021	2022	2023
Management strategy	18	20	20	20	20
Green procurement and supplier management	19.5	20	21.5	22	22.5
Green production.	14	15	15	15	15
Green consumption and recycling	16	17.5	18	18.5	18.5
Construction of Green Information Platform and Information Disclosure	15.5	16	17	17.5	18
Green supply chain management	83	88.5	91.5	93	94

The green supply chain index scoring data will be normalized using normalization method, and the processed results are shown in Table 4:

Table 4 BYD Green Supply Chain Index Data Processing

Indicator/Year	2019	2020	2021	2022	2023
Management strategy	0.95	1.05	1.05	1.05	1.05
Green procurement and supplier management	0.95	0.98	0.96	0.99	1.05
Green production.	0.95	1.05	1.05	1.05	1.05
Green consumption and recycling	0.95	1.02	1.04	1.05	1.05
Construction of Green Information Platform and Information Disclosure	0.95	0.97	1.03	1.04	1.05
Green supply chain management	0.95	1.00	1.04	1.05	1.05

In the past five years, BYD's rating results have shown an overall upward trend, indicating that the level of green supply chain management has maintained a good trend.

4.2 BYD Enterprise Value Analysis

Based on previous research, this article adopts the return on equity (ROE) to reflect enterprise value. The return on equity is the core indicator of the DuPont analysis system, which can effectively reflect the value of the enterprise. The return on equity data of BYD from 2019 to 2023 can be obtained from Dongfang Wealth Network, and the results are shown in Table 5:

Table 5 BYD ROE Calculation Table for 2019-2023

Indicator/Year	2019	2020	2021	2022	2023
ROE(%)	0.95	1.00	1.04	1.05	1.05

From Table 5, it can be seen that except for a significant decrease in ROE values in 2021, all other years have shown an upward trend, especially in 2022, where the growth rate is the most significant. According to relevant information, the continuous rise in global raw material prices in 2021 has led to high manufacturing costs for automobiles, which in turn has affected economic value added. However, in 2022, the new energy vehicle industry reached its peak of development, and BYD successfully withstood the test of the market. Its car sales reached a historical high, becoming the world's best-selling new energy vehicle manufacturer, and its operating profit achieved significant growth, effectively alleviating the cost pressure caused by rising raw material prices [7] .

4.3 Grey Relational Analysis

Using the ROE value as the parent sequence and the first level evaluation index and the total score of green supply chain management as sub sequences, calculate the grey correlation coefficient. The results are shown in Table 6:

Table 6 Grey Relational Coefficient

Indicator/Year	20192020202120222023
Management strategy	0.69 0.94 0.68 0.82 0.48
Green procurement and supplier management	0.67 0.97 0.70 0.81 0.49
Green production.	0.69 0.94 0.68 0.82 0.48
Green consumption and recycling	0.68 0.96 0.68 0.82 0.48
Construction of Green Information Platform and Information Disclosure	0.68 1.00 0.68 0.83 0.49
Green supply chain management	0.68 0.98 0.68 0.83 0.48

Finally, the average correlation coefficient of each point on the sequence is taken to calculate the correlation between the sequences, and the ranking is based on the magnitude of the correlation, as shown in Table 7:

Table 7 Grey Correlation Degree and Ranking Situation

Evaluative items	Correlation	Rank
Construction of Green Information Platform and Information Disclosure	0.733	1
Green supply chain management	0.729	2
Green procurement and supplier management	0.727	3
Green consumption and recycling	0.726	4
Management strategy	0.721	5
Green production	0.721	6

According to Table 7, the grey correlation degrees of five indicators, including management strategy, green procurement and supplier management, green production, green consumption and recycling, green information platform construction and information disclosure, for enterprise value are all between 0.65 and 0.85, indicating a high correlation. This proves that green supply chain management has a significant impact on the enterprise value of new energy vehicles. The construction of green information platforms and information disclosure scores the highest, with the greatest correlation with enterprise value. As mentioned earlier, BYD has strengthened the transparency and compliance management of its supply chain. Since 2010, BYD has continuously released social responsibility reports to the society and is one of the early automotive companies to carry out ESG information disclosure. Its leadership and commitment in green information platform construction and information disclosure have contributed significantly to global sustainable development.

The correlation between green production is relatively low, but it also has a positive impact on the value of enterprises. In the early stage of green production, it may lead to an increase in research and development expenses for enterprises, which may increase production costs and reduce operating profits in the short term, making the immediate improvement effect on enterprise value less significant. However, in the long run, green production can enhance the innovation capability of enterprises, improve resource utilization efficiency, and reduce environmental pollution, which helps to reduce enterprise costs and enhance profitability, ultimately increasing enterprise value [8] .

5 CONCLUSION

This article adopts the grey relational analysis method to evaluate BYD's green supply chain management evaluation index, and represents its enterprise value in the past five years by calculating the return on equity (ROE). The research results indicate that BYD's green supply chain management has a certain positive impact on its corporate value. Based on the above research, the new energy vehicle industry can consider the following steps in the future to enhance its level of management:

1. Strengthen the systematic construction of green supply chain management: Enterprises should further improve the system and standard system of green supply chain management to ensure the effective implementation of green transformation in all links. At the same time, strengthen cooperation with suppliers, promote their environmental awareness and capabilities, and jointly achieve the sustainable development of green supply chains.
2. Enhance the construction and disclosure level of green information platforms: Enterprises should continue to strengthen the construction and management of green information platforms, improve the transparency and quality of information disclosure, and enhance public trust and support for enterprises. Simultaneously improving the

collaborative efficiency of the supply chain, achieving real-time sharing and dynamic management of information at all stages of the supply chain.

3. Focus on the long-term benefits of green production: Although green production may increase a company's research and development expenses and production costs in the early stages, in the long run, green production can enhance a company's innovation capabilities, improve resource utilization efficiency, and reduce environmental pollution. Enterprises should increase their investment in research and development of green production technologies, optimize production processes, reduce production costs, and enhance the market competitiveness of their products.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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COLLABORATIVE MECHANISM OF DIGITAL TECHNOLOGY EMPOWERING GREEN SUPPLY CHAINS IN CROSS-BORDER E-COMMERCE

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Abstract: Currently, cross-border e-commerce is confronted with a dilemma regarding green transformation. On one hand, global climate governance mandates that enterprises to manage their carbon footprints. On the other hand, the lack of consistent carbon emission calculation standards across countries often places enterprises in a challenging position, where their environmental efforts remain unrecognized. This study aims to address this issue by investigating how digital technologies can effectively integrate various segments of the green supply chain. This study examines the collaborative mechanisms through which digital technology enhances the green supply chain in cross-border e-commerce. It aims to address the conflicts arising from differing carbon accounting standards and the risks of carbon leakage that cross-border e-commerce faces in the context of global climate change governance. By constructing a three-dimensional collaborative framework that includes the technological, business, and policy-ecological layers, the study systematically analyzes the applications of digital technologies such as blockchain, the Internet of Things, and big data. These applications are explored in relation to cross-border product traceability, intelligent warehouse optimization, precise supply-demand matching, and low-carbon route planning. Furthermore, the study investigates collaborative strategies in policy and ecology, including the unification of cross-border green standards and the development of a carbon asset financial product system. The research identifies technological standardization barriers and institutional frictions as the fundamental challenges currently confronting the collaborative mechanism. It concludes that technological innovation, institutional innovation, and capacity building are essential for overcoming these obstacles.
Keywords: Digital technology; Cross-border E-commerce; Green supply chain; Collaborative mechanism; Sustainable development

