A BAYESIAN NETWORK MODEL FOR QUANTIFYING THE COST IMPACTS OF CLAIM CAUSES IN BUILDING PROJECTS

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Abstract: Claims are a troublesome issue and often result in adverse consequences in construction projects. Claims stem from various causes. Even though these causes may or may not finally lead to claims, they still affect certain project objectives such as project cost, time, and quality. Thus, it is necessary to develop a tool that can assess the impacts of claim causes during project execution. In this paper, we quantify the cost impacts of claim causes in building projects using a Bayesian network (BN) model. Claim causes were first compiled by a comprehensive literature review and were then verified by a group of nine experts. Face-to-face interviews with the experts were conducted to define the cause-and-effect relationships among 13 claim causes, which were in turn used for developing a BN model. An ordinal scale was established for rating the cost impact of each claim cause, which is expressed by a cost overrun level of building projects. Through a structured questionnaire survey, the historical data of claim causes in 112 building projects were gathered to demonstrate the proposed model. The results show that the proposed BN model can be used to predict the cost impact levels of claim causes along with their associated probabilities. The proposed model can characterize critical claim causes in building projects, which can subsequently be used to choose appropriate response measures.

Keywords: Bayesian network model, Building projects, Construction claims, Claim causes, Claim responses.

1. INTRODUCTION

The construction industry has been witnessing a sharp rise of claims in terms of both frequency and severity (Apte & Pathak, 2016). Zaneldin (2006) reported that 35% of the construction projects in the United Arab Emirates (UAE) encountered claims. Although claims are sometimes necessary and can be settled in a non-confrontational manner (Kumaraswamy, 1997), for other times claims can lead to negative effects such as cost overruns and schedule delays (Apte & Pathak, 2016; Khahro & Ali, 2014). Noticeably, if claims are not settled amicably, they may lead to disputes, which often contribute to project failure, loss of time and money, and jeopardize the relationships among project participants (Cheung et al., 2001; Cheung & Pang, 2013). Construction disputes cost the United States $43.4 million and last 14.8 months on average (Arcadis, 2018).

Several research works have focused on the quantification of claim severity, including the cost impacts of claims. For example, Semple et al. (1994) performed a content analysis on 24 construction claims submitted by the Canadian contractors and concluded that half of them were above 30% of respective contract sums. It is worth noting that most of the previous studies have approached claims from a reactive perspective, rather than a proactive perspective. Specifically, a limited amount of studies investigated the interdependences among claim causes to predict the cost impacts of claim causes during project execution (Likhitruangsilp et al., 2022).

In this paper, we quantify the cost impacts of claim causes in building projects using a Bayesian network model. This study focuses on building projects (e.g., residential or housing, office, hospital, and hotel) recently completed in Vietnam. The results can be used to predict the severity levels of claim causes in terms of cost, thereby we can prepare appropriate strategies to prevent or mitigate their likelihood of occurrences and consequences.

2. BACKGROUND

2.1 Cost Impacts of Claims

Costs associated with claims are often substantial (Olanrewaju & Anavhe, 2014). The average cost growth caused by claims was about seven percent of the original contract value in the US and Thailand (Sakate & Dhawale, 2017). The 18 percent of the contract sum was paid to contractors as claim fees in Portugal (Moura & Teixeira, 2007). The 50 percent of claims constituted 30% of the original contract price, and 33 percent of claims amounted to at least 60% of the original contract price (El-Adaway & Kandil, 2009). In some cases, the claim costs were as high as the original contract prices (Cheeks, 2003).

2.2 Cost Impacts of Claim Causes

Even though claim causes may or may not finally lead to claims, they still affect certain project objectives such as project cost, time, and quality. This depends on the claim causes' impact levels in each circumstance and

the relationships between contractors and owners. Predicting and recognizing the cost impacts of claim causes may help contractors plan their work related to claim causes better. For example, they can adequately allocate or reserve their budgets resulting from the project owners' delay in payment. If contractors submit a claim, they may sufficiently prepare an evidence (e.g., documents) to show their losses and damages of events causing claims.

