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Financial Risk Management Using a Bayesian Network in Public-Private Partnership Projects: A Middle School Construction Case

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Abstract

Public-private partnerships (PPPs) can help finance public education facilities, but their long contracts and reliance on future cash flows mean that risks rarely occur in isolation. This paper uses a Bayesian network to examine financing risk in a Beijing middle-school construction case. The model draws on a risk framework from the literature, a project questionnaire, and case information on government, market, and social conditions. The original study distributed 130 questionnaires and reported 100 returns, although it also classified 30 responses as invalid; this inconsistency limits the precision of the survey evidence. Within the reported results, market and social-environment risk was 63.4% and government risk 63.0%. Changing market demand (34%) and lower-than-expected market returns (23%) were the largest sub-factors. The wider case matrix also reported government credit risk at 35%, approval delay and late completion at 20% each, and legal change at 5%. By showing how these factors depend on one another, the network provides a practical basis for allocating and monitoring risks at different project stages. The case suggests that robust demand forecasts, transparent public commitments, meaningful public participation, and regular updating of risk probabilities are more useful than a static risk checklist. The reported percentages should nonetheless be treated as case evidence rather than population estimates until the underlying survey records can be reconciled.

Keywords

Public-private partnership; project financing; Bayesian network; financing risk; education infrastructure; risk allocation.

1. Introduction

Under a PPP, a public authority and one or more private partners combine resources and divide responsibility for providing infrastructure or services. In project finance, repayment depends mainly on project assets, future cash flow, and contractually committed payments rather than on the sponsor's wider balance sheet. This can unlock capital for large public projects, but it also leaves performance exposed to delay, weak demand, rising costs, policy shifts, credit problems, and poor coordination [1-3].

These tensions are especially sharp in education. A school creates public value that cannot be measured solely by direct financial return, yet building and operating a campus still require long-term funding, reliable demand estimates, and clear responsibility for service continuity. Simply transferring a risk to another party does not make it disappear. The practical task is to understand how risks interact and place each one with the party best able to manage it over the project life cycle.

Checklists and single-factor scores are useful for an initial screen, but they often miss relationships among risks. In practice, an approval delay raises financing costs, a construction delay postpones revenue, weak demand reduces operating income, and community opposition

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can disrupt both approval and implementation. A Bayesian network represents these links explicitly. It can combine expert judgement with observed data and update probabilities as new information becomes available [4-6].

Against this background, the paper asks three questions: which financing risks matter most in an education PPP; how can a Bayesian network represent their dependencies; and what controls are appropriate at different project stages? The analysis uses the Beijing Middle School case and retains the questionnaire proportions reported in the original project study. The network focuses on government, market, and social-environment factors.

2. Literature Review and Risk Framework

2.1. PPP Financing in Public Infrastructure and Education

PPP contracts range from service and management agreements to concessions and build-operate-transfer arrangements. What they share is a long-term division of functions, rewards, and risks between the public and private sectors. International evidence consistently shows that private finance alone does not make a PPP viable. A project still needs a clear scope, competitive and transparent procurement, credible public commitments, workable revenue arrangements, and a risk allocation that reflects each party's ability to control the exposure [1, 2, 7].

In China, PPP practices first spread through power, water, transport, and municipal infrastructure before moving into other public services. They are most attractive when public budgets cannot meet infrastructure demand on their own. Rapid expansion, however, can mask weak feasibility work, unclear payment arrangements, or an implicit expectation that government will absorb losses. Those problems are particularly serious in education, where affordability, access, and continuity of teaching must be protected. Studies of university and school finance therefore stress policy clarity, public accountability, and careful management of demand and credit risk [8-10].

2.2. Financing Risk Categories

The financing risks considered in the original study fall into seven broad categories: credit, completion, production or operation, market, financial, political, and environmental risk. Credit risk concerns whether the parties can and will meet their obligations. Completion risk covers delay, cost overrun, and failure to meet quality requirements. Financial risk includes interest-rate, inflation, exchange-rate, and refinancing exposure. Market risk concerns demand, user charges, and operating revenue. Political and legal risk includes policy change, approval delay, and contractual intervention, while environmental and social risk covers community opposition and changes in the surrounding social setting [3, 8, 11].

