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The Impact of Dynamic Risk Interdependencies on the Saudi Precast Concrete Industry

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Abstract: The precast concrete production process faces uncertainties and risks that reduce the efficiency of the Saudi precast concrete industry. Assessing the risk factors' interdependence yields better results than considering individual analyses only. The previous precast risk studies did not consider the interdependencies among risk factors concerning different process stages. This paper aims to identify precast risk factors and prioritize their importance in Saudi Arabia. Using a dynamic Bayesian network, the assessment considers the interrelationships among the risk factors and different production stages. The risk factors were collected from previous studies, evaluated, and classified into the five construction stages by performing structured interviews with ten experts. The probabilities of the root risks and conditional probabilities of intermediate and leaf risks were assessed based on the ten experts. Then, a Monte Carlo simulation was utilized to provide the status of these probabilities, which were considered input data for the GeNIe program. The main results revealed that erection productivity is the highest risk, with a probability value of 0.87. In addition, the design schedule's significance directly impacts production capacity, resulting in a probability value of 0.74. However, the site management risk is low, with a 0.32 probability value. This paper assists practitioners in optimizing construction schedules.

Keywords: spontaneous probability; conditional probability; dynamic Bayesian network; precast concrete; fuzzy; planning and scheduling; project budget; production capacity

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1. Introduction

The construction industry in the Kingdom of Saudi Arabia (KSA) is swiftly improving and expanding. According to Ahmed et al. [1], the construction industry is the most significant sector in KSA that receives investment with unawarded and planned projects worth over USD 825 billion. The KSA's construction contracts were USD 75 billion in 2021, a rise from USD 22 billion in 2020, supporting the evidence that demand is anticipated to increase significantly in the following years [2]. With the vast growth and expansion in the sector, there is an increased demand for building new structures. Consequently, there were proposals for using new construction systems, such as precast concrete systems (PCS), to overcome the shortcomings of traditional systems and meet the increased demand for buildings [3]. Precast systems offer numerous advantages, like decreased construction waste, faster construction, decreased costs, and higher quality than traditional systems [4]. The precast system has a better chance of obtaining a larger market share than traditional systems. For instance, in 2021, the worldwide market share of the precast system was USD 118.48 billion, an increase from USD 114.78 billion in 2020 [5]. In addition to this progress, the market share is anticipated to increase by between 4.4 and 5.5%, reaching approximately USD 159.85 billion in the next five years [6].

In addition to better quality and fast construction, the main advantage of the precast system is the vast repetition of formwork compared to the traditional cast-in-site construction methodology, which consequently saves costs. Gibb and Isack [7] argue that PCS reduces costs from between 10 and 18%. In addition, the construction sector creates large amounts of construction and demolition waste. Jaillon and Poon [8] found an average of roughly 52% waste decrease when implementing the PCS. Furthermore, there is a potential decrease in dust and noise pollution, the main pollution contributors in the construction sector [9].

On the other hand, the precast industry has challenges and uncertainties. For example, the factors that may influence the use of the PCS in the construction industry include the unwillingness of individuals to shift to new systems, limitations in the PCS's design, and the precast's aesthetic image [10]. The cost implications of using PCS compared to other construction methods can influence its adoption. Certain factors, such as the cost of manufacturing precast elements, transportation, onsite assembly, and overall project costs, need to be evaluated to determine the economic viability of PCS [11]. Additionally, the existing site conditions and constraints can affect the suitability of PCS. Factors, such as site accessibility, available space for precast element storage, and onsite assembly requirements, must be considered to determine if PCS can be effectively implemented [10]. Polat [12] stated that transportation restrictions and inadequate academic education about PCS were the key factors limiting its use in the United States.

PCS, in particular, entails massive teamwork output in a single project. As a result, different activities, like design, quality, transportation, erection, and production, are all connected by coordination and planning, which leads to the completion of any precast project [13]. These activities are related to risks that impact the time and costs in precast projects, sometimes resulting in project termination. The risks are human negligence, machinery inefficiency, climatic changes, poor management, and natural calamities. These risks should be mitigated and controlled during the construction, procurement, and design phases. The mitigation process should include defining the risk management plan as the project begins, assigning risks to various project members, and managing their execution [13]. Therefore, risks in the real world of precast projects are frequently connected by complex and factor cause-and-effect relationships. A risk factor has the potential to activate one or more additional risk factors [14,15]. Risk interdependencies should be considered, especially when managing complex project risks, as this procedure may enhance the efficacy and precision of project risk assessment and forecast the emerging behavior of severe risk propagation ahead of time.

Understanding the interdependencies of precast construction risks helps recognize and evaluate potential risks that can affect the success of a project. Project stakeholders can develop effective risk management strategies and contingency plans. In addition, project managers can identify risk factors that have the highest potential for precast productivity. This knowledge enables them to allocate resources appropriately, implement risk mitigation measures, and establish realistic project timelines. The interdependencies analysis allows project stakeholders to make informed choices when selecting construction methods, materials, and suppliers. Additionally, it helps prioritize risk mitigation efforts and effectively allocate resources to address critical risk factors. The interdependencies analysis of precast construction risks visually represents the complex relationships between risk factors. This analysis facilitates effective communication among project stakeholders, including owners, designers, contractors, and subcontractors. It allows for a common understanding of the risks and encourages collaboration in developing risk mitigation strategies.

As a result of previous results, more research is needed on the cost and time risk impact of precast concrete systems, especially considering the interrelationship risk factors. This study explores the factors influencing the time and cost of PCS in KSA. This paper assessed the precast concrete risk factors in different project stages by considering the interdependencies among risk factors (causal and dynamic interrelationships). This study evaluated the risk factors with project time by using a dynamic Bayesian network (DBN).

Interpretative structural modeling (ISM) and direct acyclic graph (DAG) were used based on the judgments of ten experts. Due to the limitations of the experts, a Monte Carlo simulation (MCS) was utilized to address the concern about the diminutive data, and then the DBN analysis was implemented. This study is organized as follows: Section 2 presents a literature review; Section 3 details the steps followed to achieve the objectives; Section 4 discusses the paper's main findings with a comparison with modern related previous studies; Section 5 summarizes the paper.

2. Literature Review

This section conducted a bibliographic review regarding the PCA risk factors and the DBN method.

2.1. Studies of PCA Risk Factors

Several research studies have explored factors that could impact the use of PCA. These studies can be classified into three main issues: design, budget, and transportation issues.

Design issues have been reported as one of the factors impacting the use of precast concrete. Design is the most significant stage of construction. The precast design starts from the conventional design and is more labor-intensive and complex. According to [16], a designer should consider definite component and module constitutions and their exact assembly. Complex modules require much design work, since more subsequent precast, assembly, coordination, and transportation work is produced [17]. Polat [12] argues that a good design can improve the building's value, whereas an ineffective design will likely result in poor building quality (such as joint failure, leakages, and cracks). In the design stage, the assembly process, the modules, and the components are determined, and it can be challenging to change them at the construction stage [8]. Theoretically, the specifications of a precast design are supposed to be "frozen" in the initial design phases. However, designers need help in practice [18]. Additionally, Abd El Fattah et al. [5] sought opinions on the architectural design of the PCA. From their study, some architects believe that precast concrete compromises architectural creativity. In contrast, other architects claim that using PCA can be helpful when building complex patterns and provides high quality results that cannot be achieved using other, traditional ways. Different opinions from architects can be attributed to the building's nature and the design concept to be attained. Similarly, Polat [12] sought the opinions of the designers, contractors, and manufacturers on whether PCA compromises architectural creativity. The findings showed that 90% of manufacturers claim that PCA improves architectural creativity. In comparison, 71% of contractors and 62% of designers believe PCA somewhat compromises architectural creativity.