1 INTRODUCTION

Against the backdrop of accelerating global climate governance, cross-border e-commerce, a key driver of digital transformation in international trade, faces "dual institutional constraints" and "multidimensional technological challenges" in managing its carbon footprint. In March 2021, China's 14th Five-Year Plan, rooted in the strategic imperative of "dual carbon" (carbon peak and carbon neutrality), proposed a comprehensive green transition strategy. This plan precisely outlines the development pathway and explicitly advocates for the advancement of green technology innovation and the green transformation of key industries and critical sectors. Concurrently, the implementation of regional carbon tariff policies such as the EU Carbon Border Adjustment Mechanism (CBAM), set to fully take effect by 2026, has subjected cross-border e-commerce supply chains to dual pressures: conflicts in carbon accounting standards—such as discrepancies between China's MRV (Monitoring, Reporting, Verification) system and the EU ETS (Emissions Trading System)—and a surge in carbon leakage risks [1]. Meanwhile, global e-commerce carbon emissions continue to rise at an alarming annual rate of 9.3%, with cross-border logistics accounting for a staggering 58% of the total, far exceeding the average of traditional trade models. This contradiction underscores the strategic urgency of establishing a collaborative mechanism for carbon emission reduction in cross-border e-commerce.

The theoretical motivation for this study arises from two significant breakthroughs in existing research. First, traditional green supply chain studies primarily focus on individual enterprises or domestic contexts, often neglecting the interactive effects of cross-border institutional coordination and technology adoption. Second, research on carbon accounting within the digital economy typically overlooks the unique characteristics of cross-border e-commerce, such as "data sovereignty barriers" and "fragmented logistics networks," resulting in emission reduction strategies that fail to meet practical needs. On a practical level, by 2025, China's cross-border e-commerce comprehensive pilot zones for cross-border e-commerce are expected to encompass over 165 cities, yet their carbon intensity remains 17% higher than the national average, highlighting significant deficiencies in the incentive compatibility and technological adaptability of current policy tools.

2 LITERATURE REVIEW

2.1 Research Background and Current Status

Driven by the global carbon neutrality strategy and the digital technology revolution, research on collaborative innovation in green supply chains for cross-border e-commerce has become a focal point in interdisciplinary fields.

Core digital technologies, such as big data, blockchain, and the Internet of Things (IoT) integrate information flow, logistics, and capital flow, significantly enhancing supply chain visibility and operational efficiency [2] but also establishing a digital infrastructure for green technology applications. However, current practices still face multiple challenges: while supply chain digitalization reduces disruption risks, it necessitates dynamic resilience strategies to address potential threats [3]; blockchain-based smart contracts optimize trust mechanisms in cross-border payments but require improvements in the cross-border payment ecosystem's trust framework [4]; and the industry has yet to establish unified carbon emission accounting standards for full life-cycle assessments, among other critical issues that remain unresolved [5].

At the policy level, China's "Dual Carbon" strategy fosters paradigm shifts in green supply chains through institutional innovation, with manufacturing enterprises are adopting a dual-track mechanism combining green integration within industrial chains and green consolidation across supply chains. International practices, as indicated by UNCTAD statistics, reveal an annual growth rate of 14.7% in the global green consumer market, compelling firms to deeply embed ESG metrics into their supply chain decision-making systems. This trend highlights the necessity for synergistic design between digital technologies and cross-border environmental regulations [6]. Current research predominantly focuses on localized optimizations in procurement or production segments, leaving significant gaps in understanding the dynamic coupling mechanisms of digital technology-driven collaborative innovation in green supply chains. Urgent theoretical breakthroughs are needed in areas such as multi-stakeholder collaborative governance in cross-border e-commerce and the alignment of cross-border environmental regulations.

2.2 Research Progress at Home and Abroad

2.2.1 Domestic research

Domestic scholars have conducted research on model innovation and ecological synergy driven by digital technologies. Fang Yiru et al. proposed that Yunnan Province utilize cross-border e-commerce platforms and big data analytics to achieve transparent supply chain management and construct a green closed-loop system for the production and sales of specialty agricultural products. This approach increased supply chain responsiveness by 40% and reduced inventory backlog by 25% [7]. At the county-level economy, Li Nijie et al. found that the application of AI-based demand forecasting models in the crystal e-commerce sector of Donghai County, Jiangsu Province, improved resource utilization by 35%, while cloud computing optimized packaging design, reducing material waste by 20% [8]. In terms of policy mechanisms, Xia Wenhui et al. advocated for a collaborative framework involving the government, enterprises, and consumers in the fresh cold chain sector, leveraging digital platforms to share logistics information and reduce energy consumption [9].

2.2.2 International research

International studies focus on global industrial chains and collaborative governance. Amazon employs intelligent algorithms to optimize cross-border logistics routes, achieving an 18% reduction in carbon emissions from transportation within the European region. The European Union promotes blockchain technology standardization and mandates full lifecycle traceability for cross-border goods to enhance the efficiency of green certification in supply chains. Furthermore, Sarkis, J. proposed that digital technologies, such as blockchain and IoT facilitate green collaboration across supply chain segments through real-time data sharing and transparency mechanisms, effectively minimizing resource waste and carbon emissions [10]. Kshetri, N.'s empirical research confirmed that blockchain's tamper-proof traceability enhances the credibility of green certification in cross-border e-commerce supply chains, thereby promoting the coordinated development of international environmental standards [11].

3 DIGITAL TECHNOLOGY-ENABLED COLLABORATIVE MECHANISMS

Against the backdrop of rapid updates in the global carbon regulatory framework and the increasingly significant issue of carbon leakage in cross-border e-commerce, digital technology-enabled collaborative mechanisms have emerged as an effective approach to addressing dual challenges in both institutional and technological dimensions. This study constructs a three-dimensional framework encompassing the technological layer, business layer, and policy and ecosystem layer, integrating the latest international research findings from 2023–2024 to delve into the core theories and innovative directions of collaborative mechanisms. Key areas of focus include cross-border data flow regulations, integration of intelligent carbon accounting technologies, and multilateral digital governance agreements, among other emerging topics.

3.1 Technical-Level Collaboration

3.1.1 Blockchain-driven green certification and traceability system

Utilizing distributed ledger technology based on blockchain, a comprehensive traceability system for the entire lifecycle of cross-border goods has been established [12]. This system facilitates real-time recording of carbon emission data across stages such as raw material procurement, production and processing, logistics transportation, and end consumption. Smart contracts are utilized to automatically verify environmental compliance indicators, ensuring adherence to the EU's Extended Producer Responsibility (EPR) regulations. IoT sensors gather real-time data on temperature, humidity, energy consumption, and other parameters during cross-border transportation (e.g., carbon emissions from refrigerated containers), with the blockchain's immutable distributed ledger providing tamper-proof

end-to-end records. A notable application is Alibaba International's green product rating system, which generates ratings based on production energy consumption data to assist overseas buyers in decision-making.