The importance of these risks changes over the project life cycle. Development and construction bring government credit, approvals, land, procurement, financing, cost, and completion to the foreground. During trial operation, demand, service quality, operating performance, and the reliability of the implementation entity become easier to observe. In long-term operation, revenue, market conditions, financing costs, maintenance, and contract adjustment matter more. A life-cycle model can therefore use evidence at one node to update connected risks instead of treating every factor as a separate score.

2.3. Bayesian Networks for Risk Analysis

A Bayesian network is a directed acyclic graph in which nodes represent variables and arrows represent conditional dependence. Root nodes are assigned prior probabilities, while child nodes are described by conditional probability distributions. If Xi is a variable and Pa(Xi) denotes its parents, the joint distribution can be factorised as the product of P(Xi | Pa(Xi)). Once

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evidence E=e is observed, Bayes' rule updates the probability of a queried state Q through P(Q | E=e). The same structure supports prediction from risk conditions to outcomes and diagnosis from an observed outcome back to likely causes [5, 6].

Figure 1 illustrates the three building blocks used in the network. In a divergent pattern, one parent affects several child risks. A chain represents a sequence of effects, while a convergent pattern brings several parent conditions together at one outcome. A practical PPP network may contain all three.

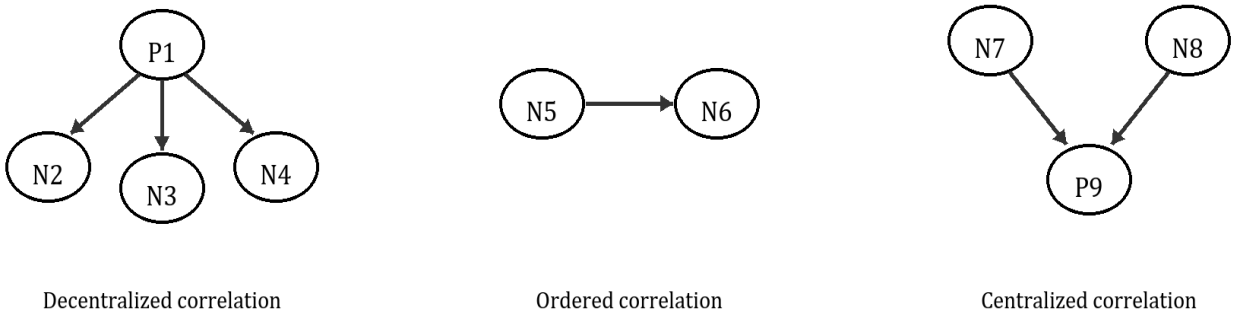


Figure 1. Elementary dependency patterns used in the Bayesian network

3. Methodology

3.1. Research Design and Case Selection

This research uses a single case to connect a financing-risk framework from the literature with questionnaire evidence and Bayesian reasoning. Beijing Middle School was chosen because the original project study discussed campus development, changing enrolment, nearby community change, and the interaction between public funding and private participation. The school was established in 2013, and its Dongba South Campus opened in 2014. These features make the case useful for examining how education demand and the surrounding social environment can affect financing risk.

The case is not presented as proof that every campus component was procured through a fully documented PPP concession. The original report indicates that public funding remained dominant and private participation was limited. The paper therefore uses the case to test how Bayesian reasoning can organise the reported risks; it does not attempt to reconstruct a complete concession agreement or project cash-flow model.

3.2. Questionnaire and Indicator Construction

The questionnaire covered government, financing, procurement, construction, operational, market, and organisational risks. Respondents were described as project leaders or staff familiar with financing in the education sector. The original report states that 130 questionnaires were distributed and 100 were returned, but it also says that 30 responses were invalid. Elsewhere it refers to '100 valid questionnaires'. Without the archived response sheets, these counts cannot be reconciled. The analysis therefore retains the reported percentages while treating the sample description as a limitation.

Risk indicators were drawn from the literature and refined through expert discussion. The questionnaire asked about government support and efficiency, concessions and policy, taxation and regulation, project approval, bidding, land acquisition, financing structure, contractor selection, delay, quality, cost growth, subcontractor and contract default, supervision, project experience, coordination, risk sharing, and trust between principals and agents. To keep the

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article within its page limit, the full questionnaire is omitted and only the central results are reported in Tables 1 and 2.