The budget plays a significant role in the precast concrete industry, influencing its operations and growth. However, several studies have shown that higher capital and initial investment costs are tremendously adverse to the development of precast construction in the long term [19–21]. Mao et al. [22] explored the budget of precast construction using several case study approaches. The findings show that the total cost of precast construction is substantially higher than that of traditional construction systems. On the other hand, Ye et al. [23] studied the budget of precast concrete structures while considering the constant budget changes through the implementation process. They established the risks affected by the cost using WSR (Wuli–Shili–Renli) principles. However, WSR does not supply standardized risk identification and category risks. The framework must show clear guidelines for systematically evaluating risks' significance or likelihood. The method's need for more standardization can result in deviations in risk assessment practices and hinder effective risk management across different projects or organizations.

Transportation is another factor affecting the use of the precast concrete systems. Both Glass Pepper [24] and Polat [12] argue that any transportation issues may negatively impact the utilization of precast concrete systems. There are different limitations associated with precast transportation. Abd El Fattah et al. [5] found that the maximum tolerable load on the truck and maximum existing truck length are some constraints experienced in Saudi

Arabia when transporting precast concrete. These limitations are significant and should be considered when selecting and designing precast concrete systems for the construction system. There is a direct association between the cost of transporting precast elements, the truckloads utilized to deliver, and the unit cost. Polat [12] stated that truckloads are majorly impacted by the size and weight of precast elements to be transported. Additionally, during delivery, the trucks' capacity affects the number of truckloads, while the distance between the construction site and the manufacturer's plant directly influences the unit cost. Moreover, Arditi and Murat Gunaydin [25] found that another limitation associated with precast transportation is the tolerable size and weight of loads that the carrying capacity of pavements and bridges permit and the vertical and horizontal clearances in underpasses and tunnels. Furthermore, the size or weight constraints stated by highway agencies are likely to limit designers' creativity by forcing them to keep the sizes of precast elements within the specified limits when designing structures with precast concrete. Jaillon and Poon [8] showed that higher transportation costs are among the significant economic limitations of precast concrete as compared to conventional construction systems.

2.2. Studies on Methods of Risk Analysis Dynamic Bayesian Networks (DBNs)

Many studies have utilized different methods in risk management, as shown in Table 1. The RII and ANN methods evaluate risks individually and do not consider interactions between risks. While the PLS-SEM method considers these interactions among factors during the evaluation, the methods listed in Table 1 do not consider the effect of these factors over time.

Table 1. Methods of risk management.

References	Methods	Field
[26]	Relative important index (RII)	Construction projects in the oil and gas sector
[27]	Artificial neural network	Pile construction risks
[28]	Agile methodology	Risks management of software projects
[29]	Partial least square-structure equation model (PLS-SEM)	Pile construction risks
[30]	RII	Risk assessment of time and cost overrun
[31]	PLS-SEM+RII	Pipeline project

DBNs act as an expansion of Bayesian networks (BNs) when variable dependencies are modeled over time [32]. BNs, as graphical models, exemplify probabilistic associations between variables, aiding cognition in uncertain circumstances. The DBNs are utilized for predicting, evolving, and analyzing intricate problems. DBNs can also be applied in different domains, such as robotics [33] and finance [34]. For instance, Wang et al. [35] explored the forms as well as the causes of offshore drilling accidents. The authors adopted the DBN analysis to calculate the drilling risk's prediction probability. In addition to this, Piao et al. [36] combined computer vision with DBN to recommend a dynamic risk assessment framework. This framework would be significant to the construction industry as it would enhance risk assessment efficiency and lessen the risk of staff falling from construction heights, since it can automatically detect data on onsite risk factors. Yuan et al. [37] used DBN and fuzzy theory models to show how fire accidents impacted gas and oil transportation and storage.

2.3. Knowledge Gap

Based on previous studies, few studies have considered the mutual influence of risk factors on precast concrete systems. However, more studies are required due to the difference in building systems from one country to another. So far as the authors know, no study has been conducted in the Kingdom of Saudi Arabia. The study was to discover common risk factors affecting the stages of precast buildings with their risk interdependencies using DBN. It also intended to investigate solutions to the cost and time impact to avoid it in the construction stages of precast buildings in Saudi Arabia. The study methodologies and data collecting were designed to achieve the following goals:

- To identify all risks associated with precast productivity, assuming quality would have a minimum impact.
- To assign these individual risks to their stages and find the impact of these risks per stage.

3. Methodology

The methodology of dynamic analysis of the precast construction process using DBN comprises five sequential steps, as shown in Figure 1, namely identifying risk factors from the reviewed literature and experts' opinions, creating interrelationships among risk factors based on experts' interviews, modeling the risk factors interrelationships by ISM, assessing the strength relationships among the factors based on the experts using a five-point Likert scale, establishing the conditional probabilities (CPs) of the risk factors by assessing of spontaneous probability (SP) and the transient probability (TP) of the risk factors using experts interview to generate interdependencies of the risk factors, utilizing MCS to develop a common of RIN-PCS, and implementing DBN analysis using the GeNle 4.0 program.

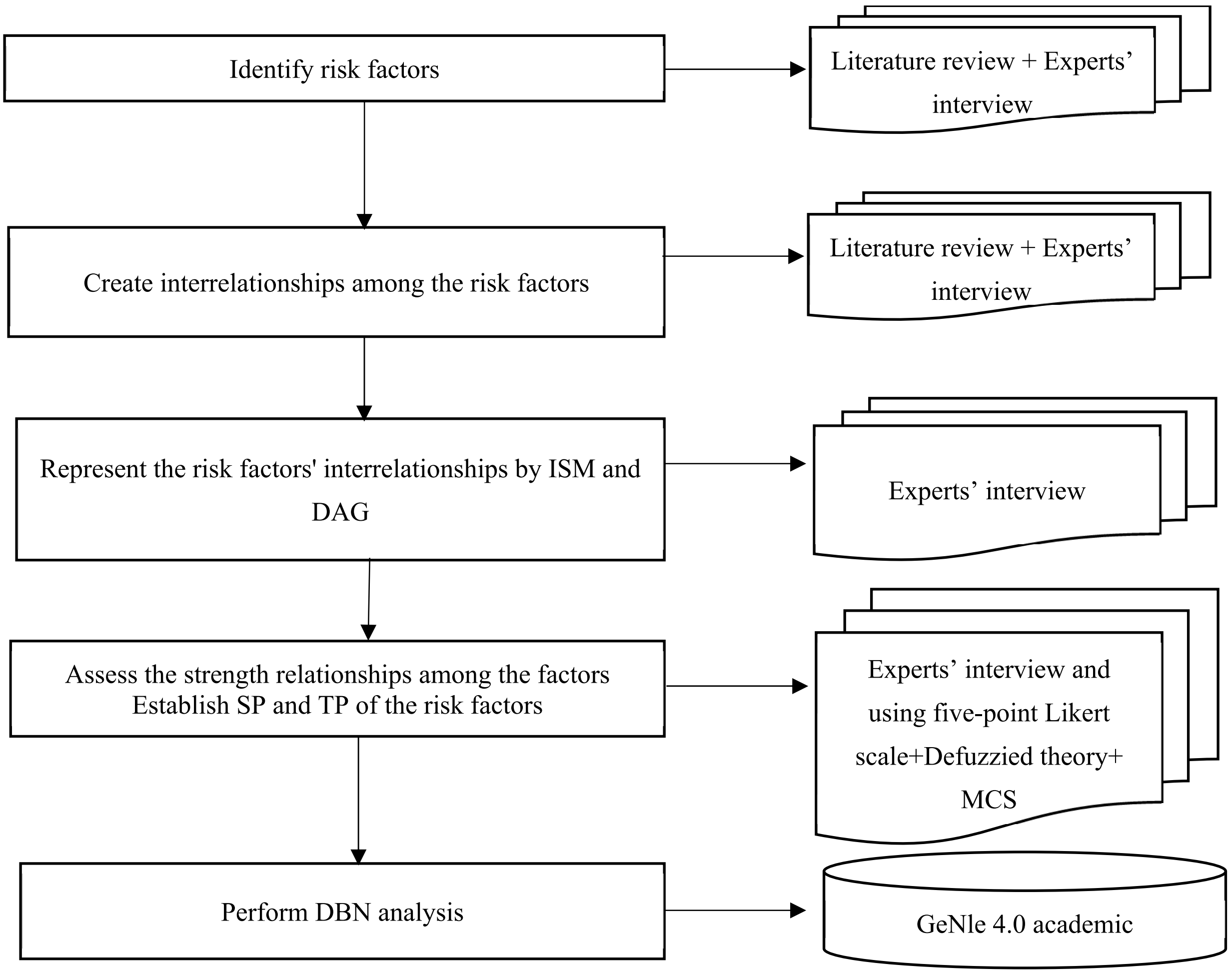

Figure 1. Methodology flowchart.