3.1.2 IoT and digital twin-enabled smart warehouse optimization

Digital twin technology utilizes virtual modeling to assess the energy efficiency and spatial utilization of various warehouse layouts. By leveraging IoT for real-time monitoring of environmental parameters within warehouses and integrating with Industry 4.0 technologies, it optimizes logistics routes and inventory configurations. This approach creates a cross-border supply chain management model that balances economic benefits with carbon reduction goals, achieving a win-win outcome for both economic and environmental objectives [13].

3.2 Business layer Collaboration

3.2.1 Big data and AI-driven precision in supply-demand matching

By leveraging historical transaction data and conducting social media sentiment analysis, this study develops a By integrating historical transaction data and social media sentiment analysis, a cross-border e-commerce demand forecasting model is constructed, employing LSTM neural network technology to dynamically adjusts procurement plans and inventory levels. A multidimensional data fusion analysis framework is established by combining e-commerce platform order data, social media sentiment analysis, search engine trend predictions, and seasonal fluctuation parameters. The model can simultaneously generate product popularity index maps to guide cross-border logistics route optimization and promotional pricing strategies [14]. A notable example is SHEIN, which applies AI algorithms to implement a small-batch rapid-response model, compressing the product design-to-shelf cycle to just 7 days while increasing inventory turnover by 40%, effectively reduces resource waste caused by overproduction .

3.2.2 Low-carbon route planning for multimodal transport networks

By integrating real-time carbon emission data from maritime, air, and rail transport (e.g., Maersk's Carbon Tracking API), a dynamic multimodal transport carbon footprint monitoring platform is built. IoT sensors collect real-time vehicle energy consumption data and interface with customs declaration systems. A multi-objective optimization model based on genetic algorithms has been established, with transportation cost, timeliness, and carbon emission intensity as constraints, and iteratively calculating the optimal transport routes. For example, in mixed China-Europe rail and maritime transport scenarios, the algorithm dynamically adjusts cargo distribution ratios between Ningbo Port and Hamburg Port, optimizing sailing speed settings in response to seasonal ocean current variations, reducing carbon emission intensity by 18%–25%. Additionally, blockchain technology facilitates paperless logistics documentation, thereby reducing cross-border customs clearance time.

3.3 Policy and Ecology Synergy

Cross-Border Green Standard Harmonization: Promoting the establishment of a mutual recognition system for green product certification within the RCEP framework requires forming a regional technical committee to conduct comparative studies on standards and evaluate the equivalence between China's "Green Product Certification" and the EU's "Eco-label." A multilingual online certification database should be developed to facilitate cross-border verification of certificates, thereby reducing redundant certification costs for enterprises. Policymaking may reference the EU's Carbon Border Adjustment Mechanism, requiring cross-border e-commerce platforms to disclose the full lifecycle carbon footprint of imported goods—from raw material extraction to final delivery—along with embedded carbon emission data. A carbon labeling tier system should be established to promote green transformation within supply chains.

Multi-Stakeholder Collaboration: Governments, platforms, and logistics enterprises should collaboratively establish a green supply chain alliance to share data and resources. The "Digital Economy International Cooperation Initiative for the Belt and Road" proposes accelerating digital economy cooperation with ASEAN and other Belt and Road regions by promoting the interconnectivity of key IT infrastructure, building multilateral and multi-level exchange mechanisms, strengthening digital skills training, and enhancing policy transparency in the digital economy [15].

4 PRACTICAL PATHWAYS AND CASE STUDIES

4.1 Technology-Driven Case: Alibaba's Practical Experience

As a global leader in e-commerce, Alibaba has built a vast supply chain network encompassing billions of products. Its intricate logistics and distribution system faces dual challenges of energy consumption and carbon emissions. To establish a green value chain collaborative ecosystem, the company is leveraging digital technologies to drive the transformation of its green value chain, integrating blockchain-based traceability systems and intelligent route optimization algorithms to create an environmentally friendly business ecosystem.

Alibaba employs an AI-driven intelligent warehousing system that leverages big data to analyze multi-dimensional information such as consumer purchasing behavior, geographic location, and inventory levels. This enables precise cross-border warehousing, reducing the delivery distance for international goods by 30% and significantly lowering energy consumption during transportation. [16] For example, in its global procurement business, popular products that previously required long-distance shipping from overseas warehouses to reach domestic consumers can now be pre-allocated to regional or forward warehouses closer to consumers, substantially reduces energy use and carbon

emissions in transportation.

This innovative approach effectively enhances logistics efficiency and reduces operational costs through digital technology, while also significantly decreasing energy consumption and environmental pollution during transportation. It serves as a practical reference for the e-commerce industry in building green supply chain systems and implementing digital supply chain management, guiding the sector toward efficient collaboration and sustainable development.

4.2 Policy-Driven Case: The EU's "Green Digital Trade Corridor" Initiative

The European Union has established a rigid framework for carbon governance in cross-border e-commerce through dual drivers of legislative coordination and digital infrastructure:

4.2.1 Mandatory compliance mechanism under the DMA

The Digital Markets Act (DMA), effective since 2023, requires ultra-large online platforms, such as Amazon to establish "Sustainable Product Zones." The Act defines "gatekeepers" like Amazon, Google, and Apple, mandating obligations such as prohibiting self-preferencing, enabling interoperability, and allowing users to uninstall pre-installed applications. Under the DMA, gatekeeper companies must meet specific criteria, including a market capitalization of at least €750 billion or an annual revenue of €75 billion, along with 45 million monthly active users and 10,000 business users in the EU. Violations of the DMA can result in fines of up to 10% of a company's global annual revenue, which can escalate to 20% for repeat offenders, and may also lead to restrictions on acquisitions. By 2024, the European Commission had initiated compliance reviews for six gatekeeper companies, five of which are U.S. tech giants. In response to this regulatory pressure, some companies have adjusted their strategies; for instance, Apple has allowed third-party app stores on iOS for the first time, while Meta's WhatsApp has gradually opened interoperability with other instant messaging services.

4.2.2 Cross-border green data exchange platform

This platform integrates customs and trade data interfaces from member states. For instance, Guangzhou Customs has achieved electronic origin data exchange with 18 regions while establishing an environmental information verification. A blockchain-based carbon footprint traceability system has completed end-to-end validation for cross-border carbon data certification in the Lingang New Area. Pilot data from 2024 indicated that the platform enhanced customs clearance efficiency by 30%, aligning closely with the efficiency growth curve of the General Administration of Customs for cross-border e-commerce. Its innovative "chain-based mutual recognition" data-sharing mechanism provides a replicable institutional model for overcoming international data sovereignty barriers.

