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Enhancing Sustainable Performance: The Innovative Strategy of Digital Transformation Leading Green Collaborative Management

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Abstract: Within the framework of the increasing demand to balance digital transformation and sustainable development in businesses, this study explores the impact of digital transformation (DT) on sustainable development performance (including environmental, social, and economic performance) with the synergistic effects of green human resource management (GHRM) and green supply chain management (GSCM). This study was centered on Chinese manufacturing firms and utilized partial least squares structural equation modeling (PLS-SEM) to examine data from 450 companies. The findings of the research suggest that GHRM and GSCM serve as partial mediators in the correlation between DT and sustainable development performance. Furthermore, the synergistic effects between GHRM and GSCM are crucial in leveraging the advantages of DT to improve overall organizational performance. These discoveries not only add to the current understanding in the field but also offer practical advice for managers.

Keywords: digital transformation; sustainable development performance; green human resource management; green supply chain management; synergy

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1. Introduction

The Industrial Revolution, characterized by technological advancements in resource exploitation and environmental utilization, has propelled the development of modern human society. As demand compels an unprecedented rapid expansion of production scale, the escalating contradictions among demand, resource availability, and the environment have become increasingly acute [1]. However, development is still the theme of today's society, and it is no longer simply the growth of economic indices, but rather it encompasses sustainable development that balances social, economic, and environmental factors [2] The United Nations defines sustainability as the movement to ensure a better and more sustainable well-being for all, including future generations. This movement aims to address persistent global inequalities, peace, climate change, pollution, environmental degradation, and other enduring issues [3]. Indeed, every organization has a responsibility to exert additional endeavors in harmonizing their economic, social, and environmental performance [4].

Since the term "Industry 4.0" began to gain widespread recognition, the digital transformation (DT) brought about by Industry 4.0 has immediately captured the attention of industries and governments worldwide [1]. Enterprises can realize process automation and informatization through DT, which can reduce the waste of human and material resources and improve production and operation efficiencies. DT encompasses the application of diverse digital technologies to drive transformations and possibilities in the activities, procedures, capacities, and frameworks of an organization [5], which is crucial to achieving green development goals.

Because there are few evaluations that specifically examine the correlation between digitization and sustainable development across different levels [6], especially in East Asia, there exists an unfilled research void. Furthermore, assessing the multifaceted impacts of digitization on socio-economic and environmental sustainability from a regional perspective introduces uncertainty and research gaps [7]. This prompted us to conduct a study in China, evaluating the effects of DT on the triple bottom line of sustainable development: economic (Ec.P), environmental (EP), and social (SP) performance. Based on the literature review and analysis, this paper measures enterprises' DT according to several characteristic dimensions of digital strategy, basic technology, and front-end technology. Digital technology itself is not the focus of this article. This research attempts to address the following question:

RQ1. Does DT affect the triple bottom line of sustainable development in businesses, including Ec.P, EP, and SP?

Despite the benefits brought by digital technologies, organizations still face challenges in implementing these technologies. These challenges involve a lack of understanding among employees regarding digital and automation systems, as well as barriers to redefining their roles [8]. Based on the study conducted by Yang et al., a significant number of businesses have made substantial financial commitments to the integration of digital technologies. However, their failures often stem from disregarding the influence of soft skills on the learning process [9]. From this standpoint, the integration of employees and technology is perceived as being significantly influenced by green human resource management (GHRM).

Consequently, carrying out effective green management to enhance an organization's sustainability performance is a multifaceted endeavor [7]. The research findings by Lai et al. [10] reveal that cross-functional communication regarding green awareness can tackle this challenge. Thus, solely focusing on GHRM is insufficient for advancing enterprises' sustainable development performance. In the present digitally driven market, Green Supply Chain Management (GSCM) is recognized as an organizational resource and capability employed to pursue more sustainable practices, uphold a competitive edge, and strike a balance between economic gains and environmental conservation [11]. However, the element of employee conduct, known as the "soft aspect" of GSCM [12], plays a crucial role in effectively executing green supply chain management [13]. Consequently, GHRM and GSCM complement each other and necessitate collaborative research.

There is a gap in the existing literature regarding whether DT can drive GHRM and GSCM, as well as their inter-departmental collaboration. The primary objective of this study is to address this research gap by examining the following research questions in order to accomplish its aims:

RQ2. Will DT affect GHRM and GSCM, as well as their synergy?

RQ3. Does GHRM and GSCM exhibit synergistic effects?

Global events of magnitude, such as the COVID-19 pandemic and climate change, have prompted businesses to reflect on their green operations and supply chains, leading to an increased emphasis on environmental concerns [14]. This has spurred efforts to optimize logistics and reduce waste. Simultaneously, regional conflicts like the Russo-Ukrainian War and the Libyan conflict threaten supply chain stability, underscoring the importance of diversified sourcing, resilient inventories, and eco-friendly measures. Organizations are compelled to seek novel approaches [15], leveraging technological innovation and work design to meet the demands of an uncertain and ambiguous business environment [16,17]. This drive has also pushed scholars in relevant fields to focus more on environmental protection, sustainability, and crisis management, aiming to provide solutions for global challenges. In this context, exploring the synergistic management of digital transformation with GHRM and GSCM holds significant importance in promoting sustainable development within enterprises.

Through a review of existing literature, it has been recognized that GSCM practices have a singular impact on EP or Ec.P. However, there is currently limited research investigating the synergistic effects of GHRM and GSCM in the context of digitization [18], or their relationship with the triple performance of economic, social, and environmental aspects. Moreover, the examination of available literature additionally exposes a dearth of empirical investigations into the management of global integration and global supply chain management within manufacturing sectors of developing nations [19]. In order to fill these research lacunae, this study aims to tackle the subsequent research inquiries:

RQ4. Does DT impact sustainable development performance through the mediating effects of GHRM and GSCM, as well as their synergistic effects?

To tackle these research inquiries, we formulated a theoretical framework grounded in prior studies and performed empirical examinations utilizing data obtained from 450 Chinese manufacturing companies. The study aimed to explore the synergistic function and interrelationships between GHRM and GSCM on sustainable development performance in the context of DT. This study has made valuable contributions to the literature. Firstly, it extends the research on the antecedents of green practices and interdepartmental collaboration by considering the digital disruption as a potential driver of green practice collaboration. Secondly, this research offers a more comprehensive comprehension of the collective impacts of GHRM and GSCM on sustainable performance and their synergistic interaction, where the combined effects are greater than the sum of their individual effects. Thirdly, this study is considered the pioneering empirical exploration that analyzes the influence of DT on a company's sustainable development performance, taking into account GHRM and GSCM as dual mediating factors.

The subsequent sections of the paper are organized as follows: Section 2 delves into the theoretical framework, conducting an extensive examination of the pertinent ideas. Section 3 presents a thorough portrayal of the suggested theoretical model and delineates the research hypotheses. Section 4 elucidates the employed research methodologies, encompassing the questionnaire design, sampling techniques, and data collection procedures. Section 5 outlines the process of data analysis and presents the resultant discoveries. Section 6 engages in a scholarly discussion of the findings and their implications. Section 7 highlights the managerial implications that can be derived from the study's outcomes. Section 8 draws conclusions based on the research findings, discusses the limitations encountered, and suggests potential directions for future research endeavors.

2. Theoretical Foundation

2.1. Key Resources for Sustainable Development: DT, GHRM, and GSCM

The resource-based view (RBV) suggests that resources possess value when they can incentivize a company to develop or execute strategies aimed at enhancing effectiveness and productivity. Applying DT to green management in businesses helps unleash its potential value, supporting sustainable environments through practices such as effective electronic waste recycling and waste reuse [20]. The manufacturing sector employs digitization to implement green and clean production processes and green management [21,22]. Within this perspective, the organic integration of DT with GHRM and GSCM lays the foundation for long-term sustainable development.

The concept of DT refers to the increasing digitization of products and services and the impact of this change on business strategies [23]. An enterprise digital transformation system should encompass both the digital transformation strategy (DTS) and the application of digital technologies (DTA). DTS is a plan for an organization to use digital technologies to change business operations and innovative approaches [1]. The definition of DTA is using digital tools, systems, software, and methods to achieve goals such as improved efficiency, innovation, and data analysis in specific domains or tasks [5]. Data and information, increasingly accessible to businesses, have become a critical foundation of competition itself, enabling tailored products and services for individual customers and more efficient operations based on accurate forecasts [24]. As a significant heterogeneous resource, DT, due to its value and non-imitative characteristics, is poised to become a key source of competitive advantage for enterprises.

