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# A Bayesian Network Model of Megaproject Social Responsibility Behavior and Project Performance: From the Perspective of Resource-Based Theory

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**Abstract:** Megaproject Social Responsibility (MSR) is widely acknowledged as contributing to project performance. However, the effect of Megaproject Social Responsibility Behavior (MSRB) implemented by organizations participating in construction on project performance remains a subject of considerable debate, and the intrinsic mechanism of MSRB's effect on the performance of megaprojects has not been elucidated. Therefore, this study employs resource-based theory to investigate the mechanism underlying MSRB's effect on project performance, taking into account both internal and external social capital as well as resource integration capacity as pivotal influences. Drawing on sample data from 206 experienced project managers across the various parties involved, this study develops a Bayesian network model to elucidate the MSRB effect mechanism. Through inference and sensitivity analysis, this study discovers variations in the enhancement effects across the four dimensions of MSRB on project performance. Notably, a combination strategy yields superior enhancement effects. Furthermore, when project performance is suboptimal, resource integration capacity emerges as a significant mediator between MSRB and project performance. Conversely, at high levels of project performance, MSRB directly contributes to enhancing project outcomes. The findings of this study offer valuable insights for the governance of MSR and the enhancement of project performance in megaprojects.

**Keywords:** megaproject social responsibility behaviors; project performance; resource-based theory; bayesian network



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## 1. Introduction

Megaproject Social Responsibility (MSR) is frequently lauded as a reliable method for integrating economic, social, environmental, and legal aspects into project activities with the aim of enhancing project performance [1–3]. In 2015, Zeng et al. conducted the first systematic analysis of the social responsibility of major infrastructures, defining MSR as "the policies and practices of stakeholders throughout the entire megaproject life cycle, which reflect responsibilities for the well-being of the wider society" [4]. Recent years have seen a significant emergence of MSR practices within the engineering community. Driven by a concern for societal welfare, organizations participating in megaprojects strive to undertake practical actions to address relevant MSR issues, actions that are termed Megaproject Social Responsibility Behavior (MSRB) [5,6].

Recent studies suggest that deficiencies, lapses, or misconceptions in the social responsibility behaviors of stakeholders involved in megaprojects might undermine the effectiveness of project investments, potentially disrupting the project's social image and diminishing its performance. For instance, there have been construction accidents and casualties resulting from the neglect of production safety awareness by the construction party [7,8]. A lack of awareness of community responsibility within management circles has led to protests by non-governmental organizations, staff strikes, social conflicts, and, in extreme cases, the project's termination [9]. MSRB encompasses a myriad of stakeholders, each with differing motives, varied expressive forms, and significant resource investments [5,6]. MSRB exhibits considerable multivariate heterogeneity, complex situational dependence, and dynamic evolution. Consequently, the specific effects of implementing MSRB are still largely undetermined [10], and its impact on project performance continues to be a "black box", warranting further investigation. To address this issue, the object of this study is to reveal the mechanism of the impact of MSRB on megaproject performance, which ultimately assists administrators in identifying key performance improvement pathways and expands strategies to overcome megaproject performance challenges.

In recent years of studying MSRB practice, scholars have identified positive effects of MSRB. Such behaviors promote project performance [2], enhance organizational financial and social performance [10], and contribute to industry sustainability [11]. Wang et al. investigated behavioral drivers to explore the dynamic effects of megaproject citizenship behaviors (MCB) as part of MSRB on project performance, discovering that the actual potential growth rate of promotions positively influences both MCB and project performance [12]. However, there exist mechanisms that exert local negative and indirect effects on the enhancement process of performance. Guo et al. demonstrated that most dimensions of project citizenship behaviors are positively correlated with sustainable project performance. Conversely, proactive responsibility behaviors exhibited a negative effect [13]. He et al. identified a positive and significant influence of MSRB and innovations on project performance, with innovative capacity serving as a mediator [2]. Wang et al. reported that environmental responsibility behaviors aimed at the broader public and local communities did not yield the anticipated project environmental performance [14].

However, some scholars have pointed out that the results produced by MSRBs of project organizations should be measured more rationally and objectively [15]. Environmental responsibility behaviors could potentially pursue project environmental performance while ignoring or forgoing project economic benefits [16]. Unilateral social responsibility behaviors may exist to camouflage and defraud project MSRs, resulting in a waste of public resources in society [6,16]. To maintain a balance between performance and MSR that includes economic, social, and environmental goals, project organizations may need to consume a large amount of resources to maintain internal and external relationships [17]. It can be seen that the research on MSRB's effect is rather fragmented, and project performance has not yet been considered comprehensively. In order to further clarify the issue of the effect of social responsibility behavior on project performance, it is necessary to consider both multidimensional MSRB and a more comprehensive assessment of megaproject performance, so as to effectively reveal the mechanism of the effect of MSRB on the performance of megaprojects.

To achieve the above research objective, this study seeks to explore the mechanisms by which MSRB affects project performance from the perspective of resource-based theory. The implementation of MSRB by organizations participating in a project is intrinsically linked to the resources and capabilities available to the project, and the realization of MSR requires both intangible and tangible resources [18]. Moreover, participating organizations can integrate resources and capabilities from internal and external stakeholders to achieve MSR [19]. Intangible resources such as knowledge, reputation, and trust represent the key resources created by MSRB for project participating organizations, which typically stem from the internal and external social networks of the project embedded in the project organization, and are also referred to as a project's social capital [20]. These intangible resources are valuable, scarce, and difficult to replicate, thereby forming the basis for enabling positive project performance [21]. Moreover, good project performance also depends on effective resource integration [22]. Firstly, MSRB promotes participation in organizational interactions, thereby increasing access and space for resource acquisition [23]. Secondly, MSRB can promote staff quality training and thus improve the resource integration ability of the project team itself, while simultaneously prompting the megaproject team to absorb and exert the resource allocation and utilization ability of participating organizations [24,25]. A megaproject requires more comprehensive and complex resources in comparison to a general project; thus, the adaptive resource integration capacity is critical to realizing the value of the project [26]. Through the appropriate combination of resources and resource integration capacity, a project can create the value shared by the economy and society [23]. MSRB influences multiple aspects of a project's social capital and resource integration capacity, which will ultimately have an impact on the project's performance. This study seeks to uncover the mechanism of that impact.

Therefore, this study endeavors to investigate the mechanism of the impact of MSRB on project performance based on the resource-based theory, integrating the resource perspective and the capability perspective. The structure of this paper is as follows: The Section 2 outlines the theoretical foundation. The Section 3 introduces the research methodology of this study, including variable measurements, data collection, and model construction. The Section 4 presents the results of Bayesian network inference analysis. The Section 5 offers a discussion of the results, and the Section 6 summarizes the conclusions drawn from this study.

## 2. Literature Review

### *2.1. MSRB and Project Performance*

According to recent academic discourse, social responsibility behaviors in megaprojects manifest in varied forms, including contractual social responsibility behaviors [27], megaproject citizenship behaviors [28], environmental responsibility behaviors [14,29,30], and greenwashing behaviors [31–33]. Contemporary studies of these behaviors fall into two primary categories: research focusing on the motivation behind MSR behaviors [3,5,29,30,34,35] and research examining the effects of MSR behaviors [2,10–12,14], which encompass outcomes related to project sustainability, organizational performance, and industry performance. Specifically, within the framework of global sustainable development, expectations regarding the value of megaprojects have surged, with MSR increasingly serving as a barometer for a project's "value" [36]. Consequently, organizational behaviors that could potentially enhance project value have attracted significant scholarly attention. Therefore, the impact of MSRB on project performance has garnered particular focus among researchers.

Project performance measurement generally refers to the process of determining the success of a project organization or individual in achieving its desired objectives after taking a series of management actions. The construction of megaprojects is large in scale, long in cycle, complex in environment, and widespread in social impact, and the evaluation of its project success focuses on the success of the systematic and comprehensive process. To measure megaproject performance, studies have proposed a performance framework including cost, quality, safety, social response, and contractual relationships [37]. Compared with traditional project performance indicators, due to the high consumption of natural resources in megaprojects [14], high technical management difficulty [38], and numerous participating parties [39], elements such as effective utilization of resources, environmental impacts, innovation outcomes, collaborative cooperation effects, and stakeholders' satisfaction have also been added to the project performance indicator system by numerous scholars [40–43]. It has been shown that there is a positive relationship between the implementation of social responsibility and project performance in megaprojects [44]. Specifically, in order to realize MSR, megaprojects contractors will stipulate the MSRBs to be performed by subcontractors in the contract, and at the same time set up clauses to encourage the implementation of MSRBs which will effectively enhance the project performance standard and promote the achievement of performance through the contract [27]. In addition, participants in megaprojects invest resources and efforts beyond the scope of the contract, including responding positively to the owner's initiatives, advising the owner proactively, taking measures to protect the environment, employing local labor, and striving to deliver the project successfully and to achieve performance that exceeds expectations [28,35,45,46].

Further studies have shown that the mechanism of MSRB's influence on project performance is nonlinear and comprehensive, involving the intervention of numerous internal and external project factors. Wang et al. identified internal and external factors, such as laws and regulations, public satisfaction, and project culture, as elements in the feedback loop of MCB's influence on megaproject performance. They found that the opportunity for potential promotion is a crucial factor in enhancing organizational citizenship behaviors, thereby facilitating project performance [12]. Guo et al.'s study demonstrated that most dimensions of project citizenship behaviors were positively associated with sustainable project performance, whereas proactive responsibility behaviors had a negative impact [13]. This finding suggests that the influence of MSRB on project performance may not be entirely positive. Wang et al. differentiated between environmental responsibility behaviors directed at the subject matter and highlighted that such behaviors failed to yield desirable project environmental performance [14], or even masked poor environmental performance [31]. Furthermore, studies have demonstrated that the influence mechanism of MSRB is not a single direct relationship, as social capital, dynamic capability, and innovation capacity have been proven to play mediating roles [2,23]. Thus, in this paper, we suggest that MSRB has both a positive and a negative impact on project performance.

Most of the above studies on the influence relationship utilize structural equation modeling or multiple regression analysis models, often for a single form of MSRB. However, the effects triggered by different MSRBs vary, and there may be a superimposed or constrained relationship between MSRBs. Research on the overall intrinsic influence of MSRBs on the performance of megaprojects is lacking. Above all, this paper summarizes MSRBs into four dimensions: economic and qualitative, political and communal, legal and regulatory, and environmental and ethical behaviors. We define megaproject performance as the degree of cost, quality, schedule, safety, green, innovation, and stakeholder satisfaction in the construction process of a megaproject. In the following section, this paper will introduce the resource-based theory to reveal the influence mechanism of different dimensions of MSRBs on megaproject performance.