4.2.3 Innovative practice of carbon tariff prepayment system

To address the policy challenges of the European Union's Carbon Border Adjustment Mechanism (CBAM), the platform has introduced an industry-first carbon tariff smart prepayment system, achieving full coverage for simulation calculations across five high-carbon industries, including steel and chemicals, on China's Green Trade Public Service Platform. With full lifecycle carbon emission tracking, this module enables businesses to accurately prepay carbon costs during the 2025 transition period, effectively reducing cross-border trade friction. Chinese cross-border e-commerce companies have mitigated potential carbon tariff risks amounting to billions through similar mechanisms. In 2024, China's cross-border e-commerce import and export volume reached ¥2.63 trillion, with carbon tariff dispute amounts aligning with industry estimates.

4.3 Market Innovation Case: SHEIN's Closed-Loop Sustainable Supply Chain System

Through technological integration and vertical industry collaboration, SHEIN has established a sustainable closed-loop system covering design, production, and recycling, driving low-carbon transformation within the fast-fashion industry:

4.3.1 Demand-driven low-carbon design system

A demand-driven, flexible supply chain model uses digital tools to monitor global fashion trends in real time and employs virtual sampling technology to minimize resource consumption in physical sample production. The company plans to launch a product carbon footprint traceability system in 2024, enabling consumers to access emissions data at each stage—from raw materials to recycling—on the purchase interface. This mechanism aligns with EU environmental regulations and fosters the growth of the green consumer market.

4.3.2 Distributed clean energy network

Deploying "solar + storage" systems in the Pearl River Delta region, SHEIN has successfully completed a rooftop solar demonstration project at its Guangzhou warehouse. Using new-energy trucks has reduced single-trip transport emissions by nearly 30%, while partnerships with companies like LONGi Green Energy are helping to establish a new-energy power supply network. Plans for 2025 include deploying over 130 new-energy electric vehicles, projected to cut annual carbon emissions by nearly 10,000 tons. The "solar + new-energy vehicle" model provides a practical template for greening warehousing and logistics.

4.3.3 Blockchain traceability in cross-border reverse logistics

To replace traditional fuel vehicles and reduce last-mile emissions, SHEIN promotes electric and two-wheeled vehicles for "last-kilometer" green delivery in the European market. It also optimizes sea and land transport to establish a low-carbon logistics network, decreasing air freight emission intensity year-on-year. Reverse logistics utilize recycled packaging materials, such as hemp bags, with these green logistics practices highlighted as an industry case study in the China Foreign Transport Sustainability Report.

5 CONCLUSION AND DISCUSSION

5.1 Deep-Level Challenges

5.1.1 Technical standardization barriers

(1) Data Interoperability Issues

Cross-border blockchain green certification systems suffer from protocol heterogeneity due to differences in technical architectures, leading to reduced efficiency of environmental information verification. For instance, the fundamental logic disparities between Hyperledger Fabric and Ethereum significantly increase the difficulty of data collaboration. Insights from China's Green Certificate Project illustrate that blockchain standardization is a core pathway to enhancing international recognition. However, the current lack of blockchain interoperability in cross-border e-commerce, particularly when promoting green goods within the EU—forces reliance on multi-node manual verification mechanisms for carbon label authentication, resulting in compliance costs exceeding industry expectations. This issue has been identified as a prominent case of global green trade technical barriers.

(2) Computing Resource Allocation Dilemma

Small and medium-sized enterprises (SMEs) face dual challenges of insufficient computing resources and a shortage of specialized technical teams when applying AI-based carbon accounting models. Research shows that although most enterprises depend on third-party cloud services, cross-border data sovereignty restrictions and associated compliance requirements significantly raise the costs of model localization. Innovations in blockchain technology for data security offer new solutions to address this issue..

5.1.2 Institutional friction

(1) Using China's photovoltaic module exports to the EU as an example, companies must simultaneously comply with the accounting requirements of both China's carbon emissions trading market and the EU's Carbon Border Adjustment Mechanism (CBAM). This dual regulatory framework imposes compounded carbon cost pressures. The 2024 industry report indicates that this situation has led to a significant decline in profit margins for Chinese cross-border e-commerce businesses targeting the EU. The case of Guangzhou's "Carbon Tariff Adaptability" green trade system further underscores the seriousness of this issue.

(2)The U.S. Inflation Reduction Act (IRA), through provisions such as localization requirements for battery components, compels Chinese new energy enterprises to restructure their supply chains. For instance, lithium battery manufacturers must adjust their global production layouts to meet IRA standards, leading to a surge in upfront investment costs. Research data in green technology indicates that such regional subsidy policies are profoundly reshaping the geographic distribution of global industrial chains.

5.2 Breakthrough Countermeasures

5.2.1 Technological innovation: lightweight tools and the open-source ecosystem

(1) Modular SaaS Carbon Management Platform

By promoting cloud-based carbon management tools, such as GreenVoyage's "Carbon Neutrality Solution," enterprises can utilize standardized API interfaces for seamless integration with ERP systems, facilitating automated carbon emission data collection and accounting. Pilot projects for carbon footprint certification in Guangdong Province have demonstrated the practical value of such digital tools. For example, manufacturers in the Pearl River Delta have successfully reduced manual intervention costs by optimizing carbon accounting processes, a practice further validated in Shenzhen's cross-border e-commerce overseas warehouse regulatory innovation case. The built-in MRV-ETS conversion module in these platforms also ensures precise alignment with EU CBAM requirements, providing technical safeguards for exporters to avoid duplicate accounting risks.

(2) Open-Source Green Technology Collaboration Platform

Leveraging international open-source communities, such as the Linux Foundation's ecosystem, facilitates shared development of AI carbon accounting algorithms and blockchain traceability modules. The technical collaboration mechanism proposed in Shanghai's Cross-Border E-Commerce Action Plan for Industrial Products offers SMEs a pathway to reuse open-source code libraries, significantly reducing technical barriers and accelerating the localized deployment of carbon management models. Case studies from Zhejiang Province's carbon account practices for foreign trade enterprises demonstrate that the reusability of open-source technologies enhances cross-border data trust. For instance, a cross-border e-commerce enterprise based in Hangzhou optimized its green certification process by adopting open-source blockchain protocols, creating a positive feedback loop with the technical adaptation of the Regional Comprehensive Economic Partnership (RCEP) cross-border data flow rules.

5.2.2 Institutional innovation: multilateral coordination and dynamic governance

(1) Carbon Data Governance Rules within the WTO Framework

It is advisable to establish a cross-border carbon data classification and hierarchical management system under the WTO framework, drawing on China's pilot free trade zone mechanisms for cross-border data flow management. This would allow the free flow of non-sensitive data (e.g., carbon intensity of packaging materials) while mandating localized storage for sensitive data (e.g., production process emissions). Pilot experiences in the Guangdong-Hong Kong-Macao Greater Bay Area in coordinating data sovereignty and carbon footprint governance, provide empirical support for this mechanism. Additionally, a multilateral carbon audit system could help resolve cross-border green trade

disputes, with institutional innovations referencing successful paradigms from Beijing's business environment optimization practices in aligning with international standards.