Table 1. Questionnaire-derived proportions of selected PPP financing risk factors

Factor	Probability range
Market and social environment	63.4%
Government	63%
Changing market demand	34%
Reduced market returns	23%

3.3. Network Construction and Inference

Network development began by translating the literature review and questionnaire into a set of variables. Directed links then connected project failure with government conditions, the market and social environment, demand change, charging risk, public opposition, third-party default, and insufficient market returns. Reported case probabilities were assigned to the corresponding states, after which the network was used for probability updating and sensitivity-oriented interpretation. The graph is intentionally compact: it highlights the dominant relationships in the case rather than every possible contractual or macroeconomic exposure.

Exact inference is practical when the graph and its state space are small. Larger networks may require sampling, model simplification, or search-based approximations. In either setting, the main benefit is the ability to revise connected probabilities when new evidence appears. A fall in enrolment, for example, may raise concern about revenue adequacy and project success. A credible government commitment may reduce financing uncertainty, but it does not remove operational or social risk.

4. Case Study and Results

4.1. Case Context

Beijing Middle School is a public secondary school serving both junior and senior grades. It was founded by the Chaoyang District Government with municipal approval and presents itself as an internationalised, modern, high-quality school. During the period considered in the original study, campus development occurred alongside residential construction, demolition, relocation, and changes in the surrounding population. Enrolment, community acceptance, and the timing of infrastructure delivery were therefore relevant to both financing and operation.

The original analysis points to two governance problems. First, there was no unified and transparent framework for choosing funding sources and assigning long-term operating responsibility. Second, reliance on a narrow funding base could increase financial exposure and encourage the assumption that government would ultimately cover repayment. These concerns support a network that considers government conditions together with market and social factors.

4.2. Bayesian Risk Structure

Figure 2 shows the principal network structure and the probabilities reported in the original study. The project-failure node is recorded as Y=30.2% and N=69.8%. Government risk is reported at Y=63.0%, and market and social-environment risk at Y=63.4%. Within the market-social branch, changing market demand has the largest reported share at 34.0%, followed by

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deficient market returns at 23.0%, third-party default at 13.0%, charging risk at 10.0%, and public opposition at 8.0%.