### 2.2. Resource-Based Theory

Formerly known as the resource-based view, the resource-based theory was initially proposed by Wernerfelt in 1984 within the field of corporate strategic management, emphasizing the fundamental role of the resource perspective on corporate strategic options [47]. The resource-based theory posits that resources are the foundation for organizational survival and growth, emphasizing that organizations must possess heterogeneous resources and effectively utilize and assimilate these critical resources through appropriate capabilities in pursuit of sustainable competitive advantages.

Taking an organization's possession of heterogeneous resources as the fundamental premise [47], the resource-based theory focuses on analyzing how to enhance competitive advantage and organizational performance through the utilization of those heterogeneous resources. Social responsibility behaviors accumulate social capital [48,49], a form of heterogeneous and valuable intangible resource that is highly specific, complex, and difficult to imitate or substitute [50]. Social capital plays a crucial role in achieving organizational performance [21,51]. Equally crucial as heterogeneous resources is an organization's resource integration capacity. No organization possesses all the required resources at all times, and resources themselves are not productive. Thus, an organization's capacity to acquire and utilize resources is critical for gaining a competitive advantage. Megaprojects, with their complex and heterogeneous stakeholder networks and high degree of asset specificity, require even greater attention to resource allocation and effective utilization. The implementation of social responsibility in megaprojects can help consolidate the stakeholder networks of participating organizations, enabling them to acquire additional resources [4]. In summary, in analyzing the mechanism of the impact of MSRB on project performance, this paper takes social capital and resource integration capacity as the influencing factors of the role of MSRB on project performance.

For megaprojects with one-time and temporary characteristics, resource-based theory has been applied in a significant number of research projects, such as Dzeng et al.'s research on the strategic management of contractors in megaprojects [52], Govan et al.'s investigation of project risk management [53], and Shi et al.'s examination of the impact of competence on subcontracting in construction projects [54]. In the realm of construction project management, RBT serves as a prevalent viewpoint for formulating a conceptual framework for performance research [55]. Emphasizing that any organization harbors distinctive resources and capabilities [47], a megaproject typically draws upon resources and capabilities from multiple participating organizations [52], thus rendering the megaproject an amalgamation of resources and capabilities contributed by various organizations. The management of large-scale construction projects involving multiple participants entails a strategic decision-making process designed to guarantee that the entire construction project team possesses sufficient resources and capabilities [52], serving as the foundation for enhancing project performance [50,56]. Additionally, Mansour et al.'s investigation examined 20 construction project management studies that applied RBT and delineated a conceptual structural model illustrating how resources and capacity influence project performance [55]. This is coupled with the assertion that RBT effectively elucidates the intermediaries of social responsibility behaviors impacting organizational performance [23,49,57]. Therefore, it is appropriate to introduce resource-based theory in this study.

#### 2.2.1. Social Capital of Megaproject

The concept of "social capital" emerged from community studies to underscore that the network of interpersonal relationships within a community is a relational resource that fosters the development of individuals within the community [58]. Viewing megaprojects as social actors integrated into social networks, the essence of social capital lies in being a relational network that enables social actors to mobilize and access resources. From a resource perspective, megaproject social responsibility behavior can assist actors in building and sustaining a wider and more stable social relationship network [59]. These relationship networks represent high-quality intangible resources, which serve as a crucial assurance of project success.

When focusing on the project aspect, the social capital of a megaproject is the sum of actual or potential resources of the project team, which are related to social networks and stakeholder relationships [23]. Previous research has noted that an increase in a project's social capital has a positive effect on project management performance improvement [60]. Organizations can build a network of social relationships through the implementation of social responsibility, which in turn leads to the formation of social capital [48]. First, organizations implementing social responsibility behaviors in megaprojects can establish and maintain good relationships with units in industry, the government and related departments at the project site, the community, and the public. Good relationships are conducive to strengthening the cooperative relationship between the participating organizations and the upstream and downstream enterprises, facilitating exchanges between the participating organizations and governmental departments, and reducing the asymmetric nature of the information between the participating organizations and other stakeholders, which in turn reduces the uncertainty and transaction costs [10]. Second, the social responsibility behavior of megaprojects establishes or consolidates the organization's stakeholder network, so that the participating organizations can expand more channels through this network, from which they can obtain knowledge, human resources, financial resources, and other resources, so as to more effectively achieve the project performance objectives. It can be seen that the social responsibility behavior of megaprojects helps to improve stakeholder relations and promote the accumulation of social capital inside and outside the project, which in turn reduces transaction costs and improves the efficiency of project construction.

Thus, in this paper, we hypothesize that MSRB has a positive impact on project social capital, but also that project social capital has a positive impact on project performance.

In early studies, scholars usually regarded social capital as a social network [61] or trust [62], but the measurement of a single dimension tends to lead to a failure to truly reflect the level of organizational social capital. Nahapiet and Ghoshal proposed a three-dimensional model of social capital that includes structure, relationship, and cognition [63], which is effective in conceptualizing social capital and has received widespread scholars' support. In the three-dimensional classification, the structural dimension refers to the connections between individuals or organizations, which in the case of projects are expressed as network connections between project participants [64]. The relational dimension refers to the resources and information in the relational network, such as trust, norms, and reciprocity, of which trust is the central element. The cognitive dimension refers to the common knowledge, common understanding, and common vision of some thing or goal among the members of the social network. Bian et al. proposed categorizing the social capital of enterprises into three types, including vertical relations, horizontal relations, and social relations, from the perspective of the connection between the enterprise and the external economy and society. The phrase "vertical relationship" refers to the relationship between enterprises and relevant government departments and their subordinate departments. A "horizontal relationship" is a variety of legitimate connections between enterprises and other enterprises, industry associations, research institutes, and so on, such as collaborative relationships, holding relationships, etc. The phrase "social connections" refers to the social interactions and connections of enterprise operators and managers in the non-economic field [65]. According to the degree of the connection's closeness, some scholars also divide social capital into categories based on the perspective of individuals inside and outside the organization or inside and outside the team. Adler and Kwon believe that social capital can be divided into two categories: bonding and bridging [66]. This perspective was applied by Huang et al. in their analysis of the relationship between a construction project team's social capital and project performance [67], while Kim and Cannella stated that social capital can be divided into internal social capital involving interpersonal connections in the central organization, and external social capital involving other connections outside the organization [68].

Megaprojects often have prominent economic and political significance, and the involvement of non-project participants such as the government, industry associations, and the public in the project tends to be more profound than in general projects. The influence of external stakeholders such as the government, industry associations, and the public on project construction management in the social network of megaprojects cannot be ignored. However, the interactions among the participants of megaprojects contain links including both formal and informal relationships, while the links between project participants and external parties are relatively homogenous. Therefore, with reference to the previous studies, this study divides the social capital of megaprojects into project internal social capital (ISC) and project external social capital (ESC). Project internal social capital refers to the internal links of the project organization, consisting of each participant and the actual or potential resources generated therefrom, with reference to Nahapiet and Ghoshal's model [63]. Project external social capital refers to the links between project participants, the world outside the project, and the actual or potential resources generated therefrom, and includes three dimensions, namely, vertical, horizontal, and social relationships [65].

### 2.2.2. Resource Integration Capacity

Resource integration refers to an intricate and complex dynamic process in which an organization identifies, selects, absorbs, configures, activates, and organically integrates resources from different sources and of different kinds, making them more flexible, rational, systematic, and valuable, so as to form a unique core resource system that is more conducive to its own development [69]. Resource integration capacity is the ability of an organization to effectively plan and configure various resources within or between organizations to achieve comprehensive benefits [70]. In the field of construction engineering, a construction project is a temporary organization formed by multiple units, and its resource integration is the process of configuring relevant resources within the participants, between the participants, and outside the project organization according to the project objectives, then obtaining the overall optimal integration of resources through the organization's institutional arrangements and management coordination [71]. According to previous studies, the resource integration capacity of a project organization is formed in the resource integration process of resource acquisition, allocation, and utilization [72,73]. Resource acquisition is the process of identifying and acquiring the required resources from a network of multiple internal and external megaproject stakeholders [74]. Resource allocation refers to the process of adjusting and combining the resources to make them more valuable so as to maximize their effectiveness [75]. Resource utilization refers to the process of applying the allocated resources to create maximum value for the organization [76].

Actively performing social responsibility is conducive to improving the resource integration capacity of the organization [23]. In the process of performing social responsibility, project participants can broaden the channels of resource integration through strong relationships with external stakeholders, attracting and acquiring more resources conducive to project construction. These resources include tangible resources, such as government subsidies, environment-friendly materials, and information on innovative technologies, as well as intangible resources, such as project reputation and learning opportunities. Furthermore, when the organization takes social responsibility initiatives, the level of internal employee competence may also be improved. Organizational social responsibility behaviors include creating a good environment and training opportunities for employees, and therefore can play a role in gathering innovative resources for the organization [24], as well as being an important means of improving organizational learning and knowledge creation [77]. In megaprojects, Wang et al. found that engineering environmental responsibility practices toward internal stakeholders is positively associated with their organizational citizenship behaviors [14]. The positive image that MSRB creates for the project has the potential to enhance the project identity of project participants, who in turn are more motivated to complete their work. The positive image created by MSRB can also promote internal knowledge sharing. The project gains excellent organizational and employee resources, and its resource integration capacity is also improved. Thus, we suggest that MSRB has a positive impact on the project's resource integration capacity.

High resource integration capacity can enhance the performance of megaprojects. The resource composition and management of megaprojects are extremely complex. Project resources are of great significance to megaprojects, but just having resources does not guarantee the successful application of those resources [78]. In particular, megaprojects face the complex internal and external environments of dynamic changes, and it is difficult to adapt static resources to meet the needs of the dynamic development of the organization. Only through the integration of resources, so that resources are constantly updated, combined, and matched to form a new resource system that adapts to the needs of megaprojects, can resources be fully and effectively utilized. Putra et al. found that the effective integration of resources in engineering projects can not only solve the problems encountered in the project, the ability of the organization to utilize its resources can also improve the project's application and cost control capabilities, which in turn promote the project's profitability [79]. The sustainable growth and success of the project requires the project organization to integrate internal and external resources. The project organization can use its own organizational management mechanism, combined with external value networks, to achieve the acquisition and absorption of internal and external resources. Integrating resources via the transfer of material and information resources and the sharing of knowledge resources increases the value of cooperation [80]. Thus, we suggest that project resource integration capacity has a positive impact on project performance.