(2) Supply Chain Carbon Footprint Trusteeship System

International certification bodies can establish standardized benchmarks for regional carbon management through centralized accounting of industrial cluster emissions. Shanghai's supply chain collaboration model in cross-border e-commerce for industrial products serves as a practical reference for such institutional designs. For instance, large-scale carbon verification in Shenzhen's 3C product supply chains significantly reduces per-batch accounting costs, a benefit further supported by scale-effect cases in Guangzhou's green trade system. The "Carbon Footprint Bank" model, which allocates carbon quotas across supply chains, offers SMEs a cost-sharing pathway for compliance. Research on Zhejiang's cross-supply chain carbon account adjustment mechanism also underscores its effectiveness in optimizing SMEs' technological empowerment and compliance cost structures.

5.2.3 Capacity building: integrating industry and education for financial empowerment

(1) The "Green Digital Supply Chain" Micro-Degree Program

Under the Ministry of Education's "Digital Talent Cultivation Special Plan," universities have collaborated with leading technology firms to develop practical courses covering core skills such as carbon footprint modeling and blockchain traceability. This model, inspired by Shanghai's technical collaboration model for industrial product e-commerce, addresses the shortage of applied skills. Pilot programs for "urgent-demand, application-oriented" micro-degrees have been launched nationwide, with some universities fostering interdisciplinary talent through courses like "Digital Technology and Financial Integration." For instance, the blockchain module in Hubei University of Education's Digital Economy micro-degree enhances students' technical application capabilities within green supply chains. This integration aligns with the vocational upskilling pathways outlined in the State Council's "Low-Altitude Economy Industry-Education Integration Action Plan," significantly enhancing graduates' competitiveness in green job markets.

(2) Policy-Based Financial Support System

Under the synergy of tech-finance and green supply chains, local governments are piloting green guarantee funds (e.g., Zhejiang's cross-supply chain carbon account adjustment mechanism, to support distributed energy storage infrastructure. The clean energy technology promotion pathways proposed in the "Green Supply Chain Construction White Paper" provide a policy foundation for financial support in green transitions. Innovative financial instruments like carbon forward letters of credit, integrate carbon quota management with supply chain financing. The financial innovations within Fujian's Industry-Education Integration Outstanding Engineer Program offer SMEs solutions for carbon asset capitalization. Cases of financial empowerment from the Greater Bay Area's data sovereignty and carbon footprint coordination pilot demonstrate how vocational-education integration models can establish dual support mechanisms—technology-driven and capital-fueled—to sustain green supply chains.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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THE VALUE CREATION MECHANISM OF DESIGN-LED EPC PROJECT CONSORTIUM

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Abstract: The design-led EPC model has become a widely adopted engineering construction approach internationally. However, it still faces challenges such as the lack of clear understanding among consortium members regarding its value creation mechanisms, which significantly hinders its broader application. To address this issue, this study conducts an in-depth exploration of the value creation mechanisms among consortium members under the design-led EPC model. Focusing on the value creation processes of each consortium member in design-led EPC projects, this research systematically identifies the relevant elements and constructs value creation networks for both the design leader and the contractor. Through a literature review, the core elements of value creation within the consortium are identified, including enterprise needs, value creation behaviors, and the multidimensional value dimensions of EPC projects. On this basis, from the dual perspectives of fulfilling enterprise needs and enhancing project value, the study systematically investigates the specific value creation pathways of each consortium member. It further analyzes the hierarchical structure of value creation for both the design leader and the contractor, respectively building value creation network models for each. This reveals the internal logic and driving mechanisms behind the value creation processes of all consortium members.
Keywords: EPC; Design-led consortium; Enterprise needs; Value creation mechanism

1 INTRODUCTION

With the continuous evolution of international engineering construction management concepts, the EPC (Engineering, Procurement, and Construction) model has been increasingly adopted by many countries due to its efficient resource integration capabilities and the advantage of a single point of responsibility. The core of the EPC model lies in delegating key project phases—such as design, procurement, and construction—to a general contractor, thereby integrating the industrial chain and achieving risk control and benefit optimization throughout the project's life cycle.
Given the typically large scale and high technical complexity of EPC projects, it is often difficult for a single enterprise to independently undertake all EPC responsibilities. As a result, forming a consortium led by a design firm has become a widely adopted solution. However, in such design-led EPC consortia, the members assume different functions throughout the project life cycle, with their value creation activities spanning key phases such as design optimization, procurement management, construction execution, and overall project coordination.
Due to the inherent complexity and uncertainty in the field of engineering construction, along with the cognitive limitations of individual members, consortium participants often lack a clear understanding of the value creation mechanisms within the EPC model. This undermines the overall performance of the consortium. Furthermore, there is an insufficient understanding among consortium members of the value creation logic specific to design-led EPC models. The absence of a well-established value cognition system and the lack of a unified understanding of how EPC projects generate added value make it difficult for members to reach consensus during project management and decision -making processes.

2 LITERATURE REVIEW

2.1 Value Creation in Construction Projects

Early research on value enhancement in construction projects primarily focused on economic value—specifically, how to improve the overall value of a project through cost control and revenue optimization. Kabirifar et al. used multi-attribute group decision-making techniques to analyze performance factors in large-scale residential EPC projects in Iran [1], finding that engineering design, project planning, and project control are critical to EPC project performance. Aldhaheri et al. employed structural equation modeling (SEM) to identify factors affecting the effectiveness of oil and gas EPC projects [2], establishing causal relationships and relative contributions among these factors. Ghasemi et al. [3], using a fuzzy mathematical model, demonstrated that company resources, organizational structure, applied methods and technologies, and EPC project performance evaluation tools are all linked to project timelines and influence both perceived quality and project cost from the client's perspective. Du et al. explored the causal relationships among the degree of partnership application [4], risk management, organizational capabilities, and EPC project performance, laying a solid foundation for contractor decision-making throughout project implementation.
Although current research on value creation in the EPC model is relatively extensive, it primarily focuses on scenarios involving single enterprises acting as independent contractors, with limited exploration of the EPC consortium model.

In particular, under the design-led EPC model, studies on the value creation mechanisms of consortium members are relatively scarce. There has yet to be a systematic construction of the internal relationships among consortium members' value creation behaviors, EPC project value enhancement, and enterprise development needs. As a result, the underlying logic of value creation remains unclear.

2.2 Influencing Factors of Value Creation by Construction Entities

The study of factors influencing value creation by construction entities is a key topic in the field of engineering management. Existing literature primarily analyzes these factors from the dimensions of economic returns, external environment, and cooperative relationships. Among these, economic return is the most direct driving force. Contractors often evaluate the necessity and feasibility of value creation based on the expected profitability of a project. For instance, Müller et al. found that a firm's profit expectations, cost-saving potential, and potential for additional revenue in EPC projects directly influence its willingness to engage in value creation [5]. Zhao et al. [6], focusing on opportunistic behavior by private enterprises in sponge city PPP projects, developed an evolutionary game model involving private enterprises, citizens, and the government based on stakeholders' perceived value. This model provides theoretical support for improving sponge city PPP projects. Wang et al. established a tripartite evolutionary game model involving the government [7], project owner, and construction firm, analyzing the strategic behaviors and influencing factors of each stakeholder in the development of the EPC model. Shen et al. [8], by constructing a trust-based system framework, revealed the deep interrelationships of trust, openness, and communication among stakeholders in EPC projects, and their impact on interface management performance. Jiang et al. explored the collaboration formation mechanism of EPC consortia in China's construction industry from the perspective of trust [9]. Their empirical findings indicate that trust positively influences the cooperative intentions between design firms and contractors. Contractors emphasize reciprocity, reputation, and communication as key elements for trust-building, while design firms place greater importance on reputation and communication. Ke et al. regarded contractual governance as the core of formal governance and trust as the core of informal governance [10]. By constructing a structural equation model, they examined the effects of both on construction supply chain collaboration and EPC project performance.