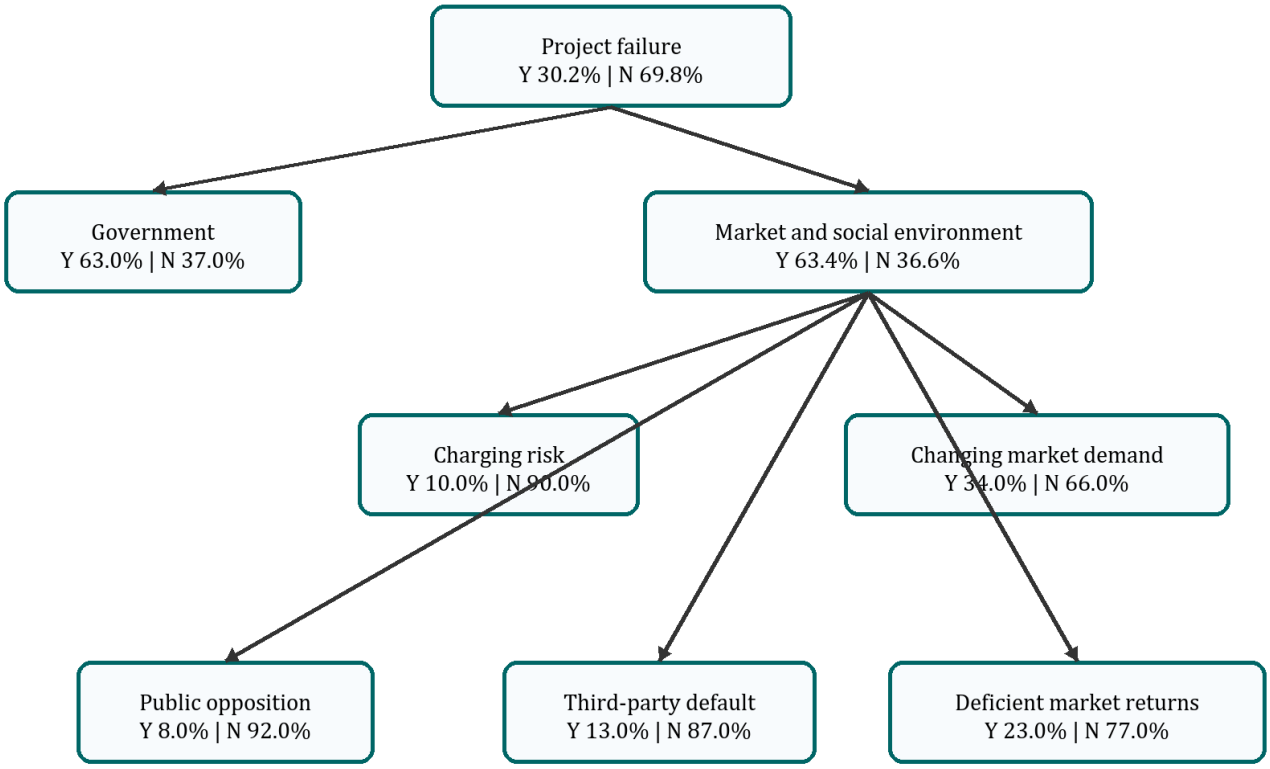


Figure 2. Bayesian network of project failure risk caused by government, market, and social-environment factors

These percentages should not be read as direct causal effects. They are better understood as signals of where monitoring and more detailed conditional modelling are most needed. Government and market-social factors have almost identical reported proportions, but the market-social branch contains several conditions that can be observed during implementation. Changes in demand, public response, third-party performance, and revenue can therefore serve as early-warning indicators.

Table 2 Financing risk categories reported for the Beijing Middle School case (%)

Risk factor	%	Risk factor	%
Market and social environment	63.4	Approval delay	20
Government credit	35	Public opposition	8
Charging risk	10	Deficient market returns	10
Third-party default	13	Changes in market demand	34
Developer financing failure	15	Unpunctual completion	20
Legal changes	5	Inflation and changes in interest rate	20

Table 2 widens the risk screen. It reports government credit at 35%, changing market demand at 34%, approval delay and late completion at 20% each, developer financing failure at 15%,

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third-party default at 13%, charging risk and deficient market returns at 10% each, public opposition at 8%, and legal change at 5%. These are descriptive inputs retained from the case study, not calibrated estimates for a wider population.

4.3. Enrolment Demand and Input-Output Pattern

The original study used student numbers to represent changing market demand. The workbook embedded in the source document records 80 students in 2014, 160 in 2015, 240 in 2016, 320 in 2017, and 400 in 2018. Enrolment clearly rose over the period, which supports the case narrative of expanding demand. It does not, by itself, show that a PPP financing structure was financially sustainable.