Green human resources and green supply chain resources are the key advantages of enterprises. Identifying resources and effectively utilizing them can enable enterprises to exert their due advantages. GHRM is defined as a set of human resource management practices aimed at enhancing employees' green performance in the workplace, thereby promoting organizational sustainable development [25]. GHRM reflects an organization's strategic orientation towards environmental protection, requiring senior management to focus on organizational processes and practices that encourage employee engagement in green work behaviors and reduce workplace environmental pollution [26], including key steps such as green recruitment (GR), green training and involvement (GTI), and green performance management and compensation (GPC) [27]. GR involves considering environmental factors in the hiring process, GTI encourages employees to take environmentally friendly actions, and GPC integrates environmental considerations into performance assessment and compensation systems [25,27]. This not only contributes to reducing resource wastage within the enterprise but also fosters employees' sense of involvement and identification, enhances production efficiency, and ultimately achieves the sustainable growth of the company.

The concept of GSCM refers to the implementation of green activities across various stages of supply chain management within a company. It encompasses the entire closed-loop process, including three key areas: green procurement (GP), green manufacturing (GM), and green logistics (GL) [28,29]. GP, GM, and GL refer to environmentally conscious practices in the areas of sourcing materials, production processes, and distribution operations, respectively [29]. Differing from traditional supply chains, GSCM includes activities aimed at minimizing the environmental impact of products [30]. It necessitates a balance between economic, environmental, and social triple bottom-line benefits [31,32] GSCM not only enables the maximization of profits but also considers advantages such as environmental sustainability and rational resource allocation, thereby facilitating a company's pursuit of sustainable development [33].

2.2. Synergy between GHRM and GSCM

Based on the Ability–Motivation–Opportunity (AMO) theory, cross-functional collaboration plays a critical role in driving corporate sustainable development. Cross-functional collaboration refers to how organizational design, strategy, and culture enable coordinated cooperation among various functional departments to achieve company objectives [34]. It is influenced by the dynamic of relationships within the internal organizational environment, as companies often adopt relational principles within their boundaries and emphasize relationship strategies to achieve this objective [35]. Cross-functional collaboration creates a positive work atmosphere [36], providing opportunities for implementing environmental practices. Different departments can collectively explore innovative solutions, facilitating the smooth diffusion of practices and resources from external sources within the company [37].

In this study, we focus on the cross-functional collaboration of GHRM and GSCM. Despite the intention for effective cooperation among various functional areas, GHRM and GSCM often do not align seamlessly due to differences in mindset, values, and objectives [37]. Cross-functional collaboration serves as an internal cooperation tool, aiding in overcoming inter-organizational challenges for environmental collaboration. It nurtures an inclusive identity and fosters a holistic understanding of value-creation activities within the company [38]. Through cross-departmental collaboration, green awareness is integrated into employee training, performance evaluations, and teamwork, promoting active engagement in sustainable actions [39]. Simultaneously, in the realm of supply chains, collaborative efforts among different departments ensure supply chain transparency, product innovation, risk management, and optimized partnerships, thereby reducing environmental impact and achieving a win–win scenario for both business and the environment [40].

3. Theoretical Framework and Hypotheses Development

3.1. DT and GHRM

DT has gained significant traction within the business community and is recognized as a crucial strategy for organizations to maintain their competitive edge and keep pace with the rapidly changing landscape [41]. The significance of digital technology and its influence on human resource functions has been further highlighted by the COVID-19 pandemic. Organizations have allocated substantial financial resources during this period to establish the necessary infrastructure and adapt to technology within their human resource management practices [42]. Leveraging digital technology enables enterprises to facilitate cross-border collaboration, effectively manage intricate relationships with diverse stakeholders, and foster skill development and knowledge sharing within the organization [43].

The DT of GHRM is a multi-dimensional structure that stems from the innovative ability of the organization and is realized through the successful integration of digital infrastructure, digital architecture, and personal ability and creativity [44]. According to Stachová et al. [45], human resources professionals can access the knowledge base in real-time through digital and intelligent functions, thereby making more objective decisions. In addition, DT can improve the efficiency of GHRM, help enterprises better track employees' environmental behaviors and awareness, and correct and train them in a timely manner. Building upon this, our suggestion is as follows:

H1. *DT has a positive, direct effect on GHRM bundles.*

3.2. DT and GSCM

Considerable research has provided substantial evidence for the benefits of digital technology in the implementation of eco-friendly supply chains and the pursuit of ecological sustainability [46]. Numerous authors have documented the advantages of utilizing digital technology in the procurement field, including improved detection of raw materials, enhanced quality monitoring and control, reduced inventory, optimized replenishment processes, and increased flexibility in procurement processes [47]. In terms of the manufacturing process, digital technology allows for seamless integration and communication among production systems, resulting in improved process flexibility, efficiency, and swift responsiveness to fluctuations in demand [48]. Additionally, digital technology has the capability to adjust environmental parameters such as resource consumption, toxicity, waste generation, greenhouse gas emissions, and energy efficiency by facilitating real-time optimization of manufacturing processes [49].

Furthermore, several scholars argue that the digitization of supply chains exerts a favorable influence on eco-friendly logistics [50]. For example, Internet of Things (IoT) technologies, such as barcodes, sensors, global positioning systems, and radio frequency identification (RFID), are employed for data capture and play a vital role in the identification, tracking, and recording of products and materials [51]. According to Lopes de Sousa Jabbour et al. [52] and Khan et al. [47], a clear and direct connection exists between the circular economy and digital technology. Mastos et al. [53] presented empirical proof regarding the impact of IoT solutions on the management of reverse supply chains based on their research involving scrap metal producers. Additionally, Plaza-Úbeda et al. [54] emphasized that the implementation of RFID systems has bolstered supply reliability, alleviated information gaps in recycling networks for reverse logistics, and improved the quality and availability of separation and inspection processes. Drawing from these viewpoints, we propose the following assumption:

H2. *DT has a positive, direct effect on GSCM practices.*

3.3. DT and Sustainable Performance

Industry 4.0 technology is widely acknowledged as a pivotal opportunity for businesses to achieve sustainable development objectives [55] and plays a significant role in augmenting organizational performance. DT empowers decision making in production planning and control by effectively processing information, thereby enhancing operational efficiency, reducing lead times for preparation and delivery, decreasing labor costs, facilitating the production of high-quality products at reduced expenses, and ultimately enhancing overall business efficacy and profitability.

From an ecological perspective, DT allows for the examination and monitoring of carbon dioxide (CO_2) emissions and eco-efficiency, facilitating the identification and evaluation of environmental impacts arising from production processes [56]. Additionally, it contributes to reducing energy consumption, minimizing waste generation, fostering energy conservation, and encouraging practices such as resource reuse and recycling to optimize resource efficiency. These efforts contribute to enhancing environmental performance (EP) [48], thereby contributing to the enhancement of EP.

Considering environmental concerns, there exist numerous advantages for the company, specifically including heightened employee contentment, enhanced stakeholder rapport, improved employee retention, and the cultivation of a more favorable brand image [57]. Moreover, there are other acknowledged benefits, such as the augmentation of social responsibility awareness among the workforce and the facilitation of talent attraction and retention [58]. In fact, Wagner [59] indicated that there is evidence to suggest that in terms of investing in social responsibility, companies reap tangible benefits in the form of customer and employee satisfaction, exceptional employee recruitment, and innovation, all of which contribute to fortifying the company's sustainability performance. Based on the aforementioned perspectives, we put forward the following assumptions:

H3a. *DT has a positive, direct effect on Ec.P.*

H3b. *DT has a positive, direct effect on EP.*

H3c. *DT has a positive, direct effect on SP.*

3.4. GHRM and Sustainable Performance

Over the past decade, there has been a growing scholarly focus on the concept of GHRM. Recent studies emphasize the need for further investigation into the factors that drive organizations to embrace GHRM practices, as well as the underlying mechanisms that link GHRM to performance outcomes [60]. According to existing literature on GHRM practices and corporate performance, there is a positive correlation between the two.

Song et al. [61] have emphasized that the internal GSCM functions as an intermediary between GHRM practices and the achievement of sustainable performance. Sobaih et al. [62] have found a positive and significant impact of green capabilities, motivations, and opportunities of enterprise owners and managers on green innovation and EP, drawing upon the theories of AMO, and the RBV. Furthermore, the influence of GHRM on EP is amplified in the presence of green innovation. Furthermore, available studies suggest that although there may not be a direct influence of effective human resource practices on the strengths of corporate social performance (CSP), they do exhibit a favorable effect on CSP strengths within highly innovative organizations or those with ample resources [63]. Building upon these discoveries, the following hypotheses are put forward:

H4a. *GHRM has a direct positive impact on Ec.P.*

H4b. *GHRM has a direct positive impact on EP.*

H4c. *GHRM has a direct positive impact on SP.*

Based on the aforementioned assumptions, it can be inferred that the DT of businesses will directly contribute to enhancing sustainable development performance. Similarly, the implementation of GHRM practices will also have a direct positive influence on sustainable development performance. Hence, the following assumptions are put forth:

H5a. *GHRM bundles partially mediate the relationship between DT and Ec.P.*

H5b. *GHRM bundles partially mediate the relationship between DT and EP.*

H5c. *GHRM bundles partially mediate the relationship between DT and SP.*

3.5. GSCM and Sustainable Performance

The optimization of GSCM processes enhances the efficient utilization of resources and materials [64], fosters environmental sustainability, diminishes unnecessary material usage, and minimizes the depletion of natural resources [65]. This results in reduced production costs and increased sales and profits [48]. Additionally, the integration of digital technology has improved demand forecasting and production planning, facilitated price optimization and product development, been better catered to customer needs, and bolstered market share and sales [56]. Concurrently, GSCM also enhances energy efficiency, lowers carbon emissions, and prolongs product lifespan [9].