3.1. Identify Risk Factors

Risk factors were primarily identified by reviewing the existing literature concerning the factors that impact the use of precast concrete systems. The examined risk factors were gathered from several well-known academic construction management and civil engineering journals. The datasets utilized in this paper were Google Scholar, Web of Science, IEEE, ASCE, Springer, and Taylor and Francis. The number of keywords used to collect information was 12. Then, the most general words, such as bridges, highways, and construction projects, were excluded, and the focus was on the words that were most logical and closest to the search, such as precast concrete, factors, productivity, performance, and challenges, to improve the search results and narrow their scope. In addition, papers in English were included to collect the risk factors. The collected papers were original research papers published in journals and conferences from 2000 to 2024. Therefore, more than 300 research papers were collected, and after applying the filtering methods mentioned above, irrelevant research was excluded, and 60 research papers were obtained. Additional manual screening was performed to filter out items unrelated to the topic. The journal articles were published between 2010 and 2024. The identified risk factors were then arranged into categories. The brainstorming session was conducted using two methods. Some experts participated in person, while others attended online sessions. On average, each session lasted 45 min, and each expert was interviewed twice. The interviews were conducted individually, and the experts represented different companies and sectors. The 31 factors collected from the literature were presented in the brainstorming session to the professional experts. Based on their experience and knowledge of issues in the precast concrete market, the experts have eliminated many factors unsuitable for the local market. The elimination process relied on consensus among all experts. After thorough discussion, a threshold of 50% was established. Any risk that received less than 50% of the votes would be eliminated. In addition, they added some factors, such as inflation, dependent periods, dependence on other materials, transportation duration, and regulation requirements, as shown in Table 2, which also shows the fifteen risks with different stages of the precast processes.

In the precast concrete process, inherent risks related to project budget and inflation can occur during production, transportation, and construction. Budget projects and inflation risks can arise from increasing raw material and labor costs during production. The price of cement, aggregates, steel, and additives can fluctuate over time due to market conditions, supply and demand dynamics, and changes in global economic factors. Labor costs can also be subject to inflationary pressures, such as wage increases or changes in industry regulations. The transportation of precast concrete elements from the production facility to the construction site involves logistical considerations and associated costs. Inflation risks can arise from fuel price fluctuations, which impact transportation costs. Rising fuel prices can increase transportation expenses, affecting the overall project budget. In the construction phase, inflation risks may manifest due to changes in labor costs, equipment rental fees, and other construction-related expenses. Inflation can impact wages and salaries for construction workers, especially if there is a high demand for skilled labor or changes in labor market conditions.

Similarly, equipment rental costs can be subject to inflationary pressures influenced by equipment availability, demand, and maintenance expenses. The social and cultural impacts generally differ in the production, transportation, and construction stages. In the general stage, the risk factors are represented by stakeholder engagement and compliance with regulations related to cultural heritage. On the other hand, the production stage risk factors promote local workers' employment and implement robust health and safety measures. In the transportation and construction stages, the factors represent the development of comprehensive traffic management plans, and the design and implementation of precast elements that are consistent with the cultural context of the region.

Table 2. List of the risk factors through different stages.

Stages	Symbol	Factors	Reference
General	R1	Demand for megaprojects	[5,38]
	R2,1	Social and cultural impacts	[39–41]
	R3,1	Project budget	[5,38–40,42–45] and experts
	R4,1	Inflation	Experts
Predesign/initiating	R5,2	Planning and scheduling	[39,40,46,47] and experts
Design	R3,3	Project budget	[5,38–40,42–45] and experts
	R5,3	Planning and scheduling	[39,40,46–52] and Experts
	R6,3	Approval period	Experts
	R7,3	Coordination and integration among the professions	[38,40,47,50]
Production	R2,4	Social and cultural impacts	[39,40]
	R3,4	Project budget	[5,38–40,42–45] and experts
	R4,4	Inflation	Experts
	R8,4	Production capacity	[39,47,53,54]
	R9,4	Usage of workforce	[46,47,52,55,56]
	R10,4	Dependent on other materials	Experts
	R11,4	Site conditions	[57] and experts
	R12,4	Transportation duration and regulation requirements	Experts
Transportation Construction/closing	R2,5	Social and cultural impacts	[39,40]
	R3,5	Project budget	[5,38–40,42–45] and experts
	R4,5	Inflation	Experts
	R5,5	Planning and scheduling	[39,40,46–52] and experts
	R13,5	Erection productivity	[5,40]
	R14,5	Construction equipment	[40,46]
	R15,5	Site management and supervision	[39,40,47]

3.2. Create Interrelationships among the Risk Factors

The studies or sources regarding precast construction risk interrelationships were identified [23,58–61]. In addition, ten diverse experts were engaged in brainstorming sessions. Open discussions were encouraged to identify and discuss the potential interrelationships among risks based on the experts' collective knowledge and expertise. This collaborative approach assisted in uncovering hidden connections and dependencies. Expert judgment is mainly applied to accumulate experts' opinions about a subject when available data and information are insufficient. The ten experts were selected based on their familiarity with the major precast suppliers to enhance the accuracy of the evaluation results. The experts' qualifications were one Ph.D., two master's, and seven bachelor's in civil engineering, as shown in Table 3. They had more than ten years of experience in the precast construction field. Table 3 shows the demographic information of the ten experts. The initial interrelationships among the factors are shown in Table 4. For example, the probability of occurrence of factor R6,3 (R6 occurring stage) is impacted by R4,1, R5,3, and R7,3, as shown in Table 4.

Table 3. Experts' details and experience.

Expert #	Role	Sector	Qualifications	Years of Experience
1	Vice president (VP)	Precast company	Ph.D., civil engineering	25
2	Sales/contract manager	Precast company	Bachelor's degree, civil engineering/MBA	18
3	Structural engineer	Contractor	Bachelor's degree, civil engineering	18
4	Project manager	Consultant	Bachelor's degree, civil engineering/PE	15
5	Co-owner of a precast factory	Investor	Master, civil engineering	20
6	QA/QC manager	Precast company	Master, industrial engineering	15
7	Design manager	Precast company	Bachelor's degree, civil engineering/PE	30
8	Project manager	Real estate company	Bachelor's degree, civil engineering	18
9	Production manager	Precast company	Bachelor's degree, civil engineering	20
10	Project manager	Consultant	Bachelor's degree, civil engineering	20

Table 4. The risk factors' interrelationships.