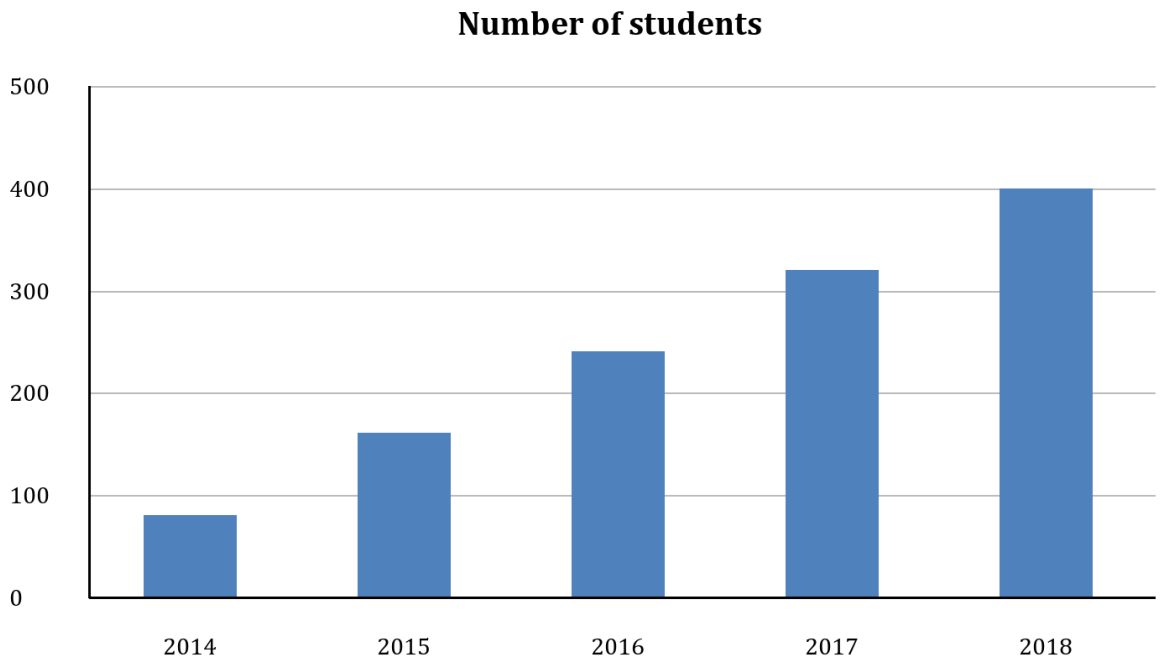


Figure 3. Enrolment data reported for 2014-2018

The input-output chart uses 2014, 2016, and 2018 as reference years. Its embedded workbook records inputs of 0.5, 3, and 10 and outputs of 0.5, 6, and 20. Output rises more quickly after the third year and again by the fifth year. Because the original study does not define the monetary units, accounting boundaries, or discounting method, the chart is best read as a relative trend rather than a cash-flow analysis.

Taken together, Figures 3 and 4 are consistent with a qualitative link between demand growth and project output. They are not a substitute for a financing model that includes capital and operating expenditure, borrowing costs, payment mechanisms, and risk-adjusted cash flow. Before the network is used for a real decision, it should be updated with verified enrolment forecasts, public-budget commitments, construction milestones, and audited financial data.

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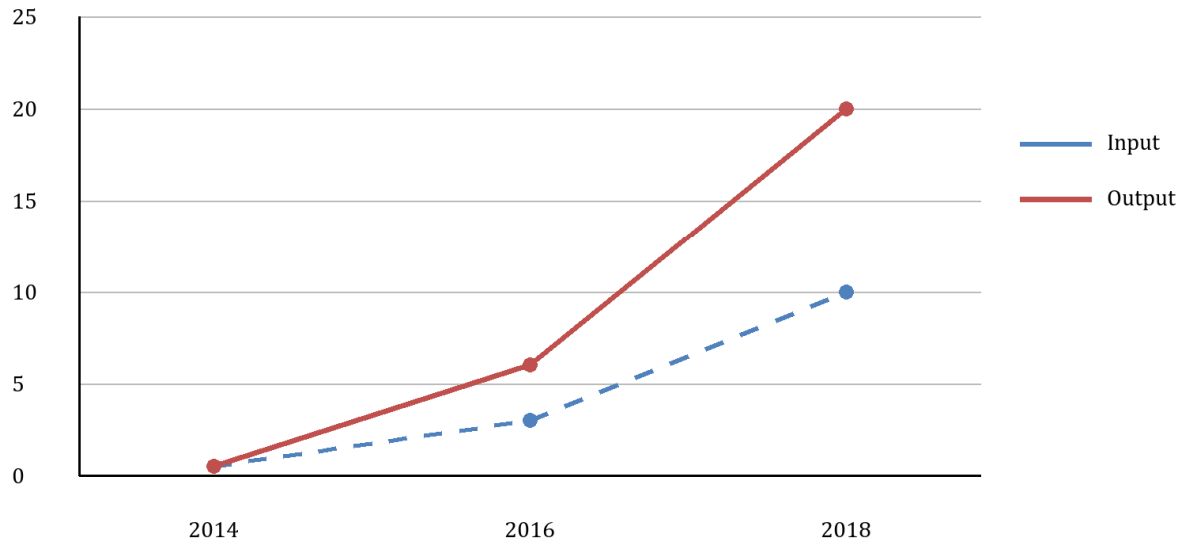


Figure 4. Input and output data reported for 2014, 2016, and 2018

5. Risk Control Implications

5.1. Development and Construction Stage

At the development stage, the public authority needs to define the educational service, expected demand, affordability limits, land conditions, payment mechanism, and the boundary between public responsibility and private performance. Feasibility testing should ask whether the financing structure remains viable if approvals are delayed, interest rates or inflation rise, demand falls, or construction costs increase. Any government support should be stated explicitly and included in the budget rather than left as an assumption.