2.3 Bayesian Networks

Bayesian networks (BNs) are directed acyclic graphs (DAG) used for descriptive and predictive purposes (Jensen, 2001). BNs can visually represent probabilistic cause-and-effect relationships among a set of random variables (Heckerman, 1997), including dependencies and independencies, which are closely aligned with real-world conditions (McCabe et al., 1998). For causal modeling, a BN is the best-fit methodology (Sharma et al., 2019).

Figure 1 shows an example of a BN. Nodes in the BN represent probabilistic variables. Root nodes (RN) are the nodes without any parent node, whereas leaf nodes (LN) are the nodes without any child node. Directed edges from a parent node to a child node depict the interdependences or causal relationships among variables (Guan et al., 2020).

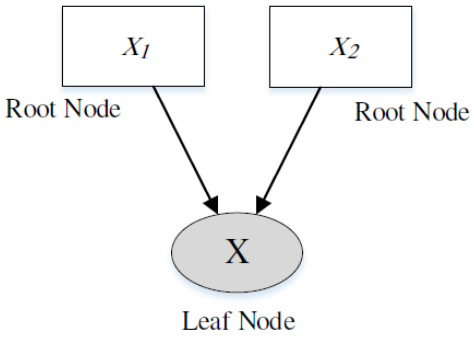


Figure 1. A Bayesian network with a directed acyclic graph (DAG) and causal relationships among nodes (Mohamad & Tran, 2021)

Bayes' theorem is the basis of the Bayesian approach. Assuming X and Y are two random events, then Bayes' theorem presenting the conditional probability dependencies among variables (Cárdenas et al., 2014) can be expressed by Equation (1):

$$P(X \mid Y) = P(Y \mid X) \times P(X) / P(Y) \quad (1)$$

where $P(X)$ and $P(Y)$ are the probabilities of X and Y, respectively. $P(Y|X)$ is the probability of Y given X. $P(X|Y)$ is the probability of X given Y.

3. RESEARCH METHODOLOGY AND RESULTS

Figure 2 depicts the five steps of this study. The details and results of each step are as follows.

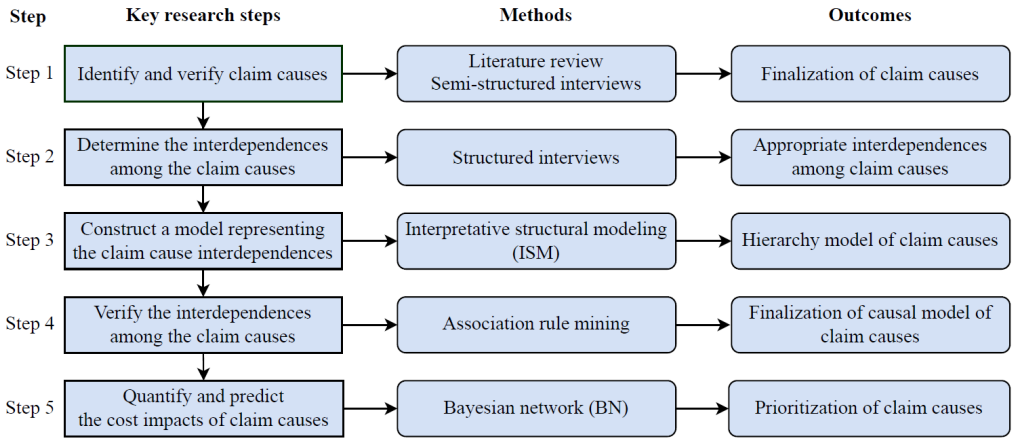


Figure 2. Research methodology

3.1 Identify and Verify Claim Causes

A comprehensive literature review was carried out to identify the preliminary list of claim causes by focusing on the claims made by contractors against owners during the construction phase in building projects. Semi-structured interviews were then conducted with nine claim experts with at least 10 years of experience in claim management to verify the list. Some claim causes were removed from the list due to their low frequency and lack of basis to claim, whereas some were combined because they share the common meanings. Table 1 shows 13 claim causes in this study.