By adopting eco-friendly practices to enrich the workplace environment for employees, individuals can enjoy an elevated sense of well-being [65]. Hence, integrating GSCM into the operational strategies of organizations might yield favorable outcomes for SP. While empirical studies examining the connection between GSCM practices and SP are limited, the available evidence indicates that eco-friendly initiatives are pivotal in fostering customer loyalty, enhancing corporate reputation [39], improving public health, promoting equal opportunities, ensuring product safety and workplace conditions, and adhering to legal and ethical standards [50]. Based on these considerations, we put forth the following hypotheses:

H6a. *GSCM has a direct positive impact on Ec.P.*

H6b. *GSCM has a direct positive impact on EP.*

H6c. *GSCM has a direct positive impact on SP.*

By incorporating digital technology into the tangible aspects of the supply chain [66], organizations can attain efficient optimization of eco-friendly product development and environmentally conscious manufacturing processes, while effectively adapting to market volatility [67], thus attaining a competitive edge and fostering ecological performance. The implementation of Industry 4.0 technology facilitates the interlinking and digitalization of procedures, goods, and services [46], thereby generating real-time data and enhancing resource planning [47], environmental monitoring, and supply chain synchronization [66].

H7a. *GSCM practices partially mediate the relationship between DT and Ec.P.*

H7b. *GSCM practices partially mediate the relationship between DT and EP.*

H7c. *GSCM practices partially mediate the relationship between DT and SP.*

3.6. The Promotion of Synergy between GHRM and GSCM through DT

Through a thorough examination of pertinent literature, we discovered that GHRM contributes to the establishment and advancement of eco-friendly relationships and collaboration within the supply chain. The works of Lorentz et al. [68] have demonstrated that capabilities and skills serve as crucial factors for driving supply chain management forward. Fu et al. [69] have also revealed that human resource management can enhance supply chain performance by fostering the creation and implementation of teams. These research studies offer substantiation for the significant role played by human resource management in the realm of supply chain management. Simultaneously, the junction of GHRM and GSCM has emphasized the pivotal role of managers operating within the logistics and GSCM domain [27]. The collaborative cooperation between GHRM and GSCM requires information sharing and resource coordination, and digital technology can effectively meet this demand.

Digitalization has diverse implications across different functions and locations within the business model, affecting the overall business environment and inter-functional coordination dynamics [70]. Building on this, Ruiz-Alba et al. [71] have emphasized that the digitization process directly influences multiple aspects related to interdepartmental collaboration, including communication resources, cloud-based software, and platforms for sharing information. Additionally, digitalization crucially boosts a company's agility in delivering tailored solutions to customers, thus promoting a customer-centric approach [67]. Drawing from these observations, the subsequent hypothesis is put forward:

H8. *DT has a positive, direct effect on collaborative cooperation between GHRM and GSCM.*

3.7. Synergistic Promotion of Sustainable Development Performance by GHRM and GSCM

Previous research has supported a strong association between integration and performance. The integration of diverse functions significantly affects various organizational outcomes, including shortened cycle times, successful new product introductions, improved customer value perception, and enhanced customer service [35]. Cross-functional collaboration plays a crucial role in the sustainable development of businesses, facilitating resource integration, problem solving, and innovation, thereby enhancing competitive advantage and long-term growth [37]. The proposed association, however, has not been extensively measured and tested. In particular, the associations between alternative forms of interdepartmental integration and performance are not well established.

By analyzing the correlation between GHRM and GSCM, we can gain a deeper comprehension of how they collectively influence various dimensions of sustainable performance The use of financial and non-financial incentives can motivate employees to work towards inter-functional goals and foster collaboration with other business units [72]. Furthermore, the involvement of cross-functional teams has been shown to accelerate speed to market and enhance profit generation [73]. According to resource dependency theory, the coordination of diverse functional units to leverage their knowledge and skills in addressing organizational challenges is crucial. Based on these findings, the following hypotheses are proposed:

H9a. *The collaboration between GHRM and GSCM has a positive impact on Ec.P.*

H9b. *The collaboration between GHRM and GSCM has a positive impact on EP.*

H9c. *The collaboration between GHRM and GSCM has a positive impact on SP.*

Considering that digital transformation fosters collaboration between GHRM and GSCM, and such collaboration enhances the sustainable development performance of enterprises, we put forward the following suggestions:

H10a. *The collaboration between GHRM and GSCM plays a partial mediating role between DT and Ec.P.*

H10b. *The collaboration between GHRM and GSCM partially mediates the relationship between DT and EP.*

H10c. *The collaboration between GHRM and GSCM partially mediates the relationship between DT and SP.*

The study's framework, as depicted in Figure 1, examines the relationships between various constructs within the context of China. The framework encompasses several direct impacts and mediating effects. Firstly, it explores the direct impact of DT on GHRM, GSCM, and the synergy between GHRM and GSCM. Secondly, it explores the immediate influence of DT on the elements of sustainable outcomes, specifically EP, Ec.P, and SP. Thirdly, it assesses the direct impact of GHRM, GSCM, and their combined effects on the constituents of sustainable performance. Lastly, the framework takes into account the intermediary role played by GHRM, GSCM, and their synergy in the connection between DT and the constituents of sustainable performance.

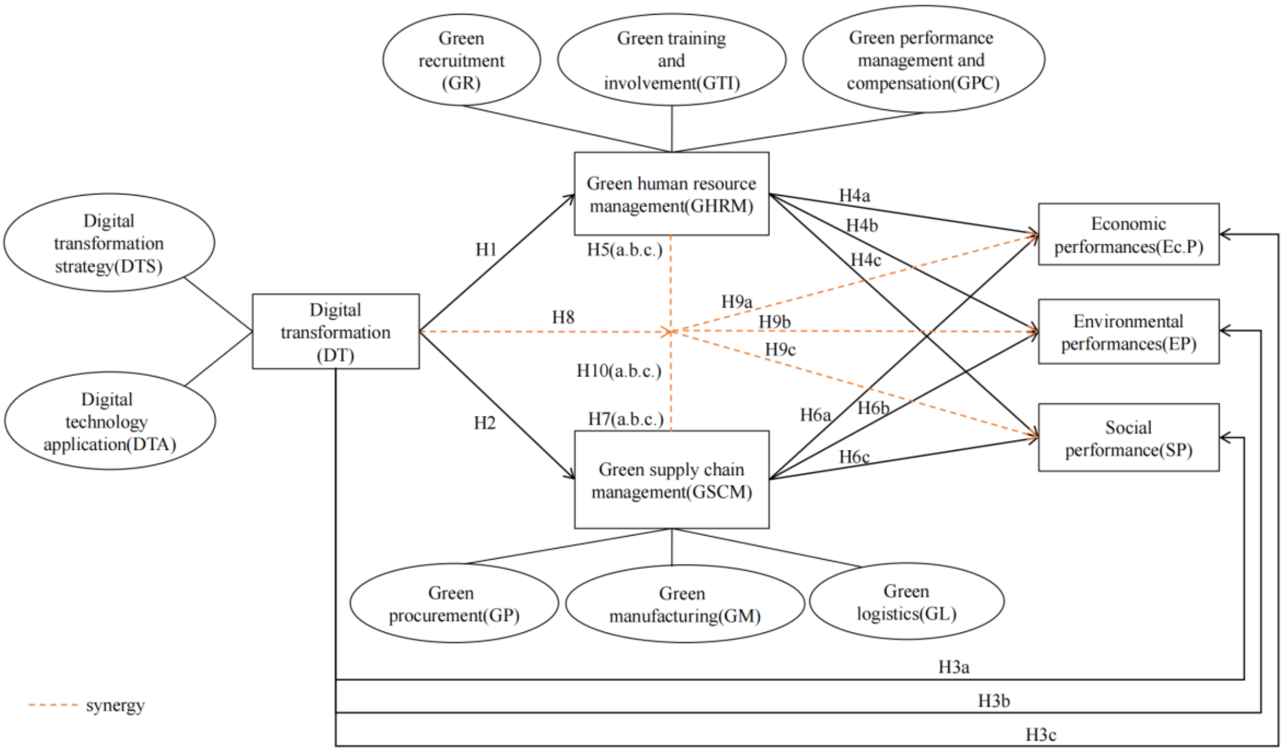

Figure 1. Conceptual framework.