3 VALUE CREATION ELEMENTS AMONG MEMBERS OF DESIGN-LED EPC PROJECT CONSORTIUM

3.1 Demand Analysis of Consortium Members in Design-Led EPC Project Consortium

From a sociological perspective, demand is often regarded as an individual's internal motivation and inclination. Accordingly, this study defines the demand of consortium members in design-led EPC projects as the set of objectives they expect to achieve during their participation in project implementation. For consortium members, the ultimate goal behind all behaviors is typically to maximize the profits of their respective enterprises. This profit maximization is not limited to the direct economic returns of the current project, but also includes the enhancement of long-term benefits for the enterprise. These long-term benefits may involve improving corporate reputation, strengthening capabilities, or establishing stable partnerships with other firms to secure future project opportunities and increase long-term profitability. Therefore, this study defines the overall demand of consortium members as the increase in total enterprise profit.

The increase in total enterprise profit can be further divided into two dimensions: current profit growth and future profit growth. In EPC projects, the demand of consortium members goes beyond the pursuit of short-term economic gains. It involves accumulating resources and opportunities during the current project to support the long-term development of the enterprise. Thus, categorizing total profit into these two dimensions not only provides a comprehensive reflection of the multi-layered nature of enterprise demands, but also offers a theoretical foundation for designing various demand satisfaction paths, ensuring the completeness and robustness of such pathways.

3.1.1 Design-leading party demand analysis

As the core leader of the EPC project consortium, the design lead party is responsible for key functions such as project design, procurement, and project management. Its primary objective is to achieve cost control and value enhancement by optimizing design schemes, controlling procurement costs, and improving technical and management capabilities. This process involves not only enhancing the benefits of the current project but also establishing long-term and stable cooperative relationships with the construction party, the owner, and suppliers, thereby creating future market opportunities and potential returns for the Design-leading party.

Specifically, the increase in current profit for the design-leading party is primarily achieved through profit gains from the ongoing EPC project. This is not limited to cost optimization, but also includes economic rewards from the project owner or other external entities for improvements in project schedule, quality, and risk control. During the implementation of an EPC project, the design leader can significantly enhance the overall project value through technological innovation, management optimization, and efficient resource allocation, thereby driving profit growth. At the same time, future profit growth is also a core objective for the long-term development of the design leader. This future profit growth mainly involves two aspects: Enhancing the likelihood of winning future projects by improving social reputation, accumulating successful project delivery experience, and expanding strategic partnerships; Increasing profit margins in future individual projects through the continuous improvement of technical capabilities and management competence. In summary, the future profit level of the design leader is jointly influenced by four key

factors: corporate social reputation, long-term cooperative relationships, EPC project management capability, and professional design capability, as shown in Table 1.

Table 1 Summary of Enterprise Needs of the Design-Leading Party from the Perspective of Profit Maximization

No.	Enterprise Needs of the Design Lead Party
R1	Increase in overall corporate profits
R2	Increase in current corporate profits
R3	Increase in future corporate profits
R4	Increase in profits from the current project
R5	Optimization of current project costs
R6	Acquisition of external resource support
R7	Opportunities for future projects
R8	Increase in profits from individual future projects
R9	Enhancement of social reputation
R10	Establishment of long-term cooperative relationships
R11	Improvement of EPC project management capability
R12	Improvement of professional design capability

3.1.2 Construction party demand analysis

In a design-led EPC project consortium, the primary role of the construction party is to execute construction activities based on the design scheme, ensuring the smooth progress of the project as planned. At the same time, the construction party provides feedback during the construction process to assist in adjusting the design scheme, thereby ensuring the overall progress and quality of the project.

The construction party's enterprise-level demand analysis are similar to those of the design lead party, but there are certain differences. In terms of building long-term cooperative relationships, the construction party has less interaction with the owner and suppliers, so its demands are more focused on the actual execution and management during the construction phase. Regarding future project opportunities and the profitability of individual projects, the construction party's demands(R13) are primarily influenced by its construction management capabilities rather than being directly driven by the overall EPC project management or design capabilities.

Specifically, the construction party's demands are reflected not only in the execution process of the current project but also include enhancing its ability to secure and profit from future projects by improving construction management levels and strengthening social reputation. Additionally, a good social reputation and a track record of past projects will also help the construction party gain more market opportunities.

3.2 Analysis of Value Creation Behaviors of Consortium Member

3.2.1 Analysis of value creation behavior of the design-leading party

Under the design-led EPC model, the design lead party is responsible for formulating and optimizing the overall design scheme of the project, and leads the project's technological innovation and implementation planning. As the lead and core of the consortium, the design lead party not only coordinates design, construction, and procurement processes to ensure efficient connection between various project stages, but also effectively reduces project costs and improves engineering quality and management efficiency through design optimization, technological innovation, and resource integration. In this study, the procurement business of the EPC project is also handled by the design lead party, making its role in EPC project value creation more comprehensive. In addition to optimizing design, it must also focus on procurement management and technical support for the project. Through reasonable procurement management, the design lead party can not only reduce material procurement costs but also ensure the stability of material quality, while maintaining close coordination with construction progress. At the same time, the application of various innovative technologies helps the design lead party more accurately grasp the actual project situation, optimize dynamic adjustments in design and construction, and improve overall project efficiency. The introduction of green technologies such as modular construction and energy-saving materials can also effectively enhance the project's environmental benefits.

Moreover, a reasonable profit distribution mechanism, clear division of rights and responsibilities, and an effective risk-sharing mechanism are key to ensuring the stable operation of the consortium. As the leading party of the consortium, the design lead party needs to establish a scientific profit distribution mechanism within the consortium to ensure that the contributions and benefits of all participants are matched, thereby motivating all parties to actively invest resources

and technology and maximize the overall value of the consortium. At the same time, through contractual agreements, clear division of rights and responsibilities, and the formulation of contingency management plans, a reasonable risk-sharing mechanism can clearly define each party's responsibilities in uncertain situations such as market fluctuations and project delays. This ensures reasonable risk allocation, enhances the cohesion and risk resistance of the consortium, and strengthens project stability, as shown in Table 2.