## 3. Research Method

### *3.1. Variables and Measurements*

Through our literature study, we identified 15 factors (see Table 1), and due to the abstract nature of the above variable factors in the practice of megaprojects, this study used the method of a questionnaire survey, which is commonly applied in related studies, to collect the variable data. The scale for this study was adapted from scales used in related studies. A Likert five-point scale was applied to investigate the data needed for this study.

**Table 1.** Research Scale.

| Factor | | Code | Item | Reference |
|---|---|---|---|---|
| Megaproject social responsibility behaviors (MSRB) | Economic and qualitative responsibility behaviors | EQRB1 | The organization conducts full and effective economic and technical feasibility studies | Lin et al. [34]; Xie et al. [3] |
| | | EQRB2 | The organization develops and implements a reasonable and complete cost-control plan | |
| | | EQRB3 | The organization develops and implements a reasonable and complete plan | |
| | | EQRB4 | The organization develops and implements a reasonable and complete schedule management plan | |
| | | EQRB5 | There are many innovations and technological advances | |
| | Political and communal responsibility behaviors | PCRB1 | The organization hires local staff to drive local employment | Lin et al. [34]; Xie et al. [3] |
| | | PCRB2 | The organization organizes public welfare activities and provides public welfare services in the relevant communities where the works are carried out | |
| | | PCRB3 | The organization deals with related accidents and public incidents in a timely manner | |
| | | PCRB4 | The organization takes a variety of measures to promote public participation | |
| | | PCRB5 | The organization takes an active role in anti-corruption and anti-corruption activities | |
| | Legal and regulatory responsibilityvbehaviors | LRRB1 | The organization discloses project information to the public in a timely manner | Lin et al. [34]; Xie et al. [3] |
| | | LRRB2 | All project participants strictly comply with laws and regulations. | |
| | | LRRB3 | All project participants follow industry standards | |
| | | LRRB4 | All project participants adhere to the principle of fair competition within the industry | |
| | Environmental and ethical responsibility Behaviors | EERB1 | The organization provides a safe and healthy working environment for its employees | Lin et al. [34]; Xie et al. [3] |
| | | EERB2 | The organization pays attention to the protection of the ecological environment in the area where the project is to be built (e.g., prevention of river pollution and destruction of vegetation, etc.). | |
| | | EERB3 | The organization pays attention to the protection of the environment in the local community (e.g., prevention of pollution from noise, dust, etc.). | Lin et al. [34]; Xie et al. [3] |
| | | EERB4 | The organization uses resources rationally and avoids wasting them during the construction of the project. | |

**Table 1.** *Cont.*

| | Factor | Code | Item | Reference |
|---|---|---|---|---|
| Internal social capital (ISC) | Structural dimension | SISC1 | During project implementation, there are frequent formal exchanges between the various parties involved in the construction, such as holding project seminars, organizing exchange and learning activities, etc. | Leana et al. [81]; Wang et al. [82] |
| | | SISC2 | During project implementation, there are frequent informal exchanges among the participants, such as exchanging information on the construction of the project in informal settings, such as at the site, lounge, gathering places, etc. | |
| | | SISC3 | During project implementation, members of the parties often use web-based media tools (telephone, e-mail, WeChat, etc.) to communicate about the project construction work | |
| | Relational dimension | RISC1 | During the project implementation, the participants will trust each other | Leana et al. [81]; Wang et al. [82] |
| | | RISC2 | The project participants keep their promises to each other. | |
| | | RISC3 | When one participant has a difficulty or dispute, the other participants are willing to help | |
| | Cognitive dimension | CISC1 | The participants have similar views on the development prospects of the project | Leana et al. [81]; Wang et al. [82] |
| | | CISC2 | Participants have a shared understanding of the key points of the project (e.g., core technologies) | |
| | | CISC3 | Participants reach consensus, especially on key project decisions | |
| External social capital (ESC) | Vertical relationships | VESC1 | During the construction of the project, the project participants maintain good relations with government departments | Leana et al. [81]; Change et al. [83] |
| | | VESC2 | During the construction of the project, the relevant government departments provide resources and support for the construction of the project | |
| | | VESC3 | During the construction of the project, the project participants maintain close communication with government departments | |
| | Horizontal relationships | HESC1 | Project participants have a wide range of contacts with other relevant organizations in the industry | Leana et al. [81]; Change et al. [83] |
| | | HESC2 | Project participants exchange project construction experience with other related organizations in the industry | |
| | | HESC3 | Project participants and other relevant organizations in the industry organize study tours and learning activities for each other. | |
| | Social relationships | SESC1 | During the construction of the project, the project participants establish good relations with the communities where the work is being carried out | Leana et al. [81]; Change et al. [83] |
| | | SESC2 | During project construction, project participants establish good relations with non-governmental organizations | |
| | | SESC3 | During project construction, the project participants establish good relations with the media | |
| | | SESC4 | During project construction, project participants establish good relations with the public | |

**Table 1.** *Cont.*

| Factor | Code | Item | Reference |
|---|---|---|---|
| Megaproject resource Integration capacity (MRI) | MRI1 | The organization is able to clearly identify resource needs and allocate them appropriately. | GE et al. [73] |
| | MRI2 | The organization has access to the resources the organization wants | |
| | MRI3 | The organization is able to divest useless resources in a timely manner | |
| | MRI4 | The organization believes that useful resources can help the project to be completed better | |
| | MRI5 | The organization is able to leverage consolidated resources to gain access to other useful resources | |
| | MRI6 | The organization is able to leverage consolidated resources to help create greater value for the project | |
| Megaproject performance (MP) | MP1 | The project is on schedule or will be completed on schedule | He et al. [2] |
| | MP2 | The project expenditure is within budget | |
| | MP3 | The project's quality is in accordance with the relevant national standards and contractually agreed standards | |
| | MP4 | The project's safety management is well executed | |
| | MP5 | The project has a high level of resource utilization efficiency and environmental protection | |
| | MP6 | The project has an innovative contribution to theory and practice in the field of technology and management | |
| | MP7 | The project participants, government departments and the public are satisfied with the project construction process and deliverables | |
| | MP8 | Participants consider continued cooperation in the future | |
| Internal social capital (ISC): Structural dimension | SISC1 | During project implementation, there are frequent formal exchanges between the various parties involved in the construction, such as holding project seminars, organizing exchange and learning activities, etc. | Leana et al. [81]; Wang et al. [82] |
| | SISC2 | During project implementation, there are frequent informal exchanges among the participants, such as exchanging information on the construction of the project in informal settings, such as at the site, lounge, gathering places, etc. | |
| | SISC3 | During project implementation, members of the parties often use web-based media tools (telephone, e-mail, WeChat, etc.) to communicate about the project construction work | |
| Internal social capital (ISC): Relational dimension | RISC1 | During the project implementation, the participants will trust each other | Leana et al. [81]; Wang et al. [82] |
| | RISC2 | The project participants keep their promises to each other. | |
| | RISC3 | When one participant has a difficulty or dispute, the other participants are willing to help | |
| Internal social capital (ISC): Cognitive dimension | CISC1 | The participants have similar views on the development prospects of the project | Leana et al. [81]; Wang et al. [82] |
| | CISC2 | Participants have a shared understanding of the key points of the project (e.g., core technologies) | |
| | CISC3 | Participants reach consensus, especially on key project decisions | |

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| Factor | | Code | Item | Reference |
|---|---|---|---|---|
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| | | VESC2 | During the construction of the project, the relevant government departments provide resources and support for the construction of the project | |
| | | VESC3 | During the construction of the project, the project participants maintain close communication with government departments | |
| | Horizontal relationships | HESC1 | Project participants have a wide range of contacts with other relevant organizations in the industry | Leana et al. [81]; Change et al. [83] |
| | | HESC2 | Project participants exchange project construction experience with other related organizations in the industry | |
| | | HESC3 | Project participants and other relevant organizations in the industry organize study tours and learning activities for each other. | |
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| | | SESC2 | During project construction, project participants establish good relations with non-governmental organizations | |
| | | SESC3 | During project construction, the project participants establish good relations with the media | |
| | | SESC4 | During project construction, project participants establish good relations with the public | |
| Megaproject resource integration capacity (MRI) | | MRI1 | The organization is able to clearly identify resource needs and allocate them appropriately. | GE et al. [73] |
| | | MRI2 | The organization has access to the resources the organization wants | |
| | | MRI3 | The organization is able to divest useless resources in a timely manner | |
| | | MRI4 | The organization believes that useful resources can help the project to be completed better | |
| | | MRI5 | The organization is able to leverage consolidated resources to gain access to other useful resources | |
| | | MRI6 | The organization is able to leverage consolidated resources to help create greater value for the project | |
| Megaproject performance (MP) | | MP1 | The project is on schedule or will be completed on schedule | He et al. [2] |
| | | MP2 | The project expenditure is within budget | |
| | | MP3 | The project's quality is in accordance with the relevant national standards and contractually agreed standards | |
| | | MP4 | The project's safety management is well executed | |
| | | MP5 | The project has a high level of resource utilization efficiency and environmental protection | |
| | | MP6 | The project has an innovative contribution to theory and practice in the field of technology and management | |
| | | MP7 | The project participants, government departments and the public are satisfied with the project construction process and deliverables | |
| | | MP8 | Participants consider continued cooperation in the future | |

To ensure that the scale collected reliable variable data, three owners, contractors, and supervisory experts who have been working in the construction industry for more than 15 years were invited to test our scale before distributing the questionnaire to ensure that the questionnaire was aligned with practical scenarios. The initial question items of the questionnaire were determined through scale development and design, and the first draft of the questionnaire was formed. In addition, before the official questionnaire was distributed, we invited five academic and industry experts to evaluate the content and academic expression of our scale to ensure that the questionnaire was aligned with practical scenarios. After making modifications and improvements based on the experts' comments, we conducted the distribution and collection of the questionnaire.