Factor	R1			R2,1		R4,1	R5,2	R6,3		
Impacted by	R2,1	R3,1	R4,1	R1	R3,1	R1	R1	R4,1	R5,3	R7,3
Factor	R5,3					R7,3		R3,3		
Impacted by	R5,2	R6,3	R7,3	R3,3	R6,3	R5,3	R6,3	R5,3		
Factor	R5,4							R2,4		
Impacted by	R6,3	R5,3	R3,3	R8,4	R9,4	R3,4	R4,4	R8,4	R9,4	
Factor	R10.4		R3.4				R12,4 to:			
Impacted by	R5,4	R8.4	R4,4	R5,4	R8,4	R1	R7,3	R2,4	R11,4	
Factor	R4,4					R11,4				
Impacted by	R5,4	R8,4	R10,4	R3,4	R12,4	R1	R12,4			
Factor	R5,5									
Impacted by	R8,4	R3,4	R11,4	R12,4	R2,5	R4,5	R3,5	R13,5	R14,5	
Factor	R2,5						R4,5			
Impacted by	R12,4	R5,5	R3,5	R13,5	R14,5	R15,5	R5,5			
Factor	R3,5						R13,5			
Impacted by	R11,4	R5,5	R2,5	R4,5	R13,5	R14,5	R8,4	R10,4	R11,4	
Factor	R13,5						R14,5			
Impacted by	R12,4	R5,5	R2,5	R4,5	R3,5	R14,5	R15,5	R11,4	R12,4	
Factor	R14,5					R15,5				
Impacted by	R5,5	R4,5	R3,5	R13,5	R15,5	R5,5	R2,5	R13,5	R14,5	

3.3. Represent the Risk Factors' Interrelationships by ISM and DAG

The structure of DBN was created by transforming expert judgment of the risk factors into interpretative structural modeling (ISM). The ISM helps to develop a structural understanding of complex systems by identifying hierarchical relationships and dependencies among variables. Applying ISM can determine a precast system's order and hierarchy of risks. This structural understanding can then be used to construct a DBN, which models the temporal dependencies and probabilistic relationships among variables. The ISM was determined by expert judgment to find the causal and dynamic relationships between the risk factors. The dynamic relationship is a relation of the two risks at different stages. In contrast, the causal relationship is between two risks at the same stage.

The collected risk factors data recorded during the previous two steps, depending on the literature reviews and brainstorming sessions, was set as a matrix. Therefore, a matrix was created for the identified risk factors. The value of ISM was changed to 0 or 1 to represent the existing or non-existing relationships, respectively. Depending on the expert's judgment, the ISM of the risk factors is shown in Table 5. It is worth noting that the $R_{x\,y}$ represents the risk occurring in several stages, x is a serial number of risks, and y is a stage in which risk occurs. For example, R4,1 refers to the risk that (R4) will happen at stage 1. The experts discussed and judged the existing or non-existing relationships among the risks in different stages by setting the cell by 1 or 0, respectively. Then, the ten ISM matrices of the experts were collected. If more than half of the experts believed that there is a causal or dynamic relationship between risks, then the causal and dynamic relationships are represented by 1 in the ISM. In addition, the diagonal cells of the matrix represent the SP risk, and they were set as hidden cells.

Table 5. ISM of the risk factors based on the ten experts' judgments.

	R1	R2,1	R3,1	R4,1	R5,2	R6,3	R5,3	R7,3	R3,3	R5,4	R8,4	R9,4	R10,4	R2,4	R3,4	R4,4	R11,4	R12,4	R5,5	R2,5	R4,5	R3,5	R13,5	R14,5	R15,5
R1		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
R2,1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R3,1	0	1		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R4,1	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R5,2	0	0	0	0		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R6,3	0	0	0	0	0		1		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R5,3	0	0	0	0	0	0		1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
R7,3	0	0	0	0	0	1	0		0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
R3,3	0	0	0	0	0	0	1	0		1	0	0		0	0	0	0	0	0	0	0	0	0	0	0
R5,4	0	0	0	0	0	0	0	0	0		1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
R8,4	0	0	0	0	0	0	0	0	0	0		1	0	0	0	1	0	0	1	0	0	0	1	0	0
R9,4	0	0	0	0	0	0	0	0	0	1	0		0	1	0	0	0	0	0	0	0	0	0	0	0
R10,4	0	0	0	0	0	0	0	0	0	0	1	1		0	0	0	0	0	0	0	0	0	1	0	0
R2,4	0	0	0	0	0	0	0	0	0	0	1	0	0		0	0	0	1	0	0	0	0	0	0	0
R3,4	0	0	0	0	0	0	0	0	0	1	1	0	0	0		0	0	0	1	0	0	0	0	0	0
R4,4	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0		0	0	0	0	0	0	0	0	0
R11,4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	1	0	0	0	1	1	0
R12,4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1		1	1	0	0	1	1	0
R5,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	1	1	1	1	1
R2,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	1	1	0	1
R4,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	0
R3,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
R13,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0
R14,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1		1
R15,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	

DBNs are probabilistic graphical models representing causal and dynamic relationships among risks over time. DAGs are a fundamental component of DBNs. DAGs enable probabilistic reasoning in DBNs. Therefore, the ISM was utilized to derive the DAG, as shown in Figure 2. It should be noted that the symbol 1 indicates the order difference between the linked two risks, which is based on the difference in the order of the two risks' stages. In addition, the symbol (?) appears for each risk, which means the risk's PP value is unknown and will be computed by the program in the latter. Figure 2 presents the conditional dependencies between variables using conditional probability distributions. By specifying the CPs in the DAG, probabilistic inference can be performed to compute the likelihood of different risk scenarios and assess their probabilities over time. This process facilitates risk assessment, prediction, and decision-making under states of uncertainty.

Expert judgment is mainly applied to accumulate experts' opinions about a subject when available data and information are insufficient. The ten experts were selected based on their familiarity with major precast suppliers to enhance the accuracy of the evaluation results.