4. Research methods

4.1. Sampling and Data Collection

This study focused on Chinese manufacturing companies as the analytical unit, with the intended participants being managers who hold decision-making positions within these enterprises. Due to the large population size, the sample size was determined using the infinite population formula. The approximate proportion of businesses holding ISO 14001 [74] certification during the preliminary survey phase was 34.3%, with an anticipated relative margin of error not exceeding 7.5% and a confidence level of 95%. The determined sample size for the final analysis amounted to 624.

We employed a stratified random sampling method to sample manufacturing firms in China, ensuring that the selected sample reflects the actual situation of DT and green management in the country's manufacturing sector as much as possible. Firstly, we adopted a stratified quota sampling based on China's seven major geographical regions. The sample size for each administrative region was calculated based on the proportion of manufacturing firms in that region. The data on the number of manufacturing firms in each region were obtained from the CNINOF website, which maintains a comprehensive national directory of companies. In the random sampling phase, we utilized a professional online survey platform to distribute questionnaires to the designated regions, specifically targeting managers in manufacturing firms as the respondent group. The sampling results are presented in Appendix A.

Our questionnaire was disseminated via digital platforms between the beginning of March and the conclusion of May 2023, resulting in the collection of a grand total of 487 fully completed surveys. According to the same proportional standards, 69 invalid questionnaires were screened out, resulting in a final count of 450 valid questionnaires. From the sample composition, approximately 45% are medium-sized enterprises, 34% are large, and 21% are small. In terms of industry types, resource processing industry enterprises account for 45%, light textile industry enterprises for 33%, and mechanical and electronic manufacturing enterprises for 22%. In addition, 28% of enterprises lack ISO 14001 [74] certification. Table 1 details all sample compositions in our study.

Table 1. Sample composition.

Descriptio		Percentage (%)
Respondent's position level	Senior manager	12.36
	Intermediate manager	21.41
	First-line manager	66.23
Company size	Small (<300 employees)	21.19
	Medium (300–1000 employees)	44.81
	Large (>1000 employees)	34
Years of establishment	Over 10 years	21.63
	6–10 years	25.83
	3–5 years	37.97
	Less than 3 years	14.57
Industry types	Resource processing industry	45.03
	Light textile industry	33.33
	Mechanical and electronic manufacturing	21.63
ISO 14001 certification [74]	Yes	71.74
	No	28.26

The research conducted by Benitez et al. [75] underscores the significance of conducting a power analysis before collecting data. This analysis aids in determining the smallest sample size necessary to attain adequate statistical accuracy and detect the desired effects in the population. In the context of the partial least squares (PLS) path model and the statistical approach employed, the study suggests that a sample size of 450 data points from manufacturing enterprises is appropriate. This sample size takes into account the highest number of indicators associated with a construct and adheres to the recommended minimum sample size of $3 \times 10 = 30$ proposed by Barclay et al. [76]. Moreover, by referring to Exhibit 1.7 in Hair et al. [77], an alternative minimum sample size of 37 arises when considering an 80% statistical power, a 5% significance level, and a minimum R^2 of 25%. It is important to note that the present investigation was conducted with a sample size exceeding the minimum acceptable requirement, indicating an ample number of data points to achieve the desired statistical power and precision.

4.2. Measures

To conduct an empirical investigation into the proposed hypotheses, a well-structured survey was formulated, incorporating established concepts from the relevant literature. The primary factors were evaluated using a Likert scale with five levels, where "1" represented strong disagreement and "5" indicated strong agreement. The measurement items and sources of all variables are shown in Table 2.

For the purpose of DT, we employed two supplementary measurement constructs. The initial one pertains to the DTS, which we assessed using five adapted items from Proksch et al. [78]. These items measure a company's achievements and positioning in digital transformation, encompassing the significance of digitization in business strategy, attention to the latest trends, prioritization of digital projects, updates and refinement of digital strategy, and the company's leadership in digital innovation. The second construct involves the DTA, comprising five items adapted from Lerman et al. [79], encompassing the Internet of Things, cloud computing, big data analysis, artificial intelligence, and blockchain.

Table 2. Questionnaire constructs, variables for each construct, and sources.

Constructs		Items	Citation
Secondary Construction	**First Level Construction**		
Digital Transformation (DT)	Digital Transformation Strategy (DTS)	DTS 1. Digitalization is among the top three most important elements of our business strategy. DTS 2. We investigate the newest trends and future scenarios in digitalization to stay competitive. DTS 3. Digital projects have a high priority within our business. DTS 4. We constantly update and refine our digital strategy. DTS 5. Our competition as well as industry experts perceive us as a leader in digital innovation.	Proksch et al., 2021 [78]
	Digital Technologies Application (DTA)	DTA 1. We use Internet of Things in our business work. DTA 2. We use cloud computing in our business work. DTA 3. We use big data analysis in our business work. DTA 4. We use artificial intelligence in our business work. DTA 5. We use blockchain in our business work.	Lerman et al., 2022 [79]
	Economic Performance (Ec.P)	Ec.P 1. Reduced energy utilization costs over the past two years. Ec.P 2. Average return on sales and investment over the past two years. Ec.P 3. Average profit and profit growth over the past two years. Ec.P 4. Average growth in market share over the past two years.	Zaid et al., 2018 [80]
	Environmental Performance (EP)	EP 1. Our company has increased material recycling over the past three year. EP 2. Our company has reduced emissions over the past three year. EP 3. Our company has reduced use/waste of resources over the past three year. EP 4. Our company has decreased its use of hazardous/environmentally harmful materials in the last three years.	Eiklenboom and de Jong, 2019 [81]
	Social Performance (SP)	SP 1. Develop programs to support vulnerable groups. SP 2. Support cultural and sports activities. SP 3. Consider the decision-making interests of local communities. SP 4. Treat the company as a part of the community and worry about its development.	Martinez-Conesa et al., 2017 [82]
Green Human Resources Management (GHRM)	Green Recruitment (GR)	GR 1. In the company hiring process, the company focuses on applicants with environmental knowledge, concern and attitude. GR 2. The company is rigorous in recruiting and selection of new employees with environmental knowledge, concern and attitude. GR 3. Before hiring from outside, the company gives its employees with environmental knowledge, concern and attitude the chance to fill vacant positions. GR 4. We use the Green Employer brand to attract green employees.	Nejati et al., 2017 [83] and Tang et al., 2018 [84]
	Green Training and Involvement (GTI)	GTI 1. The company shapes employees' green values through green training. GTI 2. The company develops the knowledge and skills required for employee green management through green training. GTI 3. Environmental responsibility is part of the job description. GTI 4. Employees participate in matters concerning environmental issues.	Guerci et al., 2016 [85] and Dumont et al., 2017 [86]
	Green Performance Management and Compensation (GPC)	GPC 1. Our company establishes green targets, objectives, and duties for each employee across organization. GPC 2. We use green performance indicators in performance management systems and evaluations. GPC 3. Our compensation system recognizes and rewards contributions in environmental protection. GPC 4. My organization recognizes green initiatives of employees via organization wide publicity and public praise.	Mahdy et al., 2023 [87]

Table 2. *Cont.*

Constructs		Items	Citation
Secondary Construction	First Level Construction		
Green Supply Chain Management (GSCM)	Green Procurement (GP)	GP 1. Our company purchases based on environmental specifications established by product design. GP 2. Our purchasing process follows procedures that minimize environmental impact. GP 3. Our purchasing process follows product labeling standards to minimize environmental impact.	Lerman et al., 2022 [79] and Green et al., 2012 [88]
	Green Manufacturing (GM)	GM 1. Our company assesses the environmental impact to develop/improve products. GM 2. Our company develops products with recyclable raw material. GM 3. Our company develops products with lowest consumption of resources.	Hsu et al., 2016 [89]
	Green Logistics (GL)	GL 1. Our company uses environmentally friendly transportation for distribution. GL 2. Our company uses green fuels such as low sulfur content and alternative fuels such as liquid natural gas. GL 3. Our company ensures community/environmental, employee health, and safety issues during transportation.	Tseng et al., 2019 [90]

The assessment of sustainable development performance encompasses three main components: Ec.P, EP, and SP. Indicators from Zaid et al. [80] were employed to evaluate Ec.P (such as energy utilization costs, average return on sales and investments, average profitability, and profit growth). The measurement item for EP was adapted from Eiklenboom and de Jong [81]. The SP of local small- and medium-sized enterprises was measured using four items from Martinez-Cornesa et al. [82].

Since the improvement of organizational performance by human resource management systems is based on employees' perceptions of human resource management practices [91], most studies use employee-perceived GHRM practices to measure GHRM [92]. In this research, GHRM was employed as a second-order formative construct with a first-order dimension (refer to Figure 1). The structure of GHRM comprises three dimensions, namely, GR, GTI, and GPC [80]. The measurement items for the three sub-variables were adapted from Nejati et al. (2017), Tang et al. (2018), Guerci et al. (2016), Mahdy et al. (2023), and Dumont et al. (2017) [83–87].