### 3.2. Sampling and Data Collection

The questionnaire was distributed to managers of megaprojects. The managers were involved in many types of megaprojects, including urban complex projects, transportation infrastructure, industrial energy, water conservancy, and hydropower. The projects are distributed in South China, East China, North China, Central China, Northeast China, Northwest China, and Southwest China. The investment amount of most individual projects is over 4 billion dollars. In terms of investment attributes, government investment projects account for more than half of the projects, which is in line with the law of the investment attributes of megaprojects. It can be seen that the samples researched in this study are in line with our research study's needs and have strong representativeness. Finally, a total of 345 questionnaires were recovered, including 247 paper questionnaires and 98 electronic questionnaires. A total of 206 valid questionnaires were obtained after screening, with an effective rate of 59.7%. Table 2 shows the descriptive statistics of the respondents. The diversity of respondents in terms of their positions, years of experience, roles in their organizations, as well as the types of megaprojects they were involved in and the attributes of their project investments reflect the views of respondents from different backgrounds, which better ensures the generalizability and reliability of the research results. Specifically, in terms of the individual characteristics of the respondents, the ratio of male respondents (181) to female respondents (25) among the 206 respondents who participated in this research is about 7:1. In terms of the number of years of working experience in the engineering field, the research subjects in the valid samples are more experienced in engineering. In terms of the level of education, 71.4% of the respondents have a bachelor's degree and 23.3% have a master's degree or above, indicating a relatively high level of education.

**Table 2.** Statistics of Interviewed Experts.

| Characteristic | | Item | Frequency | Proportion (%) |
|---|---|---|---|---|
| Individual characteristic (N = 206) | Gender | Male | 181 | 87.86 |
| | | Female | 25 | 12.14 |
| | Education attainment | College and below | 11 | 5.3 |
| | | Undergraduate | 147 | 71.4 |
| | | Bachelor's degree | 44 | 21.4 |
| | | Ph. D. | 4 | 1.9 |
| | Working experience | <5 years | 82 | 39.8 |
| | | 5–10 years | 62 | 30.1 |
| | | 11–15 years | 40 | 19.4 |
| | | 16–20 years | 12 | 5.8 |
| | | >20 years | 10 | 4.9 |
| | Management level | Top manager | 20 | 9.7 |
| | | Middle manager | 54 | 26.2 |
| | | Grassroots Manager | 126 | 61.2 |
| | | Other | 6 | 2.9 |

**Table 2.** *Cont.*

| Characteristic | | Item | Frequency | Proportion (%) |
|---|---|---|---|---|
| Individual characteristic (N = 206) | Project Roles | Government | 7 | 3.4 |
| | | Owner | 90 | 43.7 |
| | | Contractor | 66 | 32.0 |
| | | Supervisor | 11 | 5.3 |
| | | Designer | 16 | 7.8 |
| | | Consultant | 6 | 2.9 |

### 3.3. Data Pre-Processing

This study constructs a Bayesian network based on questionnaire data. The variables in the questionnaire are observed and assessed through a five-level Likert scale, with 1–5 indicating complete nonconformity, nonconformity, general, conformity, and full conformity, respectively. In this paper, the Cronbach $\alpha$ coefficient is used as a criterion to test the reliability of the questionnaire, and to test the internal consistency of the measurement data of each variable of the questionnaire, including EQRB, PCRB, LRRB, EERB, MSRB, ISC, ESC, MRI, and MP. The value of the Cronbach $\alpha$ coefficient is related to the degree of correlation between the questions of the questionnaire, and the larger the coefficient is, the better the internal consistency between the questions and the better the reliability. In existing studies, it is widely recognized that when the Cronbach $\alpha$ coefficient of the questionnaire measurement items exceeds 0.7, the reliability of these items is considered relatively good. The analysis of the valid data of the recovered questionnaire shows that the Cronbach $\alpha$ coefficient of the overall data of MSRB is 0.818, the Cronbach $\alpha$ coefficient of ISC is 0.762, the Cronbach $\alpha$ coefficient of ESC is 0.808, and the Cronbach $\alpha$ coefficient of MRI is 0.861. The Cronbach $\alpha$ coefficient of MP is 0.868. All of these data have a good level of reliability. Further testing the internal consistency of the dimensions of MSRB, the Cronbach $\alpha$ coefficients of EQRB, PCRB, LRRB, and EERB are 0.848, 0.742, 0.828, and 0.841, respectively, with a good level of reliability. The reliability test showed that the five state values of the latent variables measured by directly observing the variables could be used in the Bayesian network model. We obtained the representative value of each variable by calculating the mean score of the relevant questions of the questionnaire and rounding it up, where the score of MSRB is obtained by rounding up the mean score of all the questions of the four dimensions of social responsibility behavior. In this study, the node mean scores are normalized to the max-min value and divided into five equally spaced score intervals rated as Higher, High, Medium, Low, and Lower. From this, discretized sample data can be obtained.

### 3.4. Bayesian Network

The Bayesian network (BN), first introduced by the American scholar Pears in 1988, is a probabilistic graphical model that integrates the theories and techniques of probability theory and graph theory, with a robust modeling capability and a comprehensive inference mechanism. A Bayesian network integrates prior knowledge and sample data to infer and represent the complex correlations between multiple variables in a large framework, which is suitable for making probabilistic inferences regarding complex uncertain events.

A Bayesian network is a pair consisting of a directed acyclic graph G and a probability distribution P, i.e., $BN = (G, P)$: (1) directed acyclic graph $G = (V, E)$, where $V$ denotes the set of nodes and the nodes represent random variables; $E$ denotes the set of directed arcs, and the directed arcs connecting the nodes are used to describe the probabilistic dependencies between the nodes. If there is no directed arc from node A to node B, it indicates that the two random variables represented by node A and node B do not have a dependency relationship and are either independent of each other or conditionally independent given the conditions of the other random variables in the graph. If there exists a directed arc from node A to node B pointing from A to B, it indicates that there is a dependency relationship between node A and node B and that node A has a direct causal effect on node B. In Bayesian networks, nodes with incoming arrows are considered child nodes and nodes with outgoing arrows are considered parent nodes. The node that has no parent node is called the root node and is the underlying node in the network, which has an associated prior probability distribution. The rest of the nodes are called non-root nodes. (2) Probability distribution $P$, which is used to describe the degree of association between nodes, has a probability distribution value for each node. The conditional probability is denoted as $P(A \mid B)$, which reflects the existence of a conditional probability value between the pair of nodes A and B.

A Bayesian network is a decomposition of the joint probability distribution. A necessary condition for deciding whether a directed acyclic graph $G = (V, E)$ and a conditional probability P can be combined into a pair $BN = (G, P)$ is whether P conforms to the joint probability distribution decomposition rule specified by $G = (V, E)$:

$$PX1, X2, \ldots, Xn = \prod_{i=1}^{n} P(Xi|\ X1,\ X2,\ \ldots, Xi - 1) = \prod_{i=1}^{n} P(Xi|\ Pa(Xi)) \tag{1}$$

In Equation (1), $P(X1, X2, \ldots, Xn)$ is the joint probability distribution of the variables, $Pa(Xi)$ denotes the set of parent nodes of node $Xi$, and $P(Xi \mid Pa(Xi))$ is the conditional probability distribution of node $Xi$ given its parent nodes. The theoretical basis of Bayesian network inference is to satisfy the conditional independence assumption, upon which the joint probability of each node in the network model can be expressed as the product of its conditional probabilities. If $G = (V, E)$ and $P$ satisfy Equation (1), then $G = (V, E)$ and $P$ can be combined into a $B = (G, P)$. Bayesian networks represent correlations between variables using conditional probabilities and visualize the values in graphical form.

Bayesian networks have a strong advantage in risk assessment [84,85], effective strategy reasoning [86,87], and in complexity studies in the engineering and construction field. In addition, studies have shown that Bayesian networks can be beneficially applied to studies for stakeholder influence relationships [88] and project performance improvement [89,90]. Therefore, it is feasible for this study to explore the role path of megaproject social responsibility behaviors on project performance enhancement using a Bayesian network through its forward prediction, reverse diagnosis, and other functions.

#### 3.4.1. BN Model Structure

In the above study, we identified 15 variables. Although numerous existing studies have shown that these variables are interconnected, there is no recognized explanatory model. Given this, we aim to establish a causal model of these variables using literature research methods and structural learning methods to obtain a directed acyclic graph (DAG). There are two main approaches to BN structural learning: the scoring search-based approach and the constraint-based methods. The scoring search algorithm assigns a score to each BN structure and then selects the model with the highest score. Constraint-based search algorithms perform a set of conditional independence analyses on the data. The combination of these two approaches provides a hybrid learning framework. The search space is first reduced through dependency analysis, and then the highest-rated network structure is identified using a scoring search [91]. The MMHC (Max-Min Hill-Climbing) algorithm used in this study is a hybrid structure learning method. It integrates the MMPC (Max-Min Parent-Child) algorithm (for reducing the search space) and the HC (Hill-Climbing) algorithm (for identifying the optimal network structure within a restricted space) [92].

To align the BN model with the objectives of this study, we utilized the R language bnlearn toolkit to customize the structure learning algorithm. Based on the potential connections between MSRB and each factor identified in the literature review, we established an undirected correlation and determined the causal relationships between the factors through algorithmic learning. We also constrained the learning conditions such that MP is a parent node and MSRB is a child node, in line with the study's objectives. Finally, 660 structural tests were performed using the MMHC method for structure learning, resulting in a DAG with 15 nodes and 20 edges (see Figure 1). As inferred from the DAG, MSRB generates causal relationships for MRI, ESC, and ISC. Interestingly, the structure learning results indicate that CISC has a strong probabilistic causal relationship with MP.

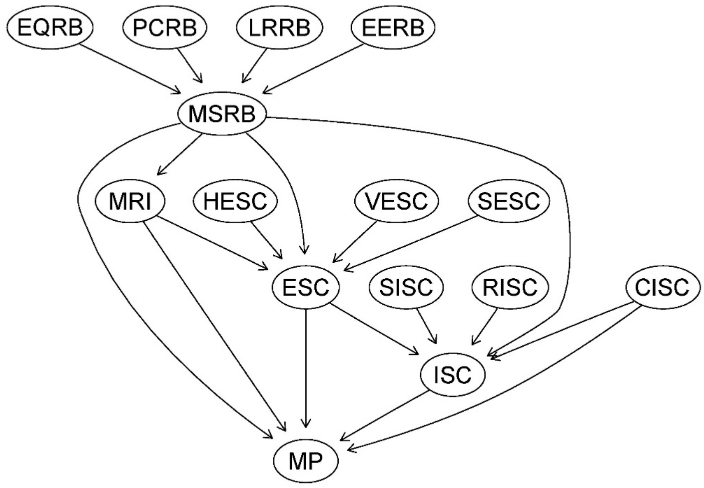



**Figure 1.** Directed Acyclic Graphical Model.

### 3.4.2. Parametric Learning

Conditional probability distributions, also referred to as belief relations, are typically denoted by CPT. In the conditional probability distribution of a Bayesian network, the sum of the probabilities of all states of a given node, under all possible combinations of the node's parent nodes, equals 1. Using the MSRB node as an example, the value of its CPT can be computed based on the variable data gathered from the questionnaire research. The parent nodes of the MSRB node encompass the four dimensions of the social responsibility behaviors of the megaprojects. Each parent node state comprises five levels: Higher, High, Medium, Low, and Lower, and the total number of possible combination states of all parent nodes is 625. Table 3 lists some of the conditional probability cases of megaproject social responsibility behaviors in this study, with the sum of probabilities in each row equating to 1.