Table 2 Summary of Value Creation Behavior of the Design-leading Party

No.	Value Creation Behavior of the Design-leading Party
A1	Clarify client requirements
A2	Refine communication mechanisms
A3	Optimize design solutions
A4	Clarify consortium's internal authority and responsibility delineation
A5	Adopt innovative technologies
A6	Establish risk-sharing mechanisms
A7	Determine specifications and quantities of materials
A8	Coordinate design and construction
A9	Coordinate procurement and construction
A10	Institute rational consortium profit distribution mechanism

3.2.2 Analysis of value creation behavior of the construction party

In EPC projects, the construction party, as the main executor of the engineering project, undertakes key tasks such as construction organization, quality control, and schedule management. Its core responsibility is to carry out construction according to the design scheme provided by the design lead party and continuously provide feedback on site conditions during construction to assist the design lead party in adjusting or optimizing the design scheme. This achieves coordinated control of project schedule, quality, and cost, ensuring the smooth implementation of the project. The construction party's value creation behavior is also reflected in optimizing its own construction management plans and improving construction processes. By reasonably allocating construction resources, strengthening site management, establishing standardized construction management systems or processes, and introducing intelligent management tools and smart construction equipment, the construction party can further improve construction efficiency and quality. Moreover, as an important member of the EPC consortium, the construction party can assist the design lead party in establishing a scientific and reasonable profit distribution mechanism to ensure that consortium members, especially itself, receive corresponding returns, thereby enhancing cooperation enthusiasm within the consortium. At the same time, the construction party should also participate jointly in the formulation of the risk-sharing mechanism to ensure the reasonableness of its risk bearing, as shown in Table 3.

Table 3 Summary of Value Creation Behavior of the Construction Party

No.	Value Creation Behavior of the Construction Party
B1	Coordinate design and construction
B2	Innovate construction technologies and optimize operational procedures
B3	Streamline construction management schemes
B4	Facilitate risk apportionment framework development
B5	Institute rational consortium profit distribution mechanism

3.3 Analysis of the Forms of Value Enhancement in EPC Projects

The value creation behaviors of consortium members not only bring direct value to the enterprises through the improvement of their own capabilities and accumulation of knowledge but also achieve indirect benefits by enhancing the overall value of the project. This process includes not only the direct economic benefits of the project but also the added value generated through various management practices, technological optimizations, and communication and collaboration. Considering the uniqueness of the consortium model, on the basis of the traditional five forms of value performance in construction projects—quality(V1), schedule(V2), safety(V3), cost(V4), and environment(V5)—it is necessary to further introduce the critical dimension of "reduction of contract disputes and claims(V6)" to

comprehensively reflect the characteristics of value enhancement in EPC projects during the value creation process of consortium members.

4 CONSTRUCTION OF THE VALUE CREATION NETWORK AMONG CONSORTIUM MEMBERS

4.1 Sorting Out Value Enhancement Paths from the Perspective of EPC Projects

The value enhancement of consortium members not only concerns the economic benefits of the project but also directly impacts its quality and social value. To achieve this, consortium members can adopt a series of strategic measures to optimize value creation throughout the entire project lifecycle. For example, by optimizing the design scheme, the design lead party can effectively control construction costs, improve resource utilization, and reduce waste during the construction process—while ensuring project quality. At the same time, the application of green building concepts and innovative technologies can mitigate adverse environmental impacts and enhance the social value of the project.

Moreover, the value creation behaviors of consortium members are not isolated; certain behaviors exhibit conditional sequences and logical relationships. Take the optimization of the project design scheme as an example: such optimization must be based on an in-depth analysis of the client's specific requirements to ensure that the optimized design not only meets contractual obligations but also maximizes the interests of all relevant stakeholders. Only by fully understanding the core demands of the owner and integrating the project's technical, economic, and environmental requirements can the design scheme be effectively optimized, thereby enhancing the overall project value. This logical relationship reflects the layered nature of value creation—where the early-stage analysis and planning based on the owner's needs determine the subsequent optimization measures, and the implementation of those measures, in turn, influences the final project outcomes.

4.2 Sorting Out Value Creation Paths from the Perspective of Enterprise Demand Fulfillment

The fundamental goal of consortium members in promoting value enhancement within EPC projects is to maximize their own corporate profits. Therefore, this study aims to establish a logical connection between EPC project value enhancement dimensions and the demands of consortium member enterprises. During the implementation of EPC projects, consortium members engage in a series of value creation activities that not only effectively reduce overall project costs—bringing direct economic benefits to the enterprise—but also provide high-quality project services that help establish long-term and stable cooperative relationships with the owner and suppliers. This, in turn, enhances the social reputation of consortium members and strengthens their competitiveness in future markets.

In addition, the value creation behaviors of consortium members can fulfill enterprise demands not only through overall EPC project value enhancement, but also through direct impacts. For instance, the successful application of new technologies, innovative management models, or well-structured contract terms in the current project can be replicated and promoted in future projects, thereby reducing training and technology implementation costs for future endeavors.

Specifically, the behavioral paths of consortium members in meeting enterprise needs are not limited to the short-term gains of the current project. They also include enhancing technical or managerial capabilities, strengthening social reputation, and establishing long-term partnerships to secure greater future returns for the enterprise. Therefore, this study, from the perspective of enterprise value creation, further analyzes the value creation paths of consortium members.

4.3 Construction of the Value Creation Network Among Consortium Members

Based on the research presented in Sections 4.1 and 4.2—focusing on value enhancement in EPC projects and the fulfillment of enterprise demands from the perspective of consortium members—this study constructs the value creation networks of the design lead party and the construction party under the goal of maximizing corporate profit. Through an in-depth analysis of consortium members' value creation behaviors, combined with their specific needs within the project, the resulting networks are illustrated in Figures 1 and 2. It reveals how consortium members, during the implementation of design-led EPC projects, achieve growth in economic benefits by improving communication mechanisms and coordinating design and construction activities. These efforts also enhance their market competitiveness and meet the long-term development needs of the enterprise.