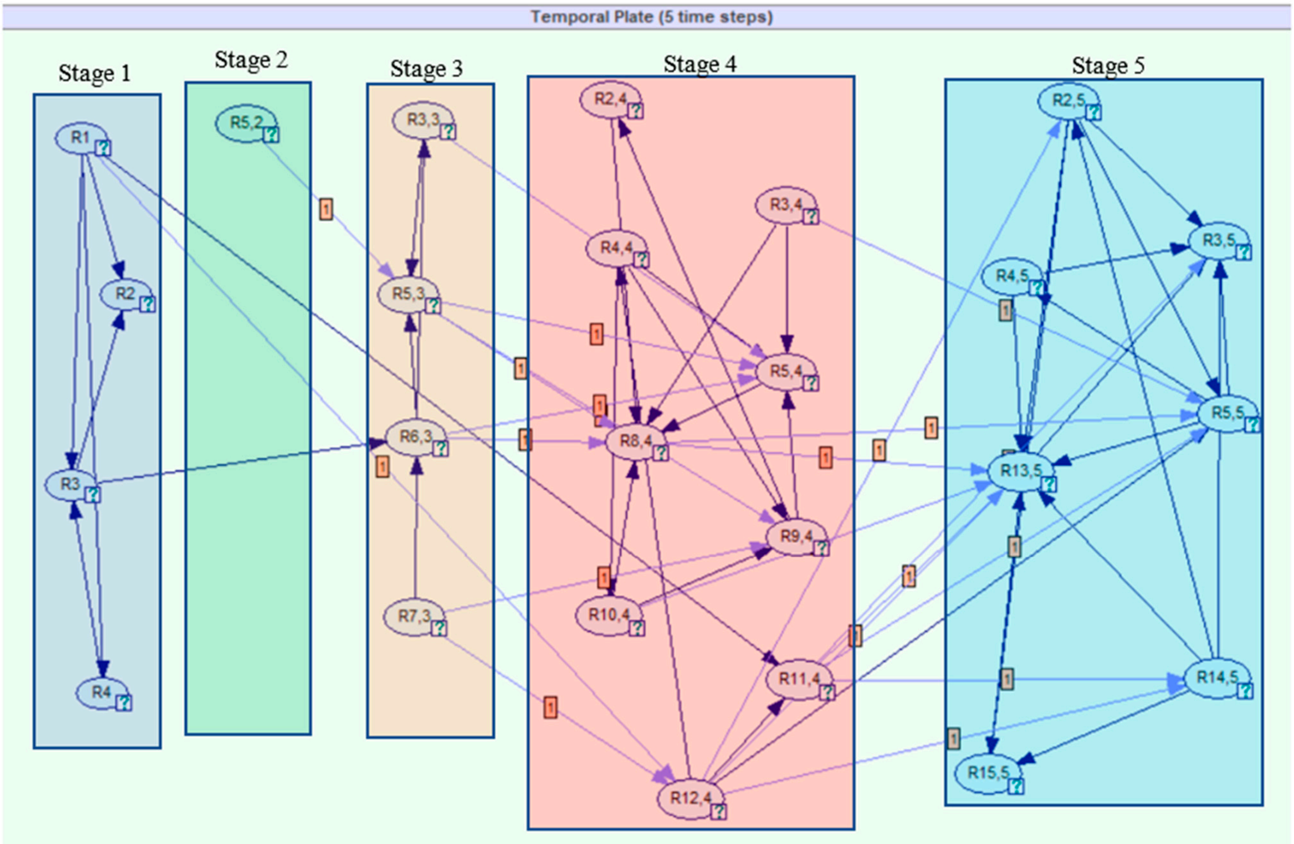

Figure 2. DAG of the precast construction risks.

3.4. *Assess the Strength Relationships among the Factors and Establish the SP and TP of the Risk Factors*

From Table 5, it is evident that there is a relationship between elements R_1 and $R_{2,1}$. In addition, the choice of 1 in their respective cell indicates that the two elements have an impact. However, it was impossible to determine whether the relation between these two factors is strong or weak. Then, the ten experts assigned the strength of the relation between the elements. A five-point Likert scale was utilized to determine the strength of the relationship between the risk factors. A value of 1 on the Likert scale denoted a meager strength, while 5 represented a solid relationship. Table 6 displays the strength relationships among the factors using a five-point Likert scale. Due to space limitations, Table 6 shows a portion of the overall results.

Table 6. Completed matrix showing the strength of relationships among the factors.

	R1	R2,1	R3,1	R4,1	…	R15,5
R1	2	2	0	5	…	0
R2,1	2	1	0	1	…	0
R3,1	0	0	5	0	…	0
R4,1	4	0	4	3	…	0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
R15,5	0	0	0	0	0	2

The risks were generally modeled as nodes in DBN and classified as root, intermediate, and leaf nodes. This paper's root nodes were R1 R7,3, R11,4, R15,5. The leave nodes were $R_{5,5}$, $R_{2,5}$. The remainder of the nodes were the intermediate nodes. The root node has only SP. On the other hand, the intermediate and leave nodes have SP and TP.

The expert response using the five-point Likert scale must be defuzzied to obtain the SP and TP of the root, intermediate, and leave nodes' risk. Every expert expressed their judgments about the probabilities of nodes by using a predefined set of linguistic variables. The linguistic variables then needed to be converted into a quantitative value. The trapezoidal fuzzy number clarified and quantified fuzzy descriptions with trapezoidal fuzzy numbers (y1, y2, y3, y4). The Likert scale points and their corresponding fuzzy numbers developed by Chen and Hwang [62] were chosen to determine the probabilities of all nodes to obtain this transformation criterion, as shown in Table 7, where the linguistic variables represent the likelihood of the risk occurring. This fuzzy number (y1, y2, y3, y4) could be computed into a p value using Equation (1) [62].

Table 7. Conversion of Likert Scale values to p values.

Linguistic Variables	Likert Scale	Trapezoidal Fuzzy Members *y*1, *y*2, *y*3, *y*4	*p*
Very low	1	0, 0, 0, 0.2	0.0167
Low	2	0, 0.2, 0.2, 0.4	0.1
Medium	3	0.3, 0.5, 0.5, 0.7	0.25
High	4	0.6, 0.0.8, 0.8, 1	0.4
Very high	5	0.8, 1, 1, 1	0.485

The values recorded in Table 6 were used with Equation (1) to calculate the p values. The calculations were repeated based on the number of experts who evaluated the strength of the risk (from one to five). In this study, ten experts evaluated the strength of each risk.

$$P = \frac{y_1 + 2y_2 + 2y_3 + y_4}{6} \tag{1}$$

Table 8 reveals the p-value results of the sample entry.

Then, the SP and TP values of the risk factors were obtained based on the judgments of ten experts. However, the data collected are relatively small. Monte Carlo simulation is a method that can be used to magnify a collected sample [63,64]. Therefore, a Monte-Carlo simulation (MCS) was used to simulate the state of the risks as normal distribution. The mean and standard deviation for each SP and TP risk factor given by the 10 experts were calculated with 500 simulations. The final values of the SP and TP of the risk factors are shown in Table 9.

Table 8. Sample entry recorded by one of the experts.

	R1	R2,1	R3,1	R4,1	...	R15,5
R1	0.1	0.1	0	0.485	...	0
R2,1	0.1	0.0167	0	0.0167	...	0
R3,1	0	0	0.485	0	...	0
R4,1	0.4	0	0.4	0.4	...	0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
R15,5	0	0	0	0	...	0.10

Table 9. The SP and TP values of the risk factors.

	R1	R2,1	R3,1	R4,1	R5,2	R6,3	R5,3	R7,3	R3,3	R5,4	R8,4	R9,4	R10,4	R2,4	R3,4	R4,4	R11,4	R12,4	R5,5	R2,5	R4,5	R3,5	R13,5	R14,5	R15,5
R1	0.11	0.26	0.38	0.24													0.08	0.11							
R2,1		0.25																							
R3,1		0.08	0.32			0.13																			
R4,1			0.36	0.21																					
R5,2					0.40		0.38																		
R6,3						0.22	0.33		0.24	0.35	0.43														
R5,3							0.44	0.38		0.33	0.18	0.05													
R7,3								0.33				0.35													
R3,3									0.39	0.29															
R5,4										0.38	0.30		0.33												
R8,4											0.47	0.41											0.43		
R9,4										0.31		0.31		0.16											
R10,4											0.46	0.30	0.37	0.00									0.32		
R2,4											0.21			0.04											
R3,4										0.39	0.45				0.04				0.26						
R4,4										0.12		0.21	0.14			0.04									
R11,4																	0.35		0.36			0.14	0.45	0.41	0.00
R12,4																0.33	0.27	0.26	0.32	0.18		0.00	0.35	0.35	
R5,5																			0.36	0.00	0.14	0.37	0.40	0.32	0.18
R2,5																			0.12	0.04	0.00	0.24	0.36		0.31
R4,5																					0.04	0.20	0.11	0.15	
R3,5																						0.14			
R13,5																						0.47	0.47		
R14,5																				0.26		0.43	0.45	0.35	0.32
R15,5																						0.00	0.28		0.13

3.5. Perform DBN Analysis

The DBN was used to assess the risks of precast production in different process stages. The program utilized to achieve this analysis was the GeNle program. The various risks were modeled as nodes inside the temporal plate to simulate the model of the different stages. The causal relationship was modeled as a link without setting the link order. On the other hand, the dynamic relationship was modeled with a link that placed its order. The value link order represents the difference in the stages of the nodes. For instance, R6,3 and R8,4 occur in the third and fourth stages. Hence, the order of the dynamic relationship between the two nodes was set as 1, as shown in Figure 2. The input data are the SP of the root nodes (risks) and the intermediate and leaf nodes' CPs.