We apply GENIE to learn the parameters of the dataset based on the DAG graph obtained by structural learning. We then calculate the conditional probability table of each node, enabling us to obtain the chartbar graph of this BN model (see Figure 2). The sum of the probabilities of the different states of each node, as calculated from the questionnaire research data, is 100%. Based on the Bayesian network model constructed from the questionnaire research data, we can infer that the evaluation of the overall social responsibility behavior of the project by the managers of megaprojects is predominantly positive, with a small number of negative evaluations. Specifically, 28.50% of the managers perceive the project's social responsibility behavior performance as being of a higher level, 36.47% view it as high level, and 21.10% consider the level of project social responsibility behavior as low or very low. This shows that in the internal management of megaprojects for the implementation of social responsibility is still more important, in the four dimensions of social responsibility behavior, the belief state of LRRB is the highest, followed by EQRB which are currently the most basic social responsibility behavior of megaprojects, with a high degree of completion and evaluation, which is in line with Ma's research [18]. The state probability distribution of PCRB is scattered, which shows that the implementation of PCRB of different megaprojects is uneven, and the managers of different projects have different praise and criticism for it. The probability of a high level is highest for MRI, ISC and ESC, and the average level of MRI, ESC, and ISC is high. Due to the wide range of questionnaire data sources, there is diversity in the evaluation of these three nodes, and the distribution of probability is also wide. In addition, on the whole, managers evaluate the performance of megaprojects well, and the probability that MP will fall into each of the five states of Higher level, High level, Medium level, Low level, and Lower level is 22.42%, 24.56%, 19.35%, 17.02%, and 16.65%, respectively. On the whole, the performance of the majority of megaprojects is evaluated to be good.

**Table 3.** MSRB's Conditional probability table (partial).

| MSRB State | | | | | Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Higher** | **High** | **Medium** | **Low** | **Lower** | **EQRB** | **EERB** | **PCRB** | **LRRB** |
| 97.14% | 0.71% | 0.71% | 0.71% | 0.71% | Higher | Higher | Higher | Higher |
| 77.50% | 15.00% | 2.50% | 2.50% | 2.50% | High | Higher | Higher | Higher |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Medium | Higher | Higher | Higher |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Low | Higher | Higher | Higher |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Lower | Higher | Higher | Higher |
| 60.00% | 10.00% | 10.00% | 10.00% | 10.00% | Higher | Higher | Higher | High |
| 30.00% | 55.00% | 5.00% | 5.00% | 5.00% | High | Higher | Higher | High |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Medium | Higher | Higher | High |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Low | Higher | Higher | High |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Lower | Higher | Higher | High |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Higher | Higher | Higher | Medium |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | High | Higher | Higher | Medium |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Medium | Higher | Higher | Medium |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Low | Higher | Higher | Medium |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Lower | Higher | Higher | Medium |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Higher | Higher | Higher | Low |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | High | Higher | Higher | Low |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Medium | Higher | Higher | Low |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Low | Higher | Higher | Low |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Lower | Higher | Higher | Low |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Higher | Higher | Higher | Lower |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | High | Higher | Higher | Lower |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Medium | Higher | Higher | Lower |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Low | Higher | Higher | Lower |
| 20.00% | 20.00% | 20.00% | 20.00% | 20.00% | Lower | Higher | Higher | Lower |

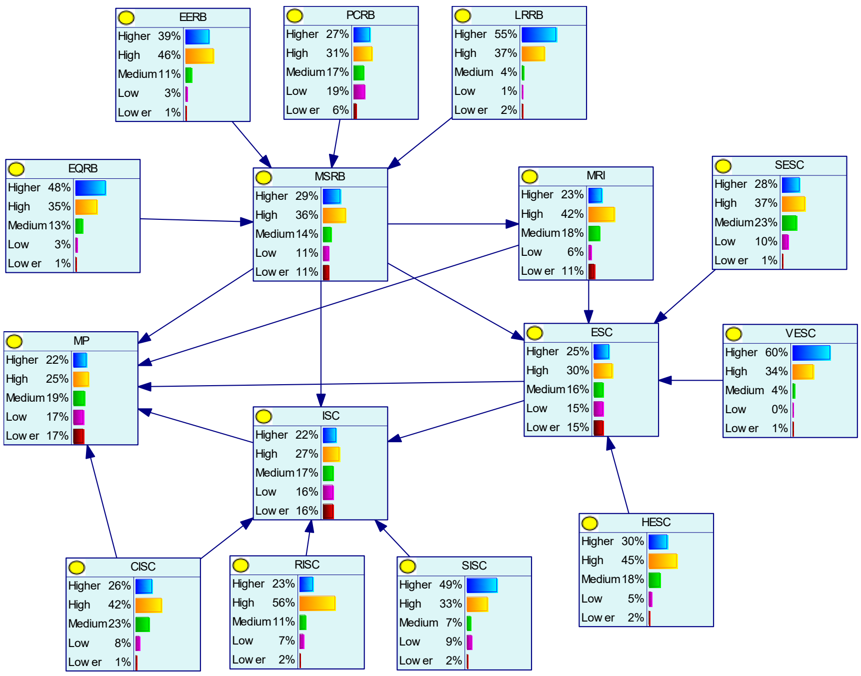



**Figure 2.** Causal reasoning model.

# 4. Results

## *4.1. Model Validation*

This study validates 206 samples of data. The greater the validity of the model, the greater the consistency between the model simulation results and the real level of MP under the given variable conditions and the closer the model's prediction results are to the real level. The data of variable nodes are fed into the constructed Bayesian network model, and the probability distribution of variable nodes "MP" is computed. See Figure 2.

The performance of the trained classifier can be assessed by calculating the prediction accuracy and kappa coefficient from the confusion matrix [93]. Tables 4 and 5 display the confusion matrix and accuracy for MSRB and MP. With accuracies of 0.951 and 0.825 for MSRB and MP, 0.888 for both nodes, and kappa coefficients of 0.928 and 0.744 (kappa coefficient > 0.6 is considered to be a reliable measure of accuracy [94,95]), it is evident from Tables 4 and 5 that this BN network exhibits superior classification performance, which can be utilized for subsequent inference analysis.

**Table 4.** MSRB's confusion matrix.

| **MSRB** | | **Predicted** | | | | |
|---|---|---|---|---|---|---|
| | | **Higher** | **High** | **Medium** | **Low** | **Lower** |
| Actual | Higher | 77 | 3 | 0 | 0 | 0 |
| | High | 5 | 67 | 1 | 0 | 0 |
| | Medium | 0 | 1 | 45 | 0 | 0 |
| | Low | 0 | 0 | 0 | 5 | 0 |
| | Lower | 0 | 0 | 0 | 0 | 2 |
| Accuracy | | 0.963 (77/80) | 0.918 (67/73) | 0.978 (45/46) | 1 (5/5) | 1 (2/2) |
| | | 0.951 (196/206) | | | | |
| Kappa | | 0.928 | | | | |

**Table 5.** MP's confusion matrix.

| **MP** | | **Predicted** | | | | |
|---|---|---|---|---|---|---|
| | | **Higher** | **High** | **Medium** | **Low** | **Lower** |
| Actual | Higher | 60 | 7 | 0 | 0 | 0 |
| | High | 8 | 68 | 1 | 1 | 0 |
| | Medium | 3 | 11 | 33 | 0 | 0 |
| | Low | 1 | 1 | 2 | 5 | 0 |
| | Lower | 0 | 1 | 0 | 0 | 4 |
| Accuracy | | 0.896 (60/67) | 0.872 (68/78) | 0.702 (33/47) | 0.556 (5/9) | 0.8 (4/5) |
| | | 0.825 (170/206) | | | | |
| Kappa | | 0.744 | | | | |

## *4.2. Bayesian Network Inference*

### 4.2.1. Predictive Inference

Predictive inference can be based on the directed arc direction of connected nodes to reason about the outcome, given the latest cause information. The purpose of predictive analysis is to forecast future outcomes given different antecedent information. This approach can effectively analyze the influence of various states of evidence nodes on the state of target nodes. In the Bayesian network model, we set different levels of social responsibility behaviors of various dimensions as evidence nodes. We can then calculate the probability distribution of the MP level after updating the network.

(1) Simple strategy for single precondition changes

To estimate the impact of changes in the states of EQRB, PCRB, LRRB, and EERB on MP, the probability of the "higher" state of each dimension of social responsibility behavior is set to 100% to simulate the scenario of adopting a single strategy. Figure 3 displays the posterior probability of MP corresponding to adjusting the probability of the higher-level state of LRRB to 100%. It can be noted that when the LRRB is set to a 100% higher level, the probability of MP being at a higher level increases from 22.42% to 23.60%.