Table 1. Potential claim causes

Code	Claim cause	Sources
CC01	Issues related to site possession	[1], [2], [3], [4], [5], [6], [9]
CC02	Issues related to inadequate documents	[1], [3], [4], [6], [7], [8], [11]
CC03	Change orders by owners	[1], [2], [3], [4], [5], [6], [7], [8], [10], [11]
CC04	Third-party interferences	[1], [3], [6]
CC05	Owner's delay	[1], [2], [3], [5], [6], [7], [8], [9], [10], [11]
CC06	Owner's procurement of material or equipment	[1]
CC07	Owner's failure to obtain licenses/permits	[1], [9], [10], [11]
CC08	Issues related to payment	[1], [2], [3], [5], [6], [7], [8], [10]
CC09	Termination/suspension of works	[1], [2], [3], [4], [6], [7], [8], [9], [10]
CC10	Differing site conditions	[1], [2], [3], [5], [8], [10], [11]
CC11	Unexpected increase in or escalation of material, labor, and equipment prices	[1], [3], [4], [6], [7], [8], [9], [10], [11]
CC12	Acts of God	[2], [3], [4], [9], [11]
CC13	Issues related to delivery/completion of work	[1], [9]

Sources: [1] Jalal et al. (2019), [2] Stamatiou et al. (2019), [3] Mishmish & El-Sayegh (2018), [4] Bu-Bshait & Manzanera (1990), [5] Cheung & Yiu (2006), [6] Enshassi et al. (2009), [7] Assaf et al. (2019), [8] Zaneldin (2018), [9] Yousefi et al. (2016), [10] Olanrewaju & Anavhe (2014), [11] Levin (2016)

3.2 Determine the Interdependences among the Claim Causes

The structured interviews with the previous nine experts were performed to identify the interdependences among the claim causes by construction contractors against project owners. A structured questionnaire, which is partially presented in Table 2, was used to support the experts in selecting an appropriate relationship between any two claim causes *i* and *j* (by ticking in the check box (☒)). The final relationship between any two claim causes was the one agreed by most of the experts. The guideline was provided in the questionnaire as follows.

- O means that claim cause *i* and claim cause *j* are not related.
- V means that claim cause *i* may lead to or influence claim cause *j*.
- A means that claim cause *j* may lead to or influence claim cause *i*.
- X means that claim cause *i* and claim cause *j* may lead to or influence each other.

Table 2. A structured questionnaire to determine the interdependences among the claim causes

Claim cause '*i*'	O	V	A	X	Claim cause '*j*'
Site possession	☐	☐	☐	☐	Inadequate documents
Site possession	☐	☐	☐	☐	Change orders by owners
Site possession	☐	☐	☐	☐	Third-party interferences
Site possession	☐	☐	☐	☐	Owner's delay
Site possession	☐	☐	☐	☐	…
Site possession	☐	☐	☐	☐	Delivery/completion of work

3.3 Construct A Model Representing the Claim Cause Interdependences

Based on the relationships among the claim causes determined in the previous step, interpretative structural modeling (ISM) was employed to construct a model which represents the interdependences among claim causes. ISM is a technique that can be used to establish the causal relationships among variables based on experts' opinions (Rezaee et al., 2019; Ruiz-Benitez et al., 2018). ISM processes can be found in Etemadinia & Tavakolan (2021) and Viswanathan et al. (2020). The ISM model in this study consists of 60 causal relationships among the claim causes.

3.4 Verify the Interdependences among the Claim Causes

Since the number of causal relationships in the ISM model is relatively large, the lift indexes of association rule mining (ARM) were calculated to check the reliability of interdependences among the claim causes. To achieve this, a questionnaire survey was conducted to collect the data related to claim causes from past building projects. There is a question in the questionnaire to determine the 'occurrence' or 'no occurrence' of each claim cause in the building projects in which the respondents were involved. The survey data was then encoded into values of "1" and "0" to support calculating lift indexes. The median value of lift indexes was considered a threshold to eliminate the weak-association relationships. Finally, 13 claim causes and 30 corresponding causal relationships were concluded, as displayed in Figure 3.