3.5.1. Establish CPs of the Intermediate and Leaf Nodes

The CPs of any intermediate or leaf node depend on the SP and TPs of the node. Risk occurrence probability (ROP) can be computed based on probability theory, as shown in the following Equation (2) [63]:

$$ROP_{i,t} = 1 - \left[(1 - SP_i) \times \Pi_{k=1}^{n}\left(1 - TP_i^k\right)\right] \quad (2)$$

where $ROP_{i,t}$ is the risk occurrence probability of the *i*th factor, which occurs in the t stage, SP_i is the self-probability of the *i*th factor, TP_i^k is the transition probability of the *i*th factor and dependent on the k factor, *i* refers to a given factor, *k* is the influenced factor, and m is the number of factors influenced by the occurrence of the *i*th factor. The following example was explained. R12,4 and R3,4 influenced R4,4. The SP of R4,4 is 0.037. The TP values of R4,4 from R12,4 and R3,4 were 0.275 and 0.113, respectively, as shown in Table 9. There were four occurrence statuses of R4,4, as shown in Table 10. When R12,4 and R3,4 occurred (TRUE), the ROP of R4,4 was calculated as $ROP = 1 - [(1 - 0.037) \times (1 - 0.275) \times (1 - 0.113)] = 0.3806$, as shown in the red cell in Table 9. If R3,4 occurred but R12,4 did not, the ROP of R4,4 was computed as $OP = 1 - [(1 - 0.037) \times (1 - 0.00) \times (1 - 0.113)] = 0.1461$. as shown in the blue cell. The remainder of the ROP of R4,4 can be computed. Hence, the CP of all intermediate and leaf nodes can be determined in the above manner.

Table 10. The CP of R4,4.

R12,4	TRUE		FALSE	
R3,4	TRUE	FALSE	TRUE	FALSE
TRUE	0.308	0.3017	0.1461	0.0370
FALSE	0.6194	0.6983	0.8539	0.9630

3.5.2. Probabilistic Propagation

After calculating the SP and TP of all joints and determining the CPTs, the probability of the occurrence of the fifteen risks could be analyzed using probabilistic propagation. Probability propagation consists of an inference process between the root node and the leaf nodes, which could be used to evaluate the probability of each node. When new risks are obtained, probability propagation is used to update the probabilities of the risks in the network. This process involves applying the principles of conditional probability and Bayes' theorem to calculate the revised probabilities based on the observed evidence. Then, based on the results of probability propagation, the probabilities of different nodes can be obtained. The joints with a higher probability in each stage are considered critical risks. The software used for Probabilistic propagation is GeNIe 2.3, a tool developed for working with Bayesian networks. It is commonly used for building, analyzing, and performing inference on probabilistic graphical models. The software incorporates various techniques for probability propagation, including variable elimination and s junction tree algorithm. In the Genie 4 academic software, probabilities are computed based on the principles of probabilistic graphical models.

4. Results and Discussion

In this section, the results of the DBNs method for evaluating risk factors for precast concrete systems are presented and discussed, and these results are compared with the previous literature. In addition, proactive and precautionary measures were reviewed to mitigate the most important of these risks, based on experts' opinions.

4.1. Influence of CPs on the Risks

The CPs of the risks represent the interdependencies among the risk factors. The impact of the CP on the probability risk can be studied by examining the SP and PP of the risks in different stages. Figure 3 provides a graphical presentation of the PP and SP values of the risks. The PP and SP values were equal for root risks, such as R1, R5,2, R3,3, R7,3, and R3,4, as shown in Figure 3. These root risks have no CP value. In other words, there are no risk influences on these risks, as shown in Figure 4. On the other hand, the other risks are classified as intermediate and child risks. There are differences between the PP and SP for each of these risks (the intermediate and child risks), as shown in Figure 3. The difference between the PP and SP increases due to two reasons. The first reason is the increasing number of CPs affected by the risk. For example, the number of CP influence on the R13,5, R8.4, R5,4, and R3,5 are 9, 6, 6, and 6, respectively, as shown in Figure 4. The differences between the PP and SP for the above risks were 0.409, 0.272, 0.302, and 0.585, respectively, as shown in Figure 3. These difference values represent 87%, 58%, 79%, and 430% of the SP values of R13,5, R8.4, R5,4, and R3,5, respectively. Therefore, the CP value significantly impacts the probability of the factors. On the other hand, the second reason for the increasing difference between PP and SP is attributed to the higher value of the CP that affected the risk. For instance, the number of CP of R2,5 was only two factors (R12,4 and R14,5), as shown in Figure 4. However, the difference between the PP and SP of the R2,4 was significant (0.18). The PP values of R12,4 and R14,5 were 0.343 and 0.521, respectively, as shown in Figure 3. Therefore, the interdependencies among the risks in terms of causal and dynamic relationships have to increase the probability of risks, especially in the risks that happened in the intermediate and final stages, as shown in Figure 3.

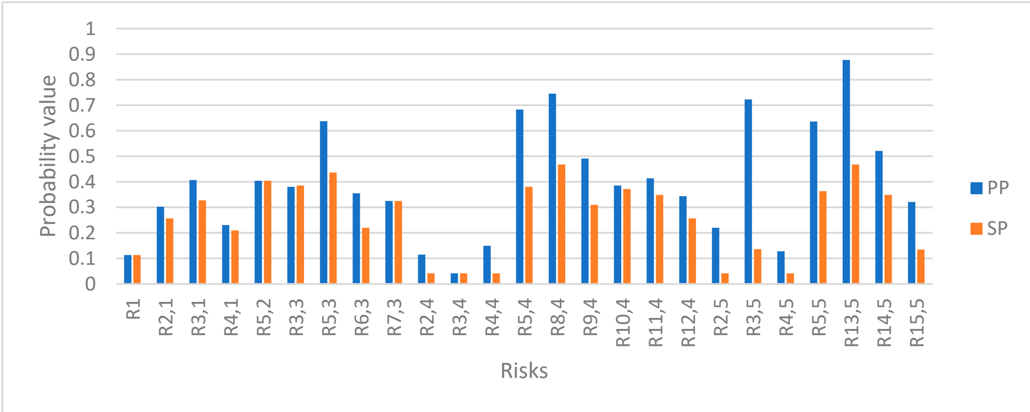

Figure 3. The SPs and PPs of the risks.

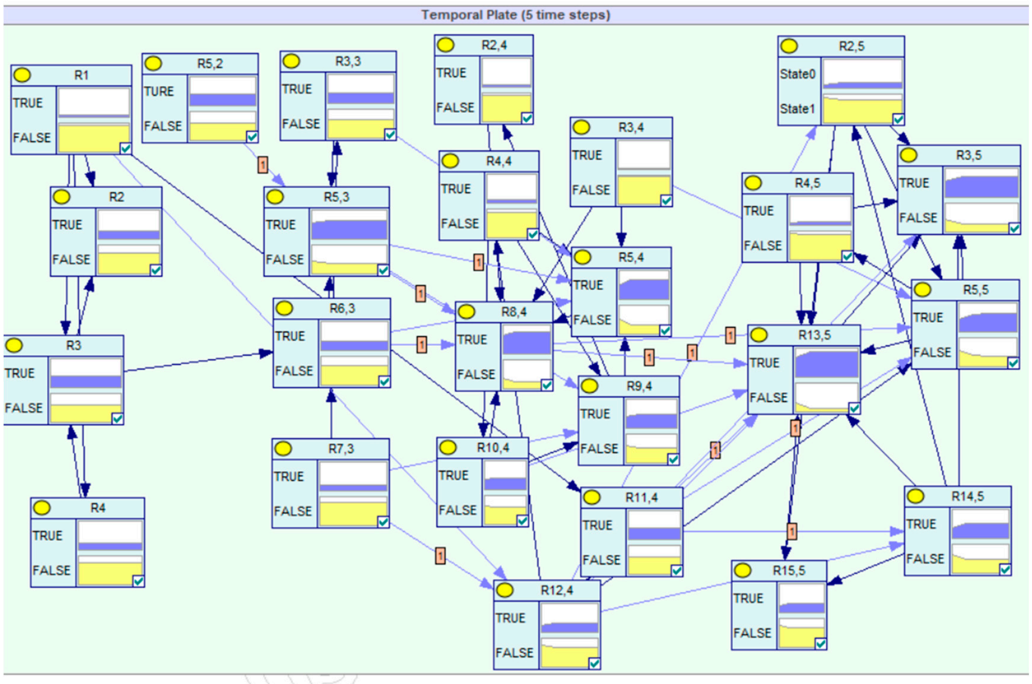

Figure 4. Interrelationships and probability of the fifteen precast construction risks.