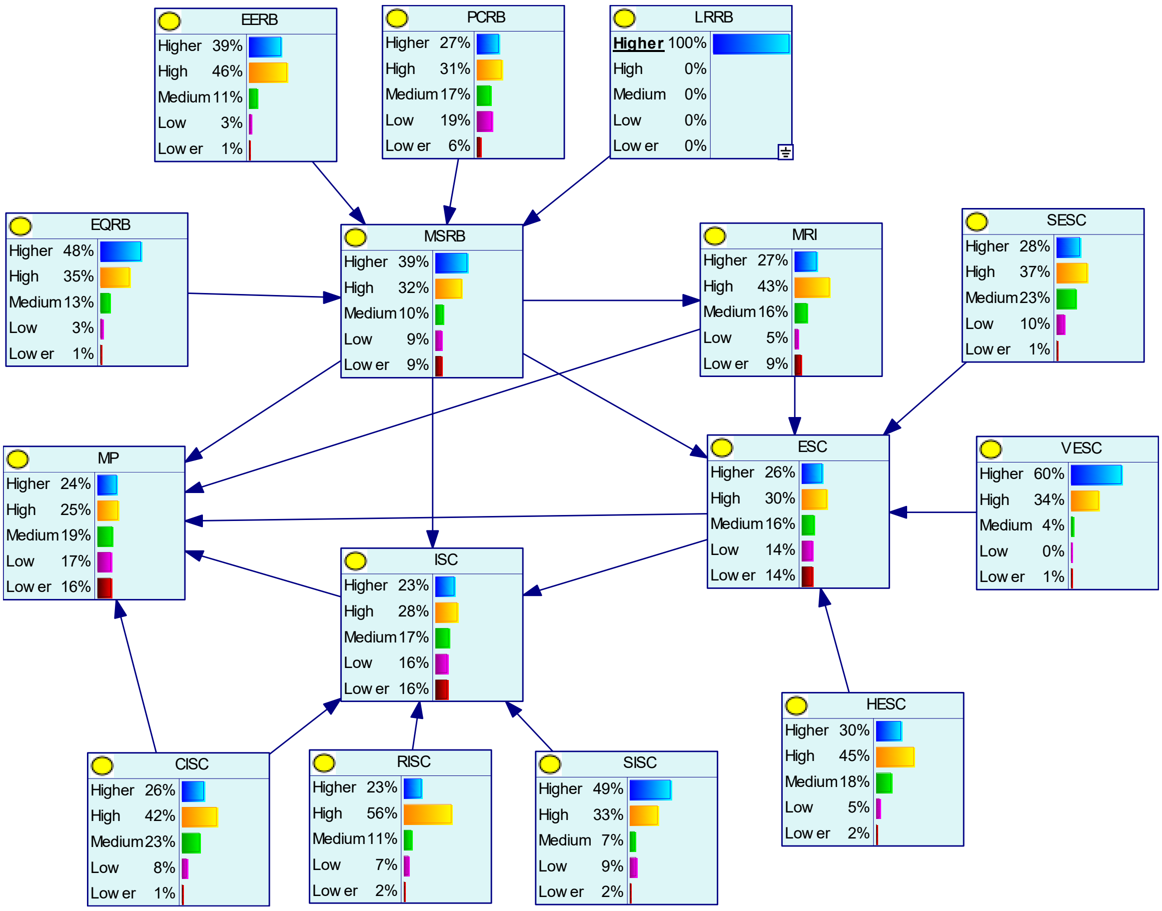



**Figure 3.** Project performance changes induced by changing single-dimensional social responsibility behaviors.

We separately adjust the level of social responsibility behavior for each dimension to a higher level and calculate the conditional probability distributions for the other nodes. The inference results are shown in Table 6. Each social responsibility behavior node influences the other nodes. PCRB, LRRB, EERB, and EQRB at higher levels contribute in decreasing order to the overall level of social responsibility behavior, while the latter two help avoid a low level of overall MSRB. The predictive analysis of these four nodes indicates that all dimensions of social responsibility behaviors influence MRI, ESC, ISC, and MP, with a particularly significant effect on MRI. However, the enhancement of social capital and resource integration capacity did not result in a comparable enhancement of MP, suggesting that its effect on MP is not linear. Megaprojects that adopt partial social responsibility measures can achieve a slight improvement in project performance due to the measures' combined effect on the ISC, ESC, and MRI.

**Table 6.** Predictive results of changing one-factor beliefs.

| Belief change: "EQRB = Higher" | | | | | |
|---|---|---|---|---|---|
| State | Belief changes | | | | |
| | MSRB | MRI | ESC | ISC | MP |
| Higher | 9.83% | 3.73% | 0.99% | 0.55% | 1.06% |
| High | −3.10% | 0.65% | 0.08% | 0.19% | 0.01% |
| Medium | −3.86% | −1.90% | −0.41% | −0.33% | −0.55% |
| Low | −1.44% | −0.90% | −0.33% | −0.21% | −0.28% |
| Lower | −1.43% | −1.57% | −0.33% | −0.21% | −0.25% |
| Belief change: "EERB = Higher" | | | | | |
| State | Belief changes | | | | |
| | MSRB | MRI | ESC | ISC | MP |
| Higher | 11.01% | 3.74% | 0.89% | 0.51% | 1.20% |
| High | −7.11% | −0.65% | −0.37% | −0.12% | −0.29% |
| Medium | −3.56% | −2.31% | −0.25% | −0.26% | −0.59% |
| Low | −0.18% | −0.40% | −0.13% | −0.07% | −0.19% |
| Lower | −0.17% | −0.38% | −0.13% | −0.06% | −0.12% |
| Belief change: "PCRB = Higher" | | | | | |
| State | Belief changes | | | | |
| | MSRB | MRI | ESC | ISC | MP |
| Higher | 14.60% | 5.13% | 1.24% | 0.71% | 1.57% |
| High | −8.16% | −0.22% | −0.27% | 0.00% | −0.27% |
| Medium | −4.41% | −2.86% | −0.41% | −0.39% | −0.76% |
| Low | −1.02% | −0.83% | −0.28% | −0.16% | −0.31% |
| Lower | −1.01% | −1.22% | −0.28% | −0.16% | −0.23% |
| Belief change: "LRRB = Higher" | | | | | |
| State | Belief changes | | | | |
| | MSRB | MRI | ESC | ISC | MP |
| Higher | 10.87% | 4.03% | 1.05% | 0.59% | 1.17% |
| High | −4.16% | 0.44% | 0.00% | 0.15% | −0.05% |
| Medium | −4.11% | −2.13% | −0.41% | −0.34% | −0.60% |
| Low | −1.31% | −0.87% | −0.32% | −0.20% | −0.28% |
| Lower | −1.30% | −1.47% | −0.32% | −0.19% | −0.24% |

(2) Combined strategies for multiple precondition changes

The multifactor strategy involves changing the level of social responsibility behavior performance in several dimensions simultaneously to improve the level of project performance. The single-factor strategy demonstrated that the probability of project performance being at a higher level reached a maximum 24.00% when controlling the level of social responsibility behaviors in one dimension alone. When a strategy of controlling several variables simultaneously was implemented, project performance might be further improved. After making several predictions by integrating control variables, it is observed that the probability of project performance being at a higher level reaches a maximum of 29.70% when controlling the four dimensions of social responsibility behaviors to reach a higher level, at which time the probability distribution of the MSRB is 97.14% for a higher level, and the probability of all other statuses is 0.71%, so it may be difficult to significantly improve the MP by improving the overall MSRB.

EQRB, EERB, PCRB, and LRRB are in the higher-level state. The probability of different combinations of strategies corresponding to higher levels of project performance is displayed in Table 7. It can be observed that the combination where the levels of PCRB, EQRB, and EERB are all at higher levels is the most effective strategy. Among the combinations that simultaneously control three dimensions of social responsibility behavioral performance, the combination with EQRB, EERB, and LRRB at higher levels simultaneously has the lowest effect, but it has a better inhibitory effect on low-level performance. The increase of the probability of project performance at a higher level when controlling for the strategy of two dimensions of social responsibility behaviors performance at a higher level simultaneously ranged from 2.64% to 3.37%, with little difference in effect.

**Table 7.** Posterior probability of MP under combinatorial condition.

| Combinatorial Condition | State of MP | | | | |
|---|---|---|---|---|---|
| | **Higher** | **High** | **Medium** | **Low** | **Lower** |
| "EQRB = Higher" + "PCRB = Higher" + "EERB = Higher" | 5.22% | −1.09% | −2.35% | −1.05% | −0.73% |
| "PCRB = Higher" + "LRRB = Higher" + "EERB = Higher" | 5.17% | −0.83% | −2.36% | −1.13% | −0.85% |
| "EQRB = Higher" + "PCRB = Higher" + "LRRB = Higher" | 5.11% | −0.45% | −2.38% | −1.25% | −1.03% |
| "EQRB = Higher" + "EERB = Higher" + "LRRB = Higher" | 4.99% | −0.45% | −2.33% | −1.21% | −1.00% |
| "EQRB = Higher" + "EERB = Higher" | 2.64% | −0.49% | −1.23% | −0.53% | −0.39% |
| "EQRB = Higher" + "PCRB = Higher" | 2.88% | −0.42% | −1.35% | −0.63% | −0.48% |
| "EQRB = Higher" + "LRRB = Higher" | 2.92% | −0.21% | −1.40% | −0.71% | −0.60% |
| "PCRB = Higher" + "EERB = Higher" | 3.37% | −0.71% | −1.54% | −0.66% | −0.46% |
| "LRRB = Higher" + "EERB = Higher" | 2.72% | −0.28% | −1.30% | −0.63% | −0.51% |
| "PCRB = Higher" + "LRRB = Higher" | 3.20% | −0.35% | −1.51% | −0.74% | −0.60% |

#### 4.2.2. Diagnostic Inference

In Bayesian networks, the consequence variable is designated as the evidence node and the cause variable as the query variable. This process of reasoning from consequence to cause is referred to as diagnostic analysis or backward reasoning. We set the probability that the MP of the target node is at a higher level to 100%, implying that the MP level is good and the project has a high likelihood of success. We then observe the performance of other nodes in the Bayesian network model of this study. The inference results are shown in Figure 4. By comparing Figure 4 with the belief data in Figure 2, we plot Table 8 to observe the results of diagnostic inference.

**Table 8.** Beliefs Changes in Diagnostic Inference.

| Nodes | Belief Changes | | | | |
|---|---|---|---|---|---|
| | **Higher** | **High** | **Medium** | **Low** | **Lower** |
| EQRB | 2.27% | −1.30% | −0.77% | −0.15% | −0.04% |
| EERB | 2.10% | −1.26% | −0.68% | −0.12% | −0.04% |
| PCRB | 1.87% | 0.22% | −0.65% | −1.08% | −0.36% |
| LRRB | 2.90% | −2.59% | −0.17% | −0.06% | −0.07% |
| MSRB | 9.63% | −4.86% | −2.44% | −1.18% | −1.15% |
| MRI | 6.44% | −1.86% | −2.64% | −0.72% | −1.22% |
| ESC | 7.68% | −2.83% | −1.55% | −1.71% | −1.59% |
| ISC | 4.81% | 1.41% | −2.56% | −1.89% | −1.78% |

As observed from Figure 4 and Table 8, when the probability of MP at a higher level is 100% and is used as an evidence node for backward reasoning, the incremental increase in the probability of a higher level of MSRB, ESC, ISC, and MRI decreases in order. This indicates that when MP is at a higher level, it is evident that the MSRB is playing a role in the higher level of MP. Among the four types of social responsibility behaviors, LRRB has the highest probability of being at a higher level, at 58.24%, followed by EQRB at 50.33%, then EERB at 41.42%, and finally PCRB at 28.57%. Therefore, the probability of the occurrence of higher levels of MP in these four dimensions of social responsibility behaviors is likely to be associated with all four dimensions of social responsibility behaviors, and the above order reflects the different requirements of higher levels of project performance for higher levels of social responsibility behaviors in each dimension.