The assessment of GSCM adopts the methodology employed by Lerman et al. (2022), Green et al. (2012), Hsu et al. (2016), and Tseng et al. (2019) [79,88–90], encompassing nine criteria across three aspects: GP, GM, and GL. These measurement items assess the company's environmental practices in green procurement, manufacturing, and logistics, including adhering to environmental standards in procurement, product assessment and material selection, environmentally friendly transportation, and safety considerations.

Furthermore, building upon previous pertinent studies, firm age, firm type, and ISO 14001 [74] certification emerge as crucial factors that require proper control [75]. Companies with longer operational history are more likely to possess adequate resources and capabilities to establish supply chain platforms and achieve enhanced performance [93]. Previous investigations have established the significant impact of ISO 14001 [74] certification on dependent variables, similar to the ones utilized in the present study [94].

5. Data Analysis and Results

This study utilized the SmartPLS4.0 software and applied the partial least squares structural equation method (PLS-SEM), which is a second-generation multivariate analysis tool, to investigate the model and validate the hypotheses [95]. The significance level of the structural equation model was determined using the bootstrap resampling technique with 5000 subsamples.

5.1. Measurement Model

In order to confirm the accuracy of the PLS-SEM model, we employed the guidelines proposed by Hair et al. [77] and Benitez et al. [75], systematically presenting the results of the PLS-SEM analysis. Considering the reflective nature of the measurement model, we conducted assessments to assess internal consistency, composite reliability, convergent validity, indicator reliability, and discriminant validity.

This article utilized conventional indicators such as Cronbach's alpha coefficient, composite reliability (CR), standardized factor loadings, average variance extracted (AVE), and heterotrait–monotrait (HTMT) values to assess the measurement model's reliability and validity. Tables 3 and 4 present the outcomes of Smart PLS 4.0 for first-order and second-order constructs, respectively. The composite reliability (CR) of the measurement model ranged from 0.752 to 0.923, demonstrating strong internal consistency across all dimensions [96]. Each dimension exhibited good reliability, with Cronbach's alpha coefficients ranging from 0.794 to 0.896 [97]. The factor loadings for all measurement items exceeded 0.6, and the AVE values surpassed 0.5, indicating sound convergent validity for each scale.

Based on the proposition put forth by Fornell and Larcker [98], a scale demonstrates satisfactory discriminant validity when the square root of the AVE for each variable exceeds the absolute value of the correlation coefficient between that specific variable and other variables. As depicted in Table 5, the correlation coefficients among the fundamental factors were lower than the square root of the AVE, indicating favorable discriminant validity of the scale. Furthermore, since a higher-order model was employed in this study, the assessment of discriminant validity also incorporated the HTMT ratio, as recommended by Henseler et al. [99] and Hair et al. [77]. The standard guideline for evaluating discriminant validity suggests that the HTMT value should deviate from 1 and ideally be below 0.85 (using a conservative approach) or 0.90 (using a liberal approach) for all constructs within the model, as proposed by Benitez et al. [75]. The findings, as illustrated in Table 6, revealed that the HTMT values fell within an acceptable range (below 0.9), as suggested by Henseler et al. [99], indicating that each dimension exhibits satisfactory discriminant validity.

Common method bias (CMB) refers to the issue in research where the use of the same measurement method or subjective evaluations from the same respondents leads to inflated or skewed correlations between measurement results [100]. To ascertain and assess the potential influence of CMB on the research outcomes and bolster the study's credibility and soundness, the Bagozzi technique was utilized in this investigation to examine CMB. If the correlation between variables falls below 0.90, it suggests that the data remains unaffected by CMB, enabling further analysis to be conducted [101]. Additionally, the internal VIF method proposed by Kock [102] was used to conduct a test for complete collinearity to examine CMB. The threshold for all internal VIF values in this study was below 5, demonstrating that CMB was not a severe issue in this research.

Table 3. Reliability and validity analysis of first-order variables and indicators.

First Order	Loading	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
DTA		0.888	0.917	0.690
DTA1	0.841			
DTA2	0.843			
DTA3	0.821			
DTA4	0.836			
DTA5	0.811			
DTS		0.896	0.923	0.706
DTS1	0.867			
DTS2	0.824			
DTS3	0.830			
DTS4	0.841			
DTS5	0.84			
EP		0.893	0.921	0.699
EP1	0.827			
EP2	0.838			
EP3	0.821			
EP4	0.848			
EP5	0.847			
Ec.P		0.870	0.911	0.720
Ec.P1	0.831			
Ec.P2	0.849			
Ec.P3	0.869			
Ec.P4	0.845			
SP		0.835	0.900	0.751
SP1	0.871			
SP2	0.887			
SP3	0.841			
GR		0.875	0.915	0.728
GR1	0.873			
GR2	0.858			
GR3	0.832			
GR4	0.849			
GPC		0.870	0.911	0.719
GPC1	0.852			
GPC2	0.855			
GPC3	0.841			
GPC4	0.844			
GTI		0.860	0.905	0.705
GTI1	0.84			
GTI2	0.857			
GTI3	0.823			
GTI4	0.838			
GP		0.834	0.900	0.750
GP1	0.862			
GP2	0.871			
GP3	0.865			
GL3	0.871			
GM		0.827	0.897	0.743
GM1	0.849			
GM2	0.871			
GM3	0.866			
GL		0.841	0.904	0.759
GL1	0.870			
GL2	0.872			
GL3	0.871			

Table 4. Reliability and validity analysis of second-order variables.

Second Order	Loading	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
DT		0.878	0.812	0.684
DTA	0.809			
DTS	0.845			
GHRM		0.876	0.812	0.590
GR	0.751			
GPC	0.750			
GTI	0.802			
GSCM		0.794	0.753	0.505
GP	0.715			
GM	0.659			
GL	0.755			

Table 5. Distinguishing validity test of the scale.

	DTA	DTS	EP	Ec.P	GL	GM	GP	GPC	GR	GTI	SP
DTA	0.831										
DTS	0.368	0.840									
EP	0.407	0.434	0.836								
Ec.P	0.325	0.405	0.346	0.848							
GL	0.337	0.290	0.370	0.402	0.871						
GM	0.222	0.357	0.343	0.280	0.264	0.862					
GP	0.293	0.319	0.371	0.407	0.297	0.209	0.866				
GPC	0.309	0.299	0.349	0.333	0.346	0.292	0.320	0.848			
GR	0.368	0.388	0.355	0.320	0.262	0.269	0.309	0.321	0.853		
GTI	0.410	0.428	0.370	0.349	0.280	0.259	0.363	0.424	0.407	0.840	
SP	0.319	0.427	0.378	0.362	0.337	0.291	0.333	0.332	0.330	0.275	0.867

Table 6. HTMT analysis.

	DTA	DTS	EP	Ec.P	GL	GM	GP	GPC	GR	GTI	SP
DTA											
DTS	0.413										
EP	0.457	0.484									
Ec.P	0.369	0.459	0.391								
GL	0.39	0.335	0.428	0.469							
GM	0.259	0.415	0.397	0.330	0.315						
GP	0.340	0.368	0.429	0.477	0.352	0.250					
GPC	0.351	0.339	0.395	0.382	0.405	0.344	0.375				
GR	0.417	0.439	0.402	0.366	0.306	0.316	0.362	0.367			
GTI	0.469	0.487	0.421	0.402	0.328	0.307	0.428	0.490	0.468		
SP	0.370	0.493	0.437	0.424	0.399	0.348	0.398	0.389	0.385	0.323	

5.2. Structural Model

5.2.1. Structural Model Evaluation

The first stage of evaluating the structural model consisted of analyzing the variance inflation factors (VIF) for each group of predictor constructs in order to detect any potential issues related to collinearity, as proposed by Hair et al. [103]. In this investigation, all VIF values were below 3.3, signifying the lack of collinearity concerns within the model, in accordance with the recommendations of Benitez et al. And Hair et al. [75,103].

Furthermore, drawing from the research of relevant scholars on assessing structural models, the paper should report the coefficient of determination (referred to as R^2), the effect size of evaluation (referred to as f^2), the predictive relevance index (referred to as Q^2), and the path coefficients [104]. According to previous researchers' studies, the empirical values for reference are 0.19 (lower impact), 0.33 (moderate impact), and 0.67 (very high impact). Therefore, as shown in Table 7 data analysis shows that the variables in the basic model have a high degree of influence. In the interaction model, DT has an impact on the collaborative collaboration between GHRM and GSCM, while the collaboration between GHRM and GSCM has an impact on Ec.P, EP, and SP. The commonly used classification for f^2 reference values in empirical analysis is as follows: 0.02 (indicating a small effect size), 0.15 (indicating a medium effect size), and 0.35 (indicating a large effect size). Table 8 presents the outcomes of the fundamental model, whereas Table 9 showcases the outcomes of the interaction model. These results highlight the significant contribution of the variables in the model towards explaining the endogenous variables, emphasizing their important role in the analysis.