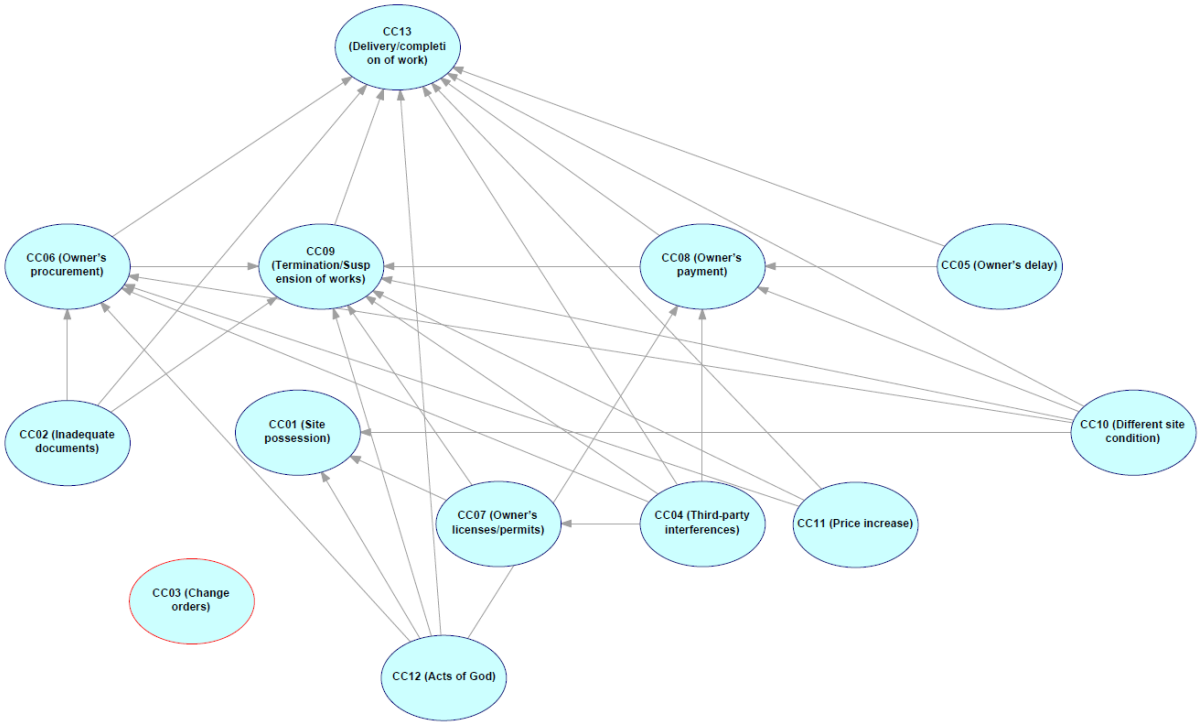


Figure 3. Refined ISM model

3.5 Quantify and Predict the Cost Impacts of Claim Causes Considering the Interdependences

In this step, we created a BN model of the claim causes considering their interdependences from the refined ISM model. Transforming an ISM model into a BN model is based on two main assumptions. First, a BN is a directed acyclic graph (DAG); that is, there is no cycle (Cinar & Kayakutlu, 2010). Thus, the cycles which exist in the ISM model must be eliminated while transforming it into a BN model. Another critical assumption is conditional independence. BN is an independence map, which guarantees that separated variables are conditionally independent given other variables. In the ISM model, A -> B -> C refers to the effect of A on B and the effect of B on C, so there is an indirect effect of A on C. In the BN model, A is relevant to C, but if we know the true state of B, knowledge of A is irrelevant to C. So, C and A are conditionally independent given B (Cinar & Kayakutlu, 2010). Thus, the procedure needs to eliminate indirect relationships between claim causes. For this purpose, the direct and indirect relationships between claim causes are first identified. Then, the indirect effects should be eliminated (Cinar & Kayakutlu, 2010). In this paper, a total of 13 indirect relationships were eliminated, and the remaining 17 relationships were taken into the BN model.

In the questionnaire, a five-point ordinal scale was used to assess the impact level of each claim cause in terms of cost (cost overrun percentage). The scale ranged from 1 to 5, where 1 means very low (cost overrun $\leq$ 0.05%), 2 means low (0.05%<cost overrun $\leq$ 0.1%), 3 means moderate (0.1%<cost overrun $\leq$ 0.25%), 4 means high (0.25%<cost overrun $\leq$ 0.5%), and 5 means very high (cost overrun>0.5%).