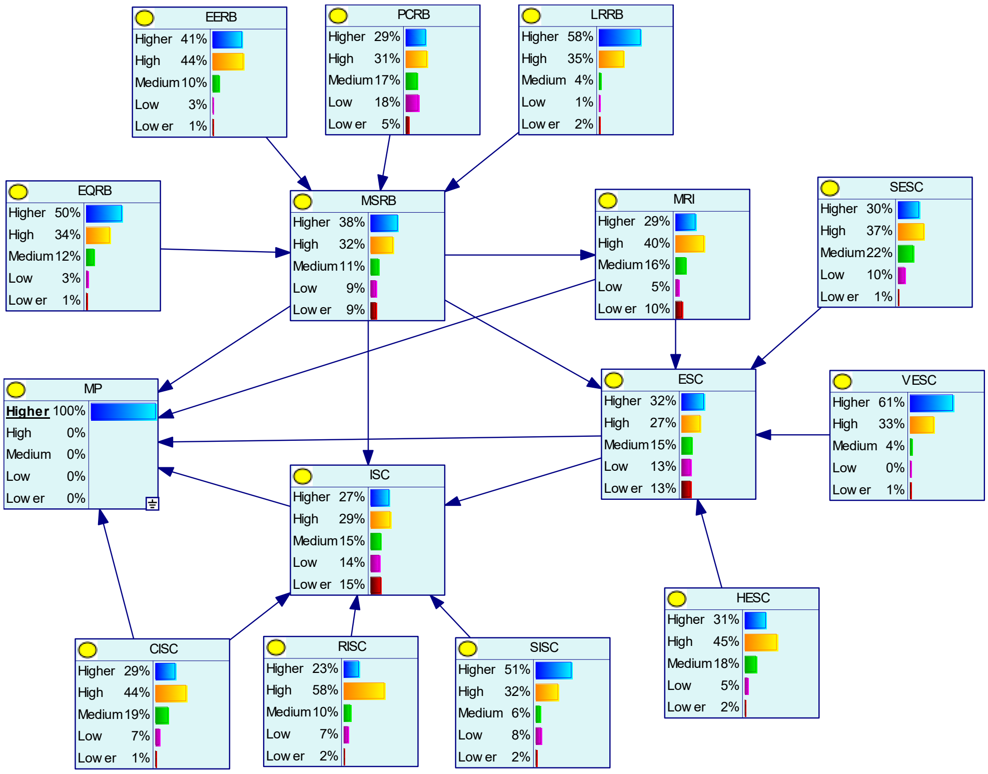



**Figure 4.** Results of Diagnostic Reasoning for Changing MP Node Beliefs.

#### 4.2.3. Sensitivity Analysis

Sensitivity analysis refers to the degree of impact on other evidence nodes when certain nodes undergo slight changes. In the Bayesian network model, sensitivity analysis constitutes an important component of the model analysis calculation. The sensitivity analysis calculation of the model can determine the degree of influence and the influence pattern on other nodes when any node changes. To explore which nodes in the Bayesian network model of the relationship between MSRB and MP are more sensitive to the impact of the MP node, we set the MP node as the target node for sensitivity analysis. Figure 5, which is obtained as a result, indicates that the darker the node, the higher its sensitivity to MP.

As observed from Figure 5, for node MP, the sensitivity of the dimensions of social responsibility behavior, MRI, and ISC is greater. Among the four dimensions of social responsibility behavior nodes, the sensitivity of LRRB is the greatest. Furthermore, a tornado diagram can be generated by the sensitivity analysis function in GENIE, which can visualize the sensitivity of MP to each parent node at each level, with red bars representing a negative correlation and green bars representing a positive correlation in the diagram. In Figure 6a, MP is most sensitive to LRRB when MP is at a higher level, and the enhancement of the higher-level probability of LRRB may produce the greatest probability of a higher level of MP. Secondly, higher levels of MP require that the CISC be controlled at a high level, and a moderate increase in the level can also have a negative effect. EQRB and EERB can help MP achieve a higher level.

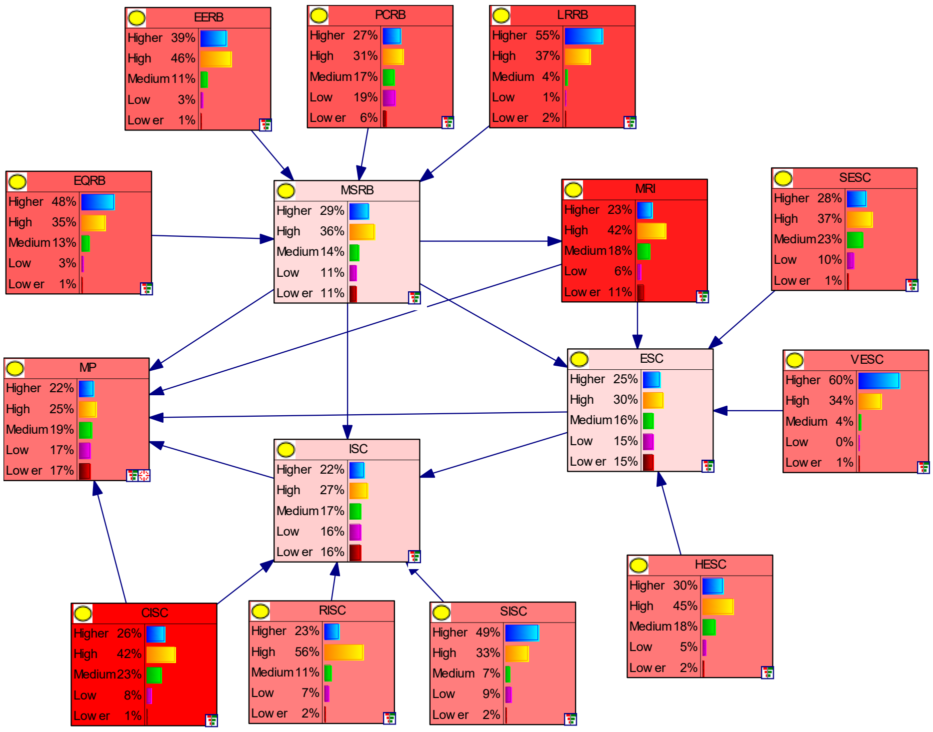



**Figure 5.** Sensitivity analysis result of project performance as a target node.

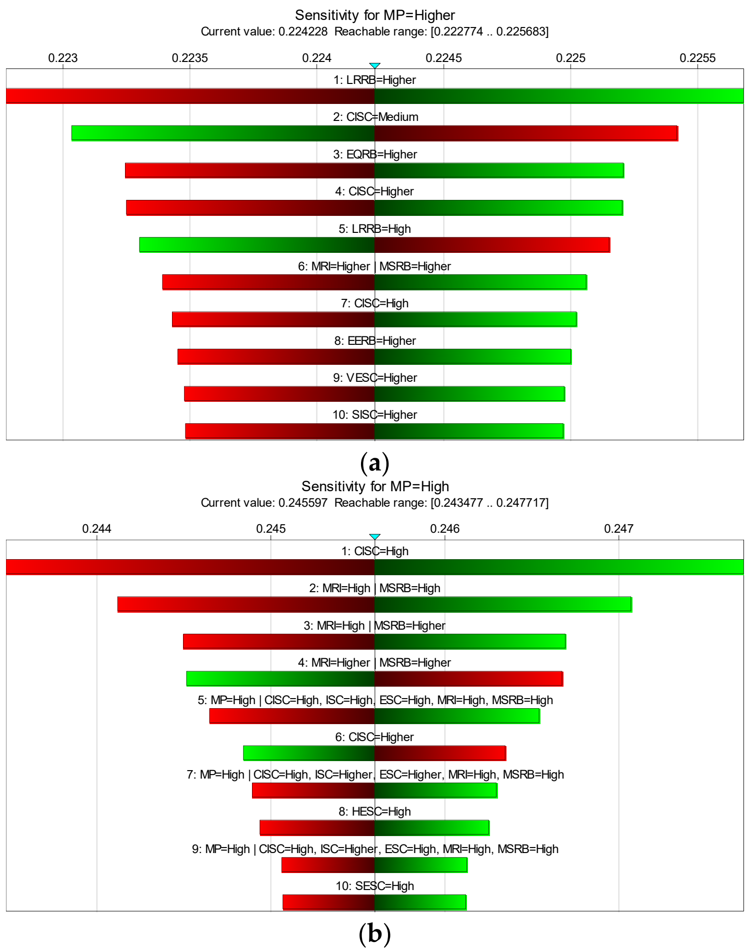
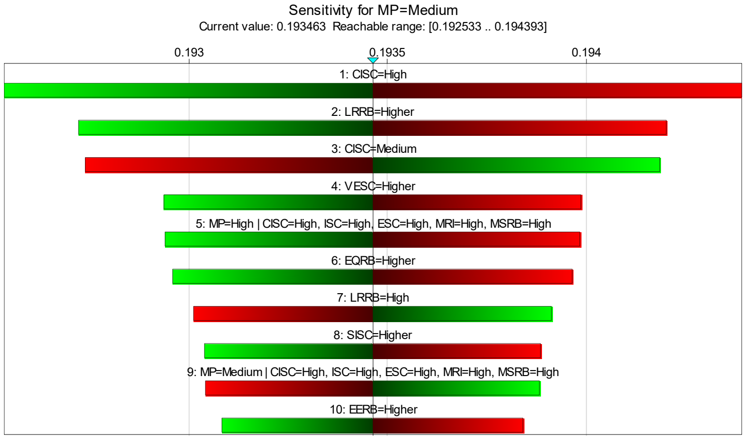
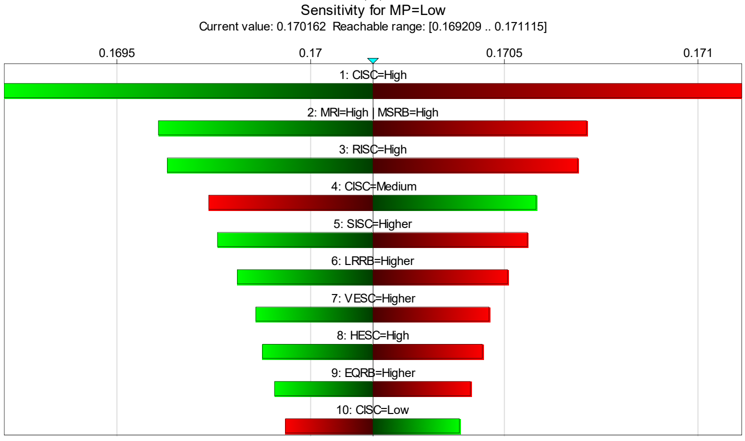