Once procurement and construction begin, completion risk should rest with the party that can best control design, schedule, cost, and quality. Prequalification should test financing capacity, technical experience, delivery history, and the ability to coordinate complex work. The project agreement should set measurable milestones and provide for performance security, insurance, controlled variations, and remedies for delay or defective work. Government still remains responsible for lawful procurement, policy stability, public oversight, and protection of the educational purpose.

5.2. Trial Operation and Long-Term Operation

Trial operation provides the first practical test of service quality, operating readiness, demand assumptions, maintenance capacity, and the payment mechanism. Evidence on enrolment, community response, defects, operating cost, and revenue should be fed back into the network. If demand weakens, managers need to distinguish a temporary fluctuation from a lasting demographic change before revising capacity or financing assumptions.

Long-term monitoring should bring financial, operational, and educational measures together. Useful indicators include debt-service capacity, the timeliness of budget payments, operating cost, asset condition, service availability, enrolment, stakeholder complaints, and compliance with education standards. Periodic updates to the network can reveal when a previously minor factor has become important. Contract adjustments should protect value for money and continuity of education rather than shift every adverse outcome back to government.

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5.3. Risk Allocation Principle

The guiding principle is simple: each risk should be assigned to the participant that can control its likelihood or consequences at the lowest whole-project cost [3, 12]. Builders have more control over schedule and quality than schools. Public authorities control approvals, education policy, and budget authorisation; operators control service performance and maintenance; and lenders can impose financial discipline. Demand and force-majeure risks may need to be shared. In every case, allocation must be backed by information, incentives, and enforceable contract terms. A paper transfer to a party with no real control merely raises the price or creates pressure for later renegotiation.

A Bayesian network makes this allocation principle operational by linking each assigned risk to indicators that can be observed. Demand risk calls for reliable enrolment forecasts and rules for policy-driven changes. Completion risk calls for evidence on schedule, cost, and quality. Government-credit risk calls for legally supported payment commitments and transparent budgets. The network therefore connects contractual allocation with day-to-day monitoring.

6. Discussion

The questionnaire scores place market and social-environment risk slightly above government risk. That result is plausible in a school project because enrolment, community development, public acceptance, and revenue assumptions all affect how the facility is used. The difference between 63.4% and 63.0%, however, is too small to support competing explanations. Government decisions shape demand through policy, funding, approvals, school assignment, and service design, while observed demand influences public decisions on capacity and expenditure.

The main advantage of the method is not a more elaborate ranking, but the move from a list of risks to a conditional structure. Such a model can support scenarios, show where better evidence is needed, and give public authorities, schools, investors, lenders, builders, and operators a common basis for discussion. It is especially useful when data are incomplete but expert knowledge can still define plausible dependencies. Its value depends, however, on clear node definitions, defensible probability inputs, sensitivity analysis, and regular updating [5, 6].

Interpretation is limited by the available evidence. The original manuscript does not include the raw questionnaire data, a detailed respondent profile, item-level results, or a reproducible conditional probability table. Its descriptions of returned and valid questionnaires are inconsistent. The input-output chart does not define its units, and the case file contains neither a complete PPP contract nor audited cash-flow data. The percentages should therefore be treated as reported evidence from one case, not as externally validated estimates. Future studies should archive anonymised data, document ethics and consent procedures, explain probability elicitation, report reliability and sensitivity tests, and compare several education-infrastructure projects.

7. Conclusion

PPP finance can broaden the resources available for public education infrastructure, but it also creates risks that extend well beyond construction cost. In the Beijing Middle School case, government, market, and social-environment factors dominate the reported results, while changing demand and reduced market returns stand out within the market-social branch. The two tables and four figures bring together questionnaire proportions, the network structure, enrolment growth, and a relative input-output trend.

A Bayesian network adds value because it links risk identification to updating and decision-making. It helps participants replace a static checklist with stage-specific monitoring and

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allocation. In practice, the model needs verified data, explicit conditional probabilities, sensitivity tests, and governance arrangements that protect educational outcomes. The most useful controls are early feasibility work, transparent government commitments, careful selection of project partners, enforceable completion and performance terms, continuous demand monitoring, public participation, and allocation of each risk to the party best able to manage it.

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