The overall model adequacy was evaluated using the standardized root mean square residual (SRMR), which quantifies the average difference between the observed and predicted correlation matrices. SRMR falls under the category of absolute goodness-of-fit indicators. In accordance with the criterion put forth by Hu and Bentler [105], an SRMR value of less than 0.1 is considered acceptable, while a more stringent criterion suggests an SRMR value below 0.08. In the current analysis, the SRMR index was 0.097 for the basic model and 0.085 for the interaction model, suggesting a strong alignment between the recorded and anticipated information. Figures 2 and 3 show the results of PLS−SEM analysis for basic and interactive models, respectively.

Table 7. Determination coefficient (R^2) analysis.

	Model 1 (Base)		**Model 2 (Interactive)**	
	R-Squared	**R-Squared Adjusted**	**R-Squared**	**R-Squared Adjusted**
DTA	0.654	0.653	0.891	0.891
DTS	0.713	0.713	0.399	0.398
EP	0.358	0.349	0.341	0.334
Ec.P	0.32	0.311	0.294	0.286
SP	0.28	0.27	0.255	0.247
GHRM	0.336	0.335		
GR	0.564	0.563		
GPC	0.562	0.561		
GTI	0.644	0.643		
GSCM	0.267	0.266		
GP	0.511	0.51		
GM	0.434	0.433		
GL	0.57	0.569		
GHRM&GSCM			0.348	0.347

Table 8. Efficiency evaluation of each dimension (f^2) of the basic model.

	DT	DTA	DTS	EP	Ec.P	GHRM	GL	GM	GP	GPC	GR	GSCM	GTI	SP
DT		1.891	2.488	0.071	0.031	0.507						0.365		0.053
DTA														
DTS														
EP														
Ec.P														
GHRM				0.022	0.017					1.283	1.292		1.807	0.012
GL														
GM														
GP														
GPC														
GR														
GSCM				0.076	0.109		1.323	0.768	1.044					0.056
GTI														
SP														

Table 9. Efficiency evaluation of each dimension (f^2) of the interactive model.

	DT	DTA	DTS	EP	Ec.P	GHRM&GSCM	SP
DT		8.191	0.665	0.055	0.015	0.534	0.028
DTA							
DTS							
EP							
Ec.P							
GHRM&GSCM				0.164	0.192		0.125
SP							

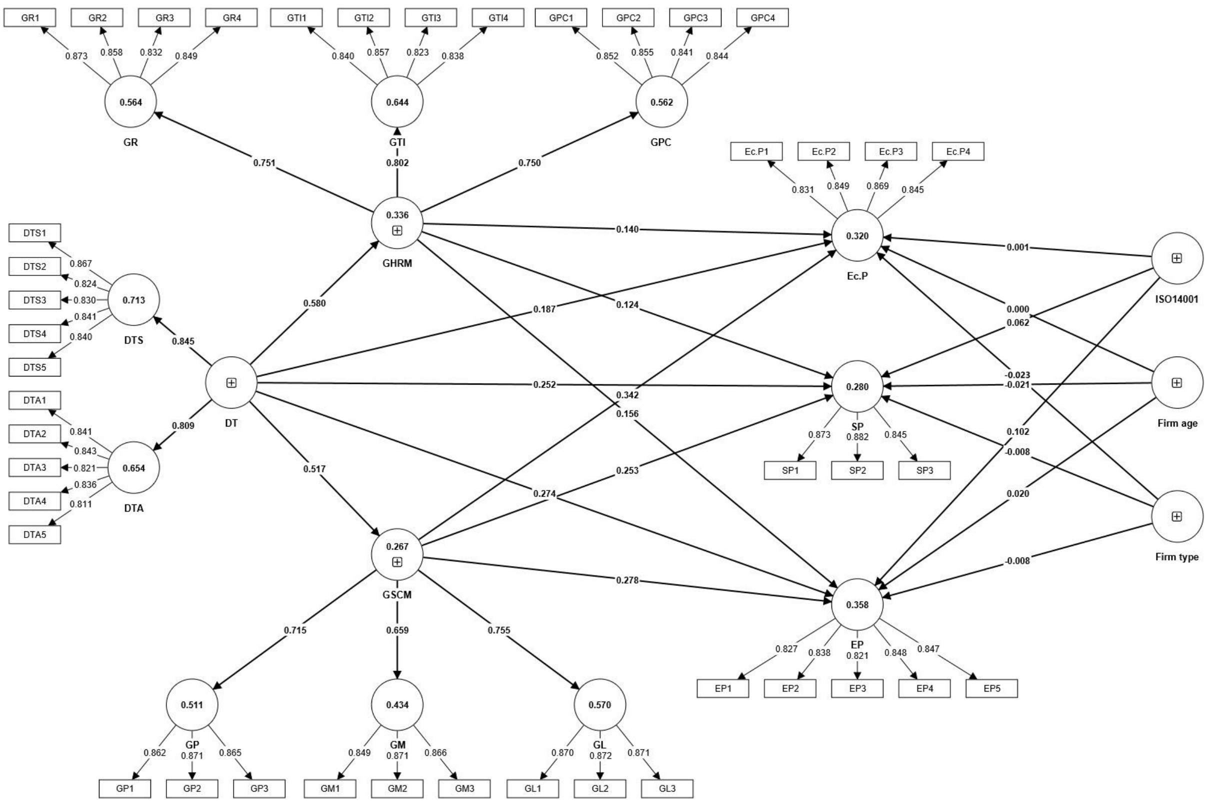

Figure 2. Basic structural equation model diagram (Model 1).

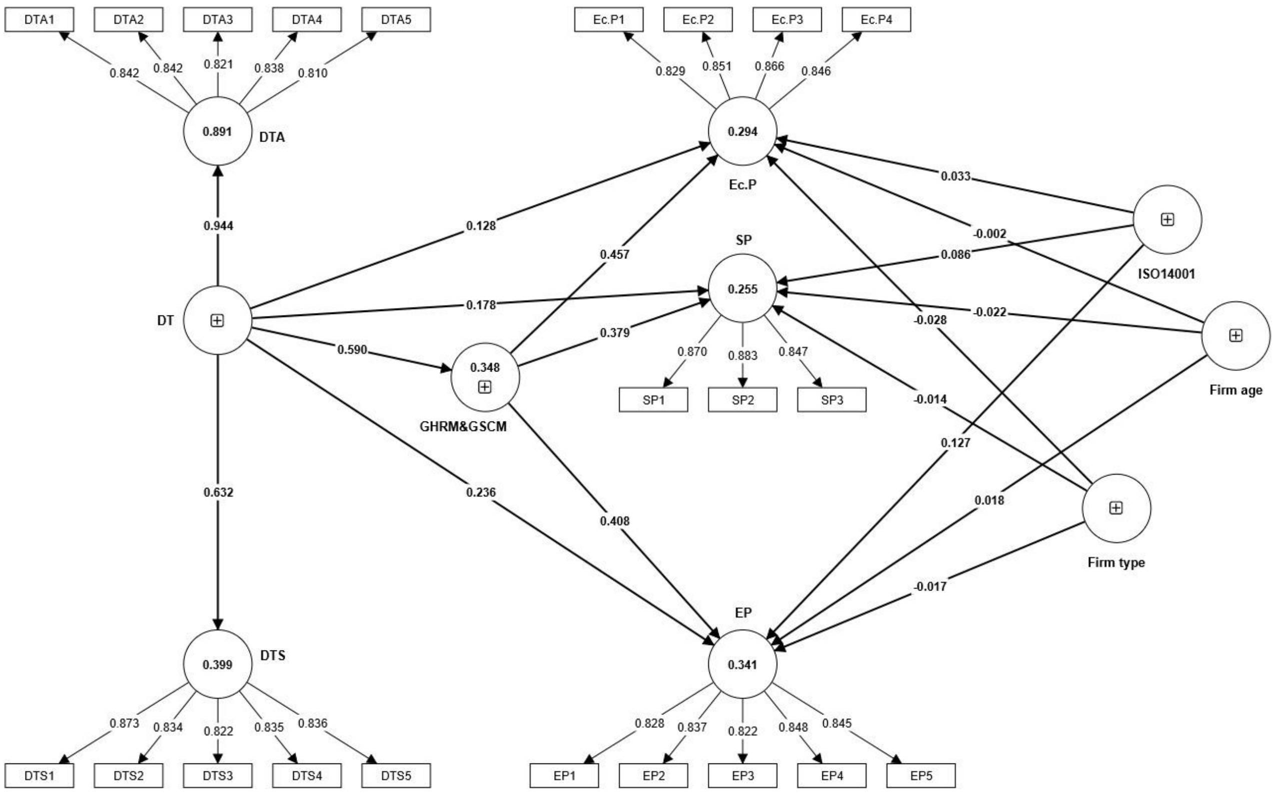

Figure 3. Interactive structural equation model diagram (Model 2).