4.2. Classification of the Risk Probability

The authors classified the risk probability based on the PP values and the Pareto charts into high, medium, and low. The PP value ranges from 0.042 (R3,4) to 0.877 (R13,5), as shown in Figure 3. The three limit values that separated the high and medium levels and those that separated the medium and low levels were 0.6 and 0.4, respectively. Thus, the risks with high probability levels were R13,5, R8,4, R3,5, R5,4, R5,3, and R5,5, as shown in Figure 5, which provides the ordered risks based on the PP values. In addition, the medium risks with PP values more than 0.2 and less than 0.4 were R14,5, R9,4, R11,4, R3,1, R5,2, R10,4, R6,3, R12,4, R7,3, R15,5, R2,1, R4,1, and R2,5. On the other hand, some medium risks may have a small influence on the other risks and may be categorized as being low-risk. On the other hand, some moderate risks may have little impact on other risks and may be classified as low-risk. The Pareto chart method was utilized to divide the medium-risk zone, as shown in Figure 5. The pattern of 20/80 was considered. Thus, 80% of the cumulative PP was utilized as the threshold value to divide the low risks from medium risks, as shown in Figure 5. Therefore, the modified medium risks were R14,5, R9,4, R11,4, R3,1, R5,2, R10,4, and R6,3. The remainder of the risks were classified as low risks. A proactive maintenance approach is crucial to mitigate the implications of air leakage. This procedure includes regular inspections to identify and seal leaks, proper sealing techniques, and periodic testing of the air distribution system's integrity. Additionally, implementing duct insulation, sealing terminal units, and optimizing system design can help minimize air leakage. By addressing air leakage issues, the HVAC system can operate more efficiently, provide better indoor air quality, reduce energy consumption, and prolong the lifespan of the equipment.

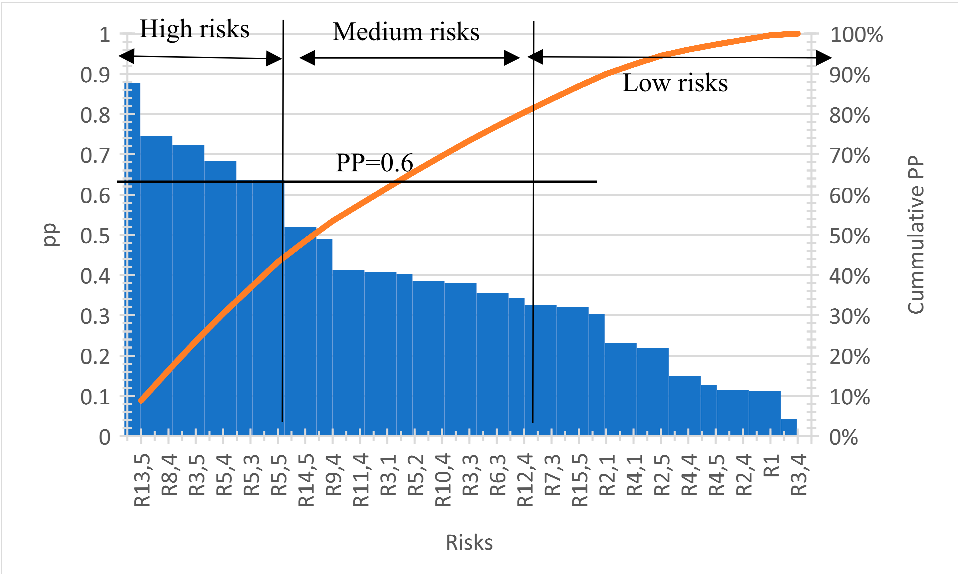

Figure 5. Pareto chart of the risks.

5. Discussion

This section discusses the influence of high-risk probability on precast industry systems and provides solutions to mitigate the influence of those risks. In addition, the section discusses the main contrast between this paper's results and previous studies and supplies the rationale interpretation for this contrast.

For the highest risk probability, R13,5, erection productivity carries the highest PP value of 0.75. Precast concrete components are typically large and heavy and require specialized equipment for installation. The erection process involves precise coordination, lifting operations, and alignment of components. Any inefficiencies or errors in the erection process can lead to delays, rework, or compromised structural integrity, impacting productivity. Moreover, efficient and safe precast concrete erection requires skilled labor with expertise in handling and installing precast components. The availability of trained and experienced erection crews can influence productivity. Insufficiently skilled labor or inadequately trained workers may result in slower installation rates, errors, and potential safety hazards, affecting overall productivity. This risk factor can be attributed to various factors that impact erection productivity, like the number of elements erected daily. Production productivity directly influences erection productivity. The absence of elements at the construction site results in idle cranes and workers, thereby leading to additional costs [65]. To minimize the risk associated with erection productivity, production capacity should be determined based on construction capacity to ensure an adequate supply of elements at the construction site. To maintain production capacity, design teams must adhere to planned drawing issuance, as highlighted in risk factor 5, which remains significant at each project stage. The risk factor of production not meeting planned targets can be minimized by addressing these considerations, including synchronization between design and production, monitoring material availability, and aligning production capacity with construction needs.

Regarding high group risk factors, the risk factor of production capacity that occurs at stage 4 (R8,4) is classified as high-risk with a PP value of 0.745, as shown in Figure 5. Precast concrete manufacturing involves the production of large and complex components off-site. If the production capacity is limited, it can result in delays in manufacturing, project bottlenecks, and potential schedule disruptions. More production capacity is needed to meet project demands, especially for large-scale or time-sensitive projects. It is evident from Figure 4 that the planning and scheduling at stage 4 (R5,4) and stage 5 (R5,5) directly impact production capacity (R8,4). R8,4 is crucial because it facilitates the alignment of construction activities with respective schedules. Precast concrete projects often have strict time constraints, requiring precise coordination between manufacturing, transportation, and installation activities. If the production capacity is inadequate to meet project schedules, it can delay the delivery of components to the construction site. These delays can impact the project timeline and potentially result in financial penalties or contractual disputes. According to Yuan et al. [66], their modified scheduling method enhances production scheduling as it leads to an 81.6% reduction in the cost of production. Several measures should be put in place to ensure that production takes place according to the laid-down plan. First, the design phase should stick to the recognized plan. This procedure includes timely issuing of fabrication drawings and ensuring that all embedded items are ready at the factory [66]. The risk factor of the project budget at stage 4 (R3,4) impacts the risk of production capacity (R8,4) in precast concrete projects, as shown in Figure 4. Adequate production capacity requires investment in manufacturing facilities, equipment, and infrastructure. These capital expenditures contribute to the project budget. If the project budget is insufficient or constrained, it may limit the ability of companies to invest in the necessary production capacity. This risk factor can lead to underinvestment in manufacturing capabilities, resulting in limited production capacity and potential bottlenecks. The project budget is crucial in resource allocation, including allocating funds for labor, equipment, raw materials, and other production-related expenses. Greater budget allocation is needed to ensure the availability of these resources, which will impact production capacity. For example, insufficient funds may exist to hire skilled labor or purchase additional equipment to expand production capacity, so this should be remedied.