To construct a BN model, we used software GeNIe Academic Version 4.0.2304.0 by "BayesFusion, LLC" (http://www.bayesfusion.com/). Data of claim causes' cost impact levels were encoded and input into the BN model. The five-point ordinal scale of cost impact is encoded by using the following rules: "1" (very low) and "2" (low) are changed into "1" (low), "3" (moderate) is changed into "2" (changes value but still remains moderate level), whereas "4" (high) and "5" (very high) are changed into "3" (high). Finally, each claim cause consists of three cost impact states (i.e., low, moderate, and high). Each state provides its corresponding probability. Figure 4 shows the BN model.

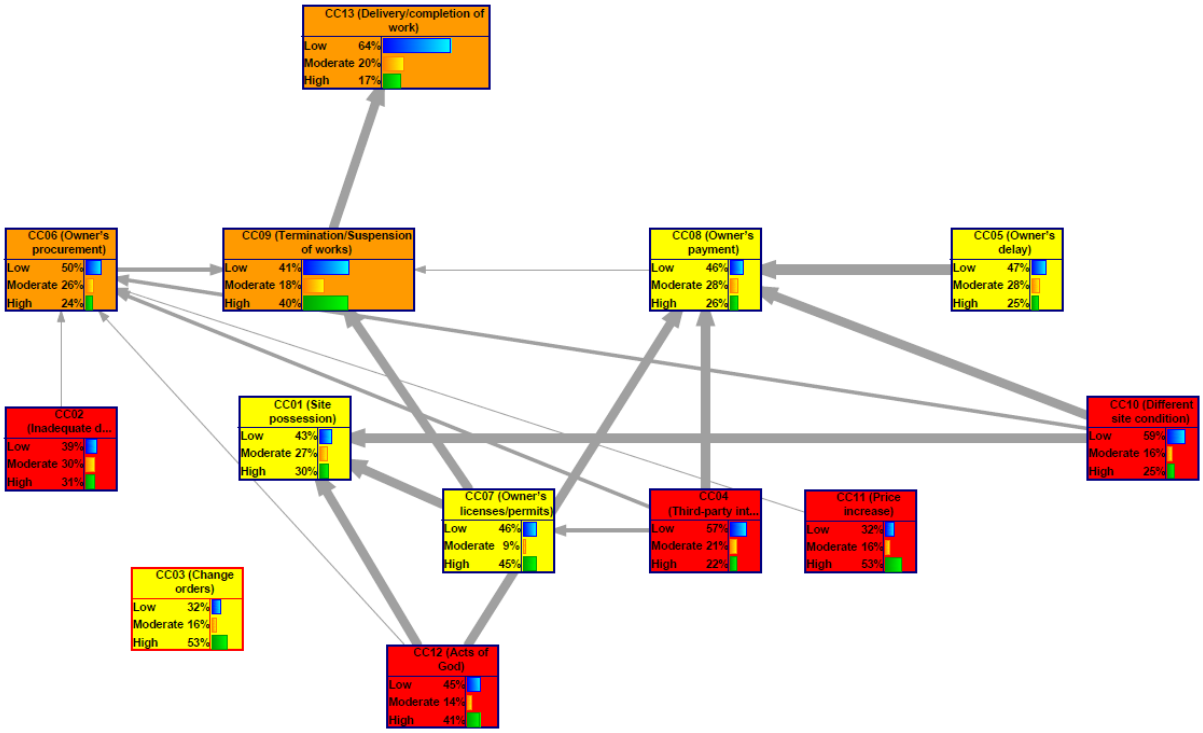


Figure 4. Bayesian network model and claim causes' states developed in GeNIe

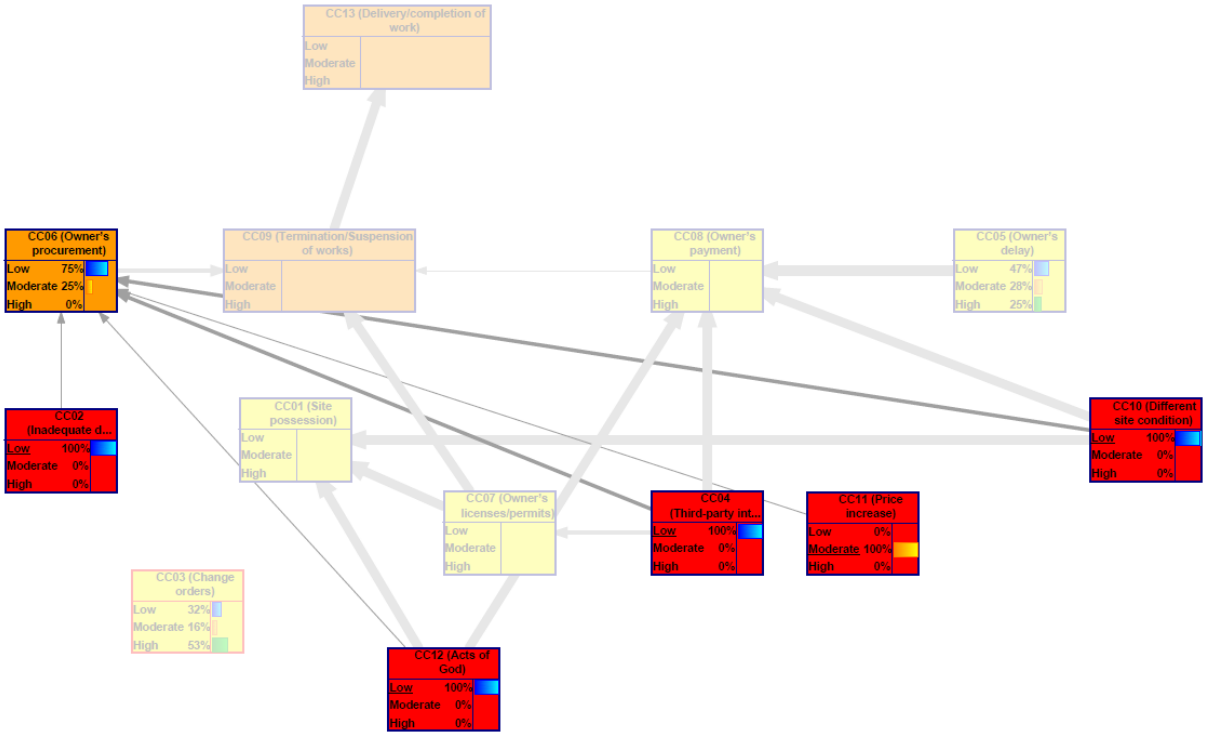


Figure 5. Bayesian network model presenting states of claim cause CC06, given states of claim causes CC02, CC04, CC10, CC11, and CC12

In this paper, we used claim cause *Owner's procurement of material or equipment* (CC06) in a project that was not included in the training data to demonstrate the predictive capability of the BN model. This claim cause is children node of 5 parent nodes, including *Issues related to inadequate document* (CC02), *Third-party interferences* (CC04), *Differing site condition* (CC10), *Unexpected increase in or escalation of material, labor,*