5.2.2. Path Analysis and Hypothesis Testing

The existing predominant approach, known as bootstrap (5000 iterations), is employed to assess the statistical significance of path coefficients and the mesomeric effect [104]. By analyzing the calculated path coefficients depicted in Figures 2 and 3, it can be observed that there was a positive correlation between each latent variable, which aligned with the hypotheses. Subsequently, the path coefficient underwent a significance test based on the T value. Typically, a T value exceeding 1.96 indicates significance at a 0.05 level and can be regarded as passing the significance test. Otherwise, it is not significant, and the hypothesis cannot be supported.

The outcomes from employing Smart PLS 4.0 to analyze the direct impacts within the theoretical framework are presented in Table 10. The findings demonstrate that the T statistic values for DT regarding GHRM and GSCM were 20.833 and 15.464, respectively, thereby substantiating the validity of H1 and H2. The absolute values of the T statistic of DT for Ec.P, EP, and SP in the basic model and interaction model ranged from 2.426 to 4.802, supporting H3a, H3b, and H3c. The absolute values of T statistics for Ec.P, EP, and SP by GHRM and GSCM alone were both greater than 1.96, indicating that the path relationships of H4a, H4b, H4, H5a, H5b, and H5c were valid. For the interaction model, the absolute value of the T statistic of DT for GHRM&GSCM was 22.63, indicating that the hypothesis of the eight-path relationship was significantly valid. Examining the influence of GHRM&GSCM on the triple performance of sustainable development (Economic Performance, Environmental Performance, and Social Performance), the T-statistic values for the corresponding pathways ranged from 7.349 to 9.545 in absolute terms, therefore supporting H9a, H9b, and H9.

Table 10. Direct effect analysis.

Path	Path Coefficient		Standard Deviation (STDEV)		T Statistics		*p*-Values	
	M1	M2	M1	M2	M1	M2	M1	M2
DT -> DTA	0.809	0.944	0.019	0.005	42.773	183.579	0.000 ***	0.000 ***
DT -> DTS	0.845	0.632	0.016	0.035	52.198	18.127	0.000 ***	0.000 ***
DT -> EP	0.274	0.236	0.057	0.055	4.802	4.317		0.000 ***
DT -> Ec.P	0.187	0.128	0.053	0.053	3.507	2.426		0.015 *
DT -> SP	0.252	0.178	0.055	0.056	4.583	3.208		0.001 **
DT -> GHRM	0.580		0.028		20.833		0.000 ***	
DT -> GSCM	0.517		0.033		15.464		0.000 ***	
GHRM -> EP	0.156		0.054		2.882		0.004 **	
GHRM -> Ec.P	0.140		0.050		2.826		0.005 **	
GHRM -> SP	0.124		0.055		2.258		0.024 *	
GHRM -> GPC	0.750		0.028		26.384		0.000 ***	
GHRM -> GR	0.751		0.028		26.745		0.000 ***	
GHRM -> GTI	0.802		0.019		42.145		0.000 ***	
GSCM -> EP	0.278		0.049		5.669		0.000 ***	
GSCM -> Ec.P	0.342		0.056		6.077		0.000 ***	
GSCM -> SP	0.253		0.057		4.448		0.000 ***	
GSCM -> GL	0.755		0.027		27.880		0.000 ***	
GSCM -> GM	0.659		0.041		16.140		0.000 ***	
GSCM -> GP	0.715		0.035		20.578		0.000 ***	
DT -> GHRM&GSCM		0.590		0.026		22.630		0.000 ***
GHRM&GSCM -> EP		0.408		0.049		8.268		0.000 ***
GHRM&GSCM -> Ec.P		0.457		0.048		9.545		0.000 ***
GHRM&GSCM -> SP		0.379		0.052		7.349		0.000 ***
ISO14001 -> EP	0.102	0.127	0.076	0.078	1.332	1.638	0.183	0.101
ISO14001 -> Ec.P	0.001	0.033	0.084	0.086	0.006	0.385	0.995	0.700
ISO14001 -> SP	0.062	0.086	0.089	0.088	0.699	0.974	0.485	0.330
Firm age -> EP	0.020	0.018	0.038	0.039	0.516	0.457	0.606	0.648
Firm age -> Ec.P	0.000	−0.002	0.037	0.037	0.005	0.056	0.996	0.956
Firm age -> SP	−0.021	−0.022	0.041	0.041	0.510	0.535	0.610	0.593
Firm type -> EP	−0.008	−0.017	0.038	0.038	0.215	0.445	0.830	0.657
Firm type -> Ec.P	−0.023	−0.028	0.038	0.039	0.604	0.737	0.546	0.461
Firm type -> SP	−0.008	−0.014	0.040	0.041	0.212	0.341	0.832	0.733

Note: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.001$.

Based on Hair et al. [77], if the sample size is insufficient or the indirect effects do not follow a normal distribution, the detection of the mediating effect through PLS does not align with the Sobel test. Instead, it relies on the proportion of the introduction effect to the total effect, specifically the VAF value. According to Table 11, the T values of several mediation pathways were all greater than 1.96, with significant *p*-values and VAF values between 20% and 80%, indicating significant mediation effects. Specifically, the T values for the relationships between DT and GHRM with Ec.P, EP, and SP were 2.795 (variance accounted for—VAF = 0.302), 2.819 (VAF = 0.247), and 2.233 (VAF = 0.222), respectively, providing support for H5a, H5b, and H5c. The T values for the relationships between DT and GSCM with Ec.P, EP, and SP were 5.890 (VAF = 0.486), 5.108 (VAF = 0.344), and 4.213 (VAF = 0.342), respectively, supporting H7a, H7b, and H7c. The T values for the relationship between the collaborative cooperation of DT and GHRM with Ec.P, EP, and SP were 8.809 (VAF = 0.591), 7.644 (VAF = 0.468), and 6.993 (VAF = 0.471), respectively, confirming H10a, H10b, and H10c. Finally, regarding the control variables, the results indicate the relationship between ISO 14001 [74] certification, company age, and company type with Ec.P, EP, and SP were not significant.

Table 11. Mesomeric effect analysis.

Path	Path Coefficient	Standard Deviation (STDEV)	T Statistics	*p*-Values	Variance Account for (VAF)
		Model 1 (Base)			
DT -> GHRM -> Ec.P	0.081	0.029	2.795	0.005 **	0.302
DT -> GHRM -> EP	0.090	0.032	2.819	0.005 **	0.247
DT -> GHRM -> SP	0.072	0.032	2.233	0.026 *	0.222
DT -> GSCM -> Ec.P	0.177	0.030	5.890	0.000 ***	0.486
DT -> GSCM -> EP	0.144	0.028	5.108	0.000 ***	0.344
DT -> GSCM -> SP	0.131	0.031	4.213	0.000 ***	0.342
		Model 2 (Synergy)			
DT -> GHRM&GSCM -> SP	0.224	0.032	6.993	0.000 ***	0.471
DT -> GHRM&GSCM -> EP	0.241	0.031	7.644	0.000 ***	0.468
DT -> GHRM&GSCM -> Ec.P	0.270	0.031	8.809	0.000 ***	0.591

Note: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.001$.

As shown in Tables 9 and 10, the findings from Model 2 revealed the collaborative impact of GHRM and GSCM. The path coefficients for GHRM&GSCM -> EP, GHRM&GSCM -> Ec.P, and GHRM&GSCM -> SP were 0.408, 0.457, and 0.379, respectively, with corresponding T values of 0.049, 0.048, and 0.052, respectively (as shown in Table 10). These coefficients were significantly higher compared to the individual effects of GHRM and GSCM on the respective paths of Ec.P, EP, and SP. Furthermore, the *p*-value indicates that the combined impact of GHRM and GSCM on the triple performance of sustainable development surpassed the individual effects of GHRM and GSCM. Let us look at the mesomeric effect again. The VAF value range of GHRM and GSCM's synergistic mediation path was 0.471–0.591, while the VAF value range of GHRM and GSCM's separate mediation path was 0.222–0.486 (in Table 11), which further explained the synergistic effect of GHRM and GSCM.

Specifically, of the two models proposed, the collaborative interaction model had stronger explanatory and predictive power, thus providing theoretical inspiration for the literature on manufacturing enterprise management and practice.

6. Discussion

Drawing on existing research and theories related to sustainability and green management, this study found positive impacts of DT, GHRM, and GSCM, as well as the synergistic cooperation between GHRM and GSCM on economic, environmental, and social performance.