Additionally, the risk of being dependent on other materials at stage 4 (R10,4), such as those for maximum design and reinforcement suppliers, should be obtained in time. Monitoring the number of cast elements compared to the planned quantity on a weekly basis is also crucial. Lastly, effective communication between the production and design teams, the presence of skilled workers, and quality assurance/quality control (QA/QC) procedures contribute to successful production and on-time delivery. In addition, precast concrete manufacturing relies on various materials, such as aggregates, cement, admixtures, reinforcement bars, and molds. If there is a dependency on specific materials essential for production, any disruptions or delays in the availability of these materials can hinder manufacturing processes. Insufficient availability of materials can lead to production delays, reduced production capacity, or even temporary shutdowns.

To minimize and mitigate the risk factor of production capacity (R8,4), risk factors, such as the planning and schedule of the project, the project budget, and anticipated demand (dependent on other materials), should be considered. This procedure will help ensure that the production capacity is aligned with project requirements, minimizing the risk of insufficient capacity. Lean manufacturing principles and process optimization techniques should be implemented to improve production efficiency and maximize output. Analyzing the production workflow, identifying bottlenecks, and implementing measures should be carried out to streamline processes, reduce waste, and improve overall productivity. This process can include optimizing material handling, improving equipment utilization, and implementing standardized procedures. Contingency plans should be developed to address unforeseen disruptions or emergencies that could impact production capacity. The plans should consist of identifying backup suppliers, establishing alternative production sites, and creating redundancy in critical equipment. Containment plans can help mitigate the impact of unexpected events and maintain production continuity.

The project budget (R3,5) at stage 5 (transportation, construction, and closing) is considered a high risk. Precast concrete projects involve various costs, including material procurement, manufacturing, transportation, and installation. If the budget is not accurately estimated and managed, there is a risk of cost overruns. Unexpected increases in material prices, changes in project scope, or unforeseen challenges during construction can result in budgetary constraints and potential financial risks. In addition, precast concrete projects often involve subcontractors for specialized tasks, such as crane operations, site preparation, and installation. Insufficient budgetary provisions for subcontractor costs can lead to difficulties in securing qualified subcontractors or delays in project execution. Adequate budgetary allocations are necessary to ensure subcontractor expenses are accounted for, reducing the risk of project delays or quality issues.

The risk factor of planning and scheduling (R5) in stages 3, 4, and 5 is a high risks in precast concrete projects, as shown in Figure 5. Precast concrete projects involve multiple stakeholders, including architects, engineers, contractors, suppliers, and subcontractors. Coordinating the activities and timelines of these diverse entities requires meticulous planning and scheduling. Failure to plan and schedule tasks effectively can lead to miscommunication, delays, and inefficiencies, impacting project progress and overall timelines. Moreover, precast concrete projects typically involve interdependent activities, from design and manufacturing to transportation and installation. Each stage relies on the successful completion of the preceding one. Inadequate planning and scheduling can disrupt the flow of activities, causing delays, rework, and additional costs. Timely coordination of tasks is crucial to ensure smooth transitions between project phases. Planning and scheduling directly impact resource allocation, including labor, equipment, materials, and finances. Inadequate planning can result in resource shortages, inefficient utilization, and increased project costs. Effective planning considers resource availability, mobilization, and optimization to ensure the project progresses as planned. There is a need to strictly adhere to planning and scheduling when using precast elements because this construction method allows for the simultaneous completion of multiple tasks. The subsequent phases depend on the design phase; thus, planning and scheduling are crucial. All procedures should be completed within the expected timeframe.

Similarly, the production phase should run concurrently with the design phase in line with the project schedule. A smooth production phase is characterized by the progression of fabrication drawings as premeditated, the availability of embedded materials at the factory, following the assigned mold numbers, and quality control (QC) focusing on initial casts and conducting random checks to expedite the casting process—the construction phase typically banks on the elements obtained after the production phase. Wang et al. [65] pointed out that late delivery of precast elements dramatically contributes to the extension of the construction period and increases the cost of labor. During the construction phase, it is essential to ensure the readiness of all cranes and to provide the construction team with the latest approved construction drawings to facilitate smooth operations. Any delays in the foundation can result in erection delays for the precast elements.

Regarding the discussion of the contrast comparison results, R15,5 represents site management and supervision; the results reveal that the PP of that risk is 0.0.32 (shown in Figure 3), categorized as low-risk. On the other hand, the results of Ye et al. [23] revealed that poor management plays a significant role in the cost of prefabricated buildings. The contrast in the role of the management is attributed to the difference in the definition and scopes of the prefabricated and precast buildings. A prefabricated building is constructed using premanufactured components or modules manufactured off-site and then transported to the construction site for assembly. It encompasses various construction systems, including steel frame structures, modular buildings, and panelized construction. This system requires several contractors between manufacturing and installation. Therefore, high management attention is required in the prefabricated building system. On the other hand, precast concrete building specifically refers to a structure where the primary structural components, such as walls, columns, beams, and slabs, are manufactured in a controlled environment (precast industry) and then transferred to the construction site for installation. The precast concrete system requires one contractor to administrate several processes, including manufacturing and installation. Hence, the management risk is low in that system.

6. Conclusions

Precast construction provides significant advantages to contractors as well as designers. With the vast growth and expansion of Saudi Arabia's construction industry, there is an increased demand for public homes, project homes, and residential buildings. As a result, these projects have attracted developers and designers who find precast concrete systems attractive to investors because they are time-efficient and cost-effective. The earlier studies did not consider the interdependencies between precast concrete construction risks and various process phases. This study used DBN to dynamically analyze the risks associated with precast construction in Saudi Arabia. The methodology comprised sequence steps. The first step represents gathering all the risk factors from the literature review. The second step is the assessment and classification of the collected risk factors into five production stages. Several structured interviews with ten experts with ten years of precast industry experience carried out this process. The ISM and DAG among the risk factors were performed based on the ten expert judgments. The risk factors were classified into root, intermediate, and leaf risks. The experts assessed the SP and TP for these risks. Then, MCS was utilized to consider the SP and TP of the risks as a normal distribution. After that, the intermediate and leaf risks' CP was calculated based on their SP and TP values. The SP of the root risks and the intermediate and leaf risk CP values were used as input data in the GeNIe program. The primary findings showed that the erection production (R13,5), production capacity (8,4), and project budget (R3,5) are the highest risks of the precast concrete system, with PP values of 0.87, 0.745, and 0.72, respectively.

Moreover, the risk of planning and scheduling at stages 3, 4, and 5 are high-risk areas. On the other hand, the probability value of the site management risk factor is minimal, at 0.32. This paper can help optimize the construction timetable for projects involving precast concrete. The paper highlights that assessing the interdependencies among factors in the precast concrete industry produces better results than considering individual risk analyses alone. The paper also indicates that comprehending precast construction factors' interdependencies can support optimizing construction schedules. By identifying and evaluating potential risks, stakeholders can design adequate risk management strategies, allocate resources appropriately, and establish realistic project timelines. The research findings might help to evaluate and enhance the quality control procedures used to build precast concrete structures. This study is limited to the risk factors of precast concrete in Saudi Arabia. The study aims to recognize and highlight the most common risks that interdepended with other risks several times during the precast concrete process. The paper limited itself to the factors that influenced the line production of the precast concrete elements and did not consider external factors, such as bad weather and earthquakes. Therefore, future studies should be extended to deal with the management of these risks. In addition, future studies will be required to capture the risks of other types of prefabricated buildings, steel structures, and prestress structures.

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