and equipment prices (CC11), and *Acts of God* (CC12). The states of CC02, CC04, CC10, CC11, and CC12 are low, low, low, moderate, and low, respectively. The BN model predicted that the probability of claim cause CC6 for the state "low" is 75%, 25% for the state "moderate," and 0% for the state "high." Accordingly, claim cause CC6 tends to create a "low" cost impact on the project. Figure 5 depicts the predictive results of the cost impact levels of claim cause CC6, along with associated probabilities, given the states of claim causes CC02, CC04, CC10, CC11, and CC12.

4. CONCLUSION AND RECOMMENDATION

This paper employs a Bayesian network (BN) approach to quantify and predict the cost impacts of claim causes on building projects. The BN model was developed based on 13 claim causes and their interdependences. Past building projects were used to demonstrate the applicability of proposed model. The model provides the probabilities associated with the three states of cost impact levels of claim causes. Critical claim causes, which lead to high impacts, must be focused while we prepare and implement appropriate response strategies and methods.

There are some limitations of the proposed model that need to be addressed in future research works. First, the proposed model focuses on the claims made by construction contractors against project owners only. Second, our model is primarily designed to use for the construction phase. Third, the model is structured to quantify the cost impacts of claim causes of building projects. As a result, further studies may investigate other types of claim causes, different phases of building projects, or other types of projects (e.g., industrial projects and infrastructure projects).

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