Firstly, we discovered that DT has a positive impact on the GHRM and GSCM of businesses. Undoubtedly, recent endeavors in empirical research on the influence of DT on environmentally friendly practices are still relatively new. The integration of technological resources with human resource management entails devising and implementing human resource management strategies directly based on digital potential, leading to competitive advantages and value creation for organizations [106]. The findings of Jie Zhang and Chen's research [107] indicate a positive impact of digital transformation on the functions of human resource management, yet they lack the "green" factor. This study validates the positive influence of DT on GHRM, filling this gap. DT facilitates GSCM implementation by providing robust data analytics, transparency, intelligent supply chains, and collaborative platforms. This argument aligns with the findings of Lerman et al. [79] and fills a gap in this research area.

Similarly, the research has also confirmed the positive impact of DT on the cross-functional collaboration of GHRM and GSCM. With the requirement of balanced development of enterprise DT and sustainable development performance, collaboration between functions is particularly important. Despite previous research on inter-functional coordination, there are few studies on DT as a possible driver of department collaboration in enterprises that need to provide rapid solutions in complex and accelerated scenarios. The evidence provided by Hauer et al. [108] suggests that DT influences marketing and sales integration, thereby impacting overall organizational performance. However, the existing literature does not seem to explore the impact of DT on GHRM and GSCM as integration factors. Thus, this study adds empirical evidence in this regard.

Furthermore, our research has confirmed the positive impact of DT on the triple bottom line of sustainable development. Some studies in the existing literature have focused on dimensions of digital transformation, indicating that tools such as blockchain or cloud systems can enhance the transaction and monitoring of green practices, resulting in improved performance [109]. The utilization of digital technologies enables real-time transparency, agility, and flexibility, resulting in enhanced efficiency, productivity, cost reduction, and faster delivery times, ultimately contributing to sustainable development [110]. Previous studies by Nayal et al. [66] and Hellemans et al. [111] have also validated this viewpoint, suggesting that DT creates a more conducive environment for sustainable development within companies, providing a strong foundation for achieving dual economic and social benefits. Therefore, our analytical findings are in line with existing research.

Furthermore, this study has additionally validated the intermediary function of GHRM and GSCM in the correlation between DT and the triple bottom line of sustainable development. From a resource-based view, GHRM can transform employees into unique and important resources and play the role of a part of tangible and intangible resources and abilities of enterprises, which will be the source of sustainable competitive advantage for enterprises. This argument aligns with the findings of Song et al. [61]. Green Supply Chain Management integrates sustainable development principles into various aspects of the supply chain, actively promoting corporate sustainable development through reducing environmental impact, enhancing resource efficiency, and fostering social responsibility. This perspective corresponds to the research results of Wang et al. [112]. Under the influence of digital transformation, the smart green supply chain consists of three distinct levels of configuration: digital transformation strategy, foundational digital technologies, and front-end technologies. Each level can contribute to improving firm performance [79]. Therefore, GSCM plays a crucial intermediary role. It is worth noting that existing research lacks effective exploration of the effectiveness of GHRM in balancing digital transformation and sustainable development. Hence, our analytical findings fill this gap and contribute to the existing literature.

It is crucial to emphasize that this study has revealed the synergistic impacts of GHRM and GSCM, thereby making valuable contributions to the integrated research within both domains and expanding the research framework of cross-functional collaboration. This discovery aligns with the viewpoints expressed by several scholars in the field [18] who have underscored the need for further cross-functional research to explore the dissemination of green management practices across diverse functions or organizations. They also aim to identify the interrelationships and concurrent outcomes among different functions. By conducting a comprehensive examination of GHRM and GSCM practices, this empirical study enhances our understanding of their impact on sustainable performance and underscores the synergistic effect of "1 + 1 > 2". These findings will provide valuable insights for future theoretical advancements and practical applications in this domain.

7. Managerial Implications

This research can help to achieve a strong sustainable performance of manufacturing enterprises by guiding managers of manufacturing enterprises to link sustainable development goals, DT, and GHRM and GSCM practices. This kind of connection can encourage staff to deeply participate in the development of environmental practices.

For managers, the research outcomes provide guidance in highlighting the cooperative investment in GHRM and GSCM, such as implementing measures to enhance employee motivation and knowledge, in order to establish an interdisciplinary approach to environmental management. Furthermore, the findings of this study also offer recommendations for managers aiming to enhance sustainable performance concurrently. It is important to note that, in the context of DT, both GHRM and GSCM practices exert a favorable influence on sustainable performance, with the collaborative effect of GHRM and GSCM being particularly significant. As a result, enterprise managers should place importance on incorporating and implementing environmental standards that surpass organizational boundaries.

For enterprises, this research provides the direction and power of DT and green management. The implementation of DT can not only improve the sustainable development performance of enterprises but also enhance the synergy of green management. Enterprise managers can further improve the construction and implementation of a DTS to promote departmental cooperation and keep close to the goal of sustainable development. At the same time, this article outlines the perspective of organizations investing in environmental management models based on empirical arguments, which appeal to human resource managers and supply chain managers due to the potential to improve the company's sustainable performance, thus attracting their interest.

For the government, this study can provide direction and reference for promoting the digitization and sustainable development policies of manufacturing enterprises. The government can promote the dual-beneficial development of manufacturing enterprises through a combination of measures, including establishing technology support platforms, strengthening the enforcement of environmental protection regulations, fostering talent development in digitalization and environmental protection fields, and enhancing regulatory and incentive mechanisms.

One could argue that the true value of this research lies in the tangible proof it provides, allowing manufacturers to comprehend which actions exert a more significant influence on the performance of sustainable development, as well as the correlation between DT, GHRM, and GSCM.

8. Conclusions, Limitations, and Future Research

This study has provided evidence supporting the positive influence of DT on economic, environmental, and SP within enterprises, as well as highlighting the dual mediation role of GHRM and GSCM, particularly emphasizing the synergistic effect of GHRM and GSCM. The findings indicate that DT can enhance the synergy between GHRM and GSCM, and this synergy has a significantly greater impact on the sustainable development performance of enterprises compared to the independent effects of each component.

However, it is important to acknowledge several limitations in the study design. To start with, the research findings rely on a comparatively limited sample size derived solely from one nation. Subsequent investigations should strive to incorporate a broader array of industry businesses, encompassing both domestic and global spheres. This will help to enhance the generalizability and robustness of the findings.

Secondly, the data collected in this article represent participants' self-reported corporate behavior, and a single evaluation method can lead to certain deviations in the data. Future research can adopt a combination of self-evaluation and objective data.

In addition, all data collection in this article was conducted at the same time. Due to the inadequacy of cross-sectional datasets, it is not possible to test the hysteresis of impacts and the complex causal relationships between variables. Future research should attempt to use longitudinal datasets.

Then, subsequent studies have the potential to expand the range of this article and utilize the obtained findings as a foundation for constructing more intricate and comprehensive models. For instance, additional green management practices highlighted in the existing literature can be examined, and a more thorough evaluation of DT can be conducted.

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Appendix A

Table A1. Sampling results.

Geographic Area	Provincial Administrative Region	Number of Manufacturing Enterprises (Unit: Ten-Thousand Companies)	Proportion	Sampling Quantity
North China	Beijing	1.3	0.39%	2
	Tianjin	3.2	0.95%	6
	Hebei	34	10.13%	63
	Shanxi	4.2	1.25%	8
	Nei Monggol	3.7	1.10%	7
	Total	46.4	13.82%	86
East China	Shanghai	6.9	2.06%	13
	Zhejiang	42	12.51%	78
	Jiangsu	29	8.64%	54
	Shandong	35	10.43%	65
	Anhui	14	4.17%	26
	Fujian	11	3.28%	20
	Jiangxi	4.6	1.37%	9
	Total	142.5	42.45%	265
South China	Guangdong	55	16.39%	102
	Guangxi	5	1.49%	9
	Hainan	0.95	0.28%	2
	Total	60.95	18.16%	113
Central China	Henan	18	5.36%	33
	Hunan	7.6	2.26%	14
	Hubei	10	2.98%	19
	Total	35.6	10.61%	66

Table A1. *Cont.*

Geographic Area	Provincial Administrative Region	Number of Manufacturing Enterprises (Unit: Ten-Thousand Companies)	Proportion	Sampling Quantity
Northeast	Liaoning	9.8	2.92%	18
	Jilin	3	0.89%	6
	The Heilongjiang River	5.5	1.64%	10
	Total	18.3	5.45%	34
Southwest	Chongqing	5	1.49%	9
	Sichuan	7.6	2.26%	14
	Guizhou	2.6	0.77%	5
	Xizang	2	0.60%	4
	Yunnan	3.5	1.04%	7
	Total	20.7	6.17%	38
Northwest	Shaanxi Province	5.2	1.55%	10
	Gansu	2.2	0.66%	4
	Qinghai	0.6	0.18%	1
	Ningxia	1	0.30%	2
	Xinjiang	2.2	0.66%	4
	Total	11.2	3.34%	21
Total		335.65	100%	624

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