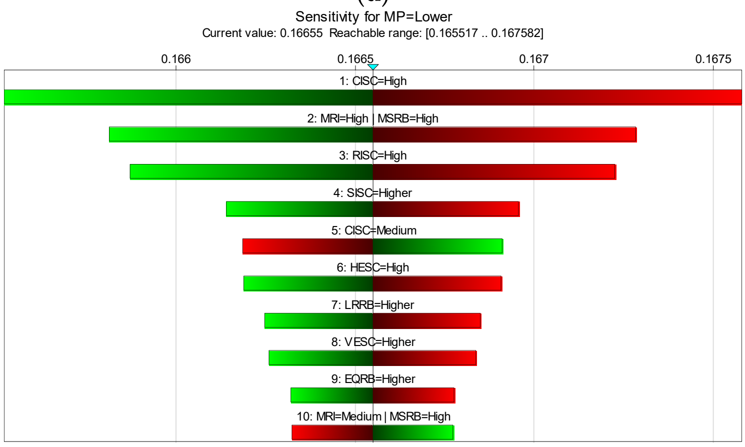

**Figure 6.** *Cont.*




(**c**)




(**d**)




(**e**)

**Figure 6.** Tornado diagram of MP: (**a**) Sensitivity for "MP = Higher"; (**b**) Sensitivity for "MP = High"; (**c**) Sensitivity for "MP = Medium"; (**d**) Sensitivity for "MP = Low"; (**e**) Sensitivity for "MP = Lower".

In Figure 6b, when project performance is at a high level, an increase in CISC can contribute the most to MP improvement, indicating that the consistency of project organization cognition is crucial in megaprojects. MRI begins to play a mediating role, and a high level of MRI enhances a high level of MP, when MSRB is at a high or higher level. In Figure 6c–e, it can be observed that each dimension of ISC has a significant impact on medium, low, and lower levels of MP, while the impact of MSRB on MP diminishes with decreasing levels of MP. This impact also shifts from a direct impact to an indirect impact through the mediating role of MRI.

The results of the sensitivity analysis indicate that when the MP is at a high level, the fulfillment of MSRB can exert a greater positive effect on MP. Among these, LRRB has the most significant influence, followed by EQRB, EERB, and PCRB. As the MP level decreases, the ISC gradually becomes the dominant factor affecting project performance. This suggests that the ISC is a fundamental factor for megaprojects seeking to achieve a high MP level. Concurrently, the influence of MSRB weakens and transforms into an indirect influence mediated by MRI. It can be inferred that the positive impact of MSRB on MP may be predicated on superior basic project performance.

## 5. Discussion and Implications

### *5.1. Discussion*

This study establishes a Bayesian network to analyze the impact of MSRB on MP. After structure learning and parameter learning, the Bayesian network model demonstrates good predictive performance. As referenced in [94], the model performs well and is capable of effective predictive analysis. This study collected 206 valid questionnaires from managers of megaprojects across various regions of China. The data from these questionnaires revealed the current fulfillment of social responsibility behaviors of megaprojects, as well as the diversity of resources and capabilities of these projects. The a priori probability of parent nodes of the MSRB corroborates the hierarchical relationship of the MSRB of each dimension as outlined in the Ma's study [18]. PCRB remains the project's desired responsibility behavior, which is currently performed in a more general way. However, the data from this study indicate that the megaprojects in the sample perform better in LRRB than EQRB, suggesting that the current LRRB of megaprojects forms the basis of MSRB. In addition, the questionnaire data also reveal that although most of the megaprojects possess a high level of social capital and resource integration capacity, there is considerable uncertainty, particularly regarding internal social capital.

Inferential analysis can quickly evaluate the effectiveness of adopting certain measures through belief updating. Inferential analysis can lead to the following findings: First, MSRB enhancement does enhance project performance, a finding that supports He's research [2]. This study also attempts to explore the mediating role played by social capital and resource integration capacity. The results show that MSRB can significantly affect resource integration capacity, and it can also weakly affect the internal and external social capital of the project. However, these indirect effects bring about an enhancement of project performance, but not significantly. Secondly, the reasoning analysis of the four dimensions of MSRB revealed that PCRB is a bonus, where the performance of PCRB acts as icing on the cake and is expected by the national government when the other dimensions of behavior are performed well, while EERB plays a similar role to the former. In contrast, while the enhancement of EQRB and LRRB do not significantly contribute to superior performance, they enable the project to reduce the likelihood of low performance.

The sensitivity analysis yielded the following findings: firstly, the sensitivity of project performance to LRRB and EQRB is high, corroborating the findings of the inference analysis. LRRB and EQRB are social responsibility behaviors that participating organizations of megaprojects should adhere to [18]. Secondly, it is interesting to note that MP exhibits the highest sensitivity to CISC. The situation of project performance is closely tied to the cognitive consistency of participating organizations. Thirdly, when the level of MP is not high, the impact of MSRB on MP performance diminishes, transitioning from a direct impact to an indirect impact mediated by resource integration capacity.

### *5.2. Theoretical Implications*

The findings of this study make some theoretical contributions to the field of megaproject social responsibility research. For the first time, this study demonstrates the positive impact of MSRB on project performance from a resource-based theory perspective. This paper introduces resource and capability factors, thereby enriching the theoretical model of MSRB's effect on project performance. In response to Ma et al.'s call for a multi-theoretical approach to understanding megaproject social responsibility [18], this paper advances the application of resource-based theory in megaproject management studies.

This paper further extends the study of MSRB's effects. Different from He et al.'s research, which found the mediating influence of innovation capability on the impact of MSR practices on project performance [2], our findings reveal the complexity of mediating factors. This study shows that both the internal and external social capital of a megaproject, as well as its resource integration capacity, can mediate the impact of MSRB in certain contexts. Additionally, we applied the Bayesian network analysis method in this study to provide an adjustable analysis function for studying MSRB's effects, enhancing the practical relevance of our findings. Therefore, this paper has made some theoretical explorations in the study of megaproject social responsibility behavior.

### 5.3. Practical Implications

The results of the study have some implications for megaproject management.

Through the predictive inference result, it can be observed that project performance is jointly dominated by internal and external social capital, and the participating organizations of megaprojects are able to use their strong social capital to create competitive advantages. However, in the context of a large number of contractual and economic relationships between the participating organizations of megaprojects, megaprojects are limited in their attempts to reduce the transaction costs and achieve better performance through MSR [10].

For MSR strategy building, EQRB and LRRB can be considered basic strategies, while PCRB and EERB can be considered further strategies. Strategy implementation for different behaviors needs to be considered in the context of project status and timing. At the initial stage of a megaproject, the general level of project performance is often dominated by the project's resources and capabilities. While MSRB can play a role, it is subject to the intermediary influence of resources and capabilities. Once the MP reaches a certain level, MSRB will exert a direct promotional effect. Therefore, the mediating role of the internal and external social capital and resource integration capacity of the project is likely to be concentrated in the early stage of the project. When the project achieves a certain level of performance, the direct facilitating effect of MSRB on MP will gradually become more prominent. A combined strategy of multidimensional social responsibility behaviors provides a greater enhancement of project performance than a single-factor strategy, and managers need to attend to the integration of each dimension of social responsibility implementation to promote the implementation of overall MSR [18].

Moreover, the study's findings remind megaproject managers of the importance of organizational cognition. For megaproject organizations, in addition to the need for a scientific structure and the establishment of good internal relations, it is crucial for participating organizations to strengthen the common vision, collective values, and cultural identity to achieve project performance [96].

## 6. Conclusions

In the context of sustainable development, megaproject social responsibility has garnered widespread attention in the field of engineering management. Managers have gradually begun to implement social responsibility behaviors in projects, which have significantly impacted the management of megaprojects. Project performance is the focal point of managers' attention. The type of changes produced by the influence of social responsibility behavior is a question that many scholars are currently attempting to answer. However, current research often overlooks considerations of overall social responsibility behavior. At the same time, it stops at identifying the existence of the effect and so far lacks a deep exploration of the mechanism of the influence. Therefore, the aim of this study is to uncover the mechanism of the impact of social responsibility behaviors of megaprojects on project performance. This study introduces the resource-based theory, incorporates the factors of internal and external social capital and resource integration capacity of the project, and employs the Bayesian network research method.

Based on the questionnaire data, this study conducted structural learning and parametric learning, established a Bayesian network model with robust predictive performance of the impact of social responsibility behaviors on project performance, and derived the following findings through inference analysis and sensitivity analysis: (1) MSRB can exert a direct and positive impact on project performance, and the impacts of different dimensions of social responsibility behaviors vary, exhibiting a hierarchical relationship. (2) Resource integration capacity plays a significant positive mediating role, while the mediating role of social capital is minimal. (3) The impact of MSRB on project performance fluctuates with the level of project performance, with a smaller impact at low levels of project performance and a larger impact at higher levels of project performance.

The findings of this study provide a solid reference for research on the mechanism of the effect of social responsibility behavior in megaprojects, and the conclusions of the study offer valuable insights for managers of megaprojects in making sustainable development decisions.

## 7. Limitations and Future Research

The sample data utilized in this study are exclusively cross-sectional, which precludes a dynamic examination of the mechanisms through which megaproject social responsibility behavior impacts project performance. The examination of the dynamic evolution of megaproject social responsibility behaviors represents a promising avenue for future research. Furthermore, while this study is primarily centered on the context of megaprojects within China, it is important to note that the practices of megaproject management may exhibit variability across different countries or regions, influenced by distinct institutional and cultural environments. Therefore, it is recommended that future research broaden the scope of sample collection, integrating case data from international contexts for comparative analysis. This would enable the derivation of more reliable and generalizable findings.

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