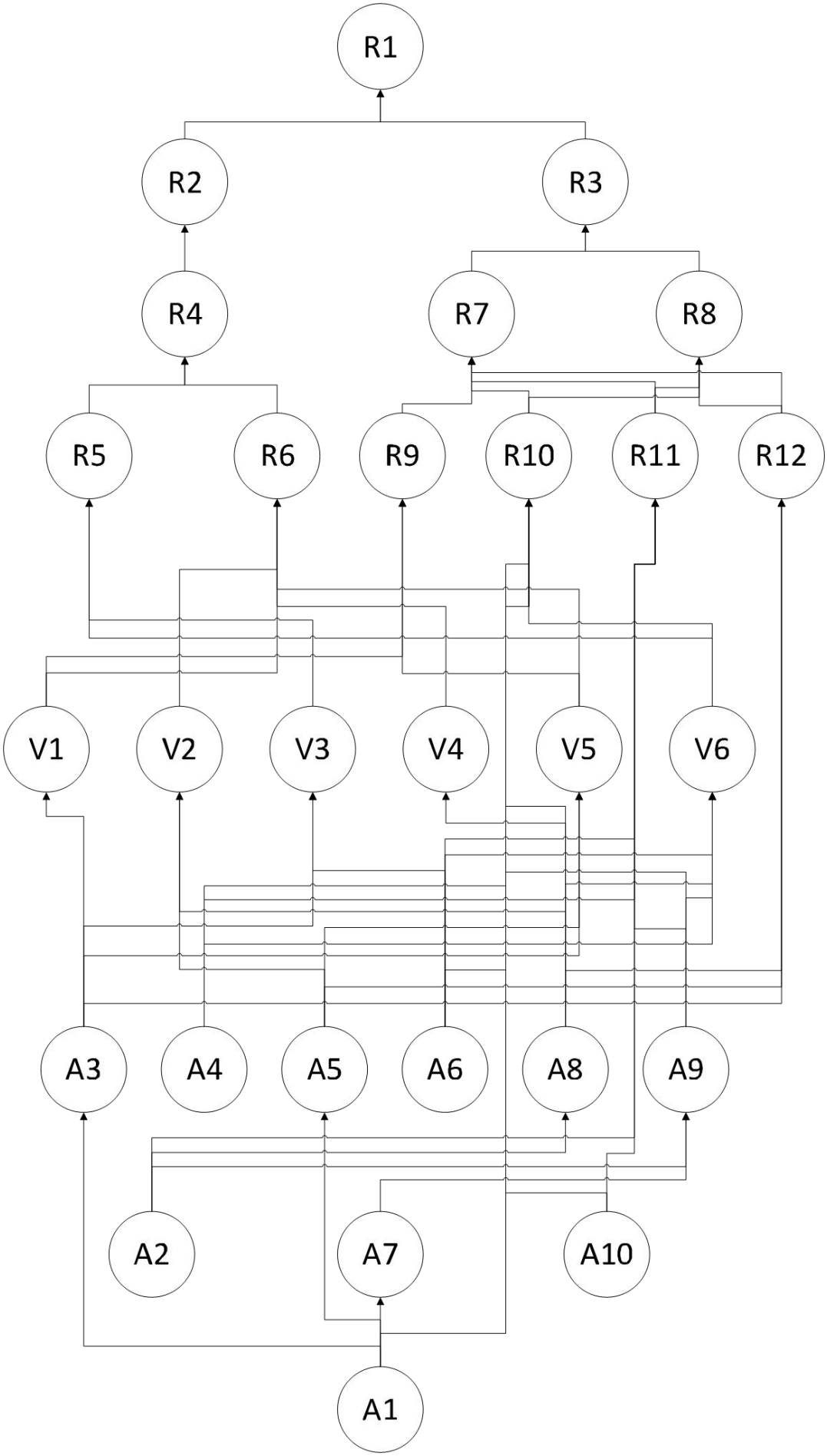

Figure 1 Value Creation Network of the Design-Leading Party

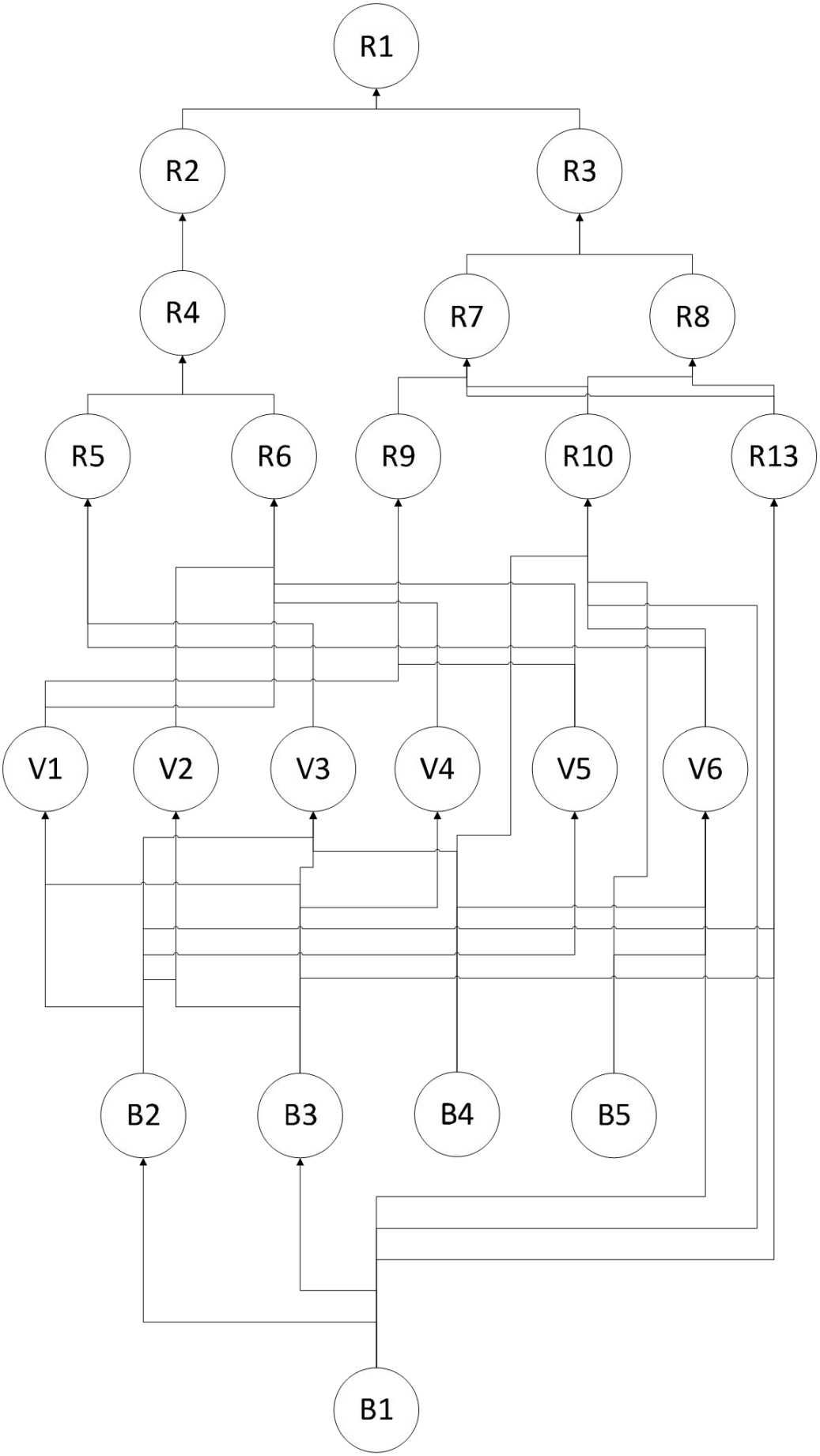

Figure 2 Value Creation Network of the Construction Party

5 CONCLUSION AND DISCUSSION

This research focuses on the value creation hierarchy of consortium members in design-led EPC projects, systematically identifying key elements and constructing value creation networks for both the design lead and the construction party. First, based on a review of the literature, the core elements of value creation were identified, including enterprise needs, key value-creating activities during project implementation, and the forms in which EPC project value enhancement is manifested. Second, from the dual perspective of meeting enterprise needs and enhancing project value, the study systematically analyzes the relationship between consortium members' value creation activities and their respective needs. It clarifies each member's contribution to both enterprise development and EPC project value, and explores their specific value creation paths. Finally, the hierarchical structure of value creation for the design lead and the construction party is mapped out, and their respective value creation networks within the design-led EPC consortium are constructed. This comprehensively reveals the value creation logic of both parties and their roles in project management and enterprise development.

However, the current analysis is primarily based on the individual perspectives of consortium members and lacks an in-depth exploration of the collaborative mechanisms between them and the process of value co-creation within the consortium.

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