

# **A Review Paper on E-Business Adaptability and Probabilistic Risk Assessment**

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## **Abstract**

Due to cybersecurity concerns, changing rules, unstable markets, and reliance on digital platforms and third parties, the quick growth of e-business has increased susceptibility to uncertainty. This study offers a systematic literature analysis that integrates the conceptualization and evaluation of e-business adaptability, elucidating the growing necessity for probabilistic risk assessment over deterministic methodologies. The review synthesizes essential adaptability dimensions-customer relationship hampered, legal concerns, poor planning, loss of reputation, and technological difficulties by analyzing studies sourced from prominent scholarly databases and evaluated against explicit inclusion/exclusion criteria. It also illustrates the interactions among these dimensions within digital ecosystems. The paper also evaluates the several probabilistic and multi-criteria methods used in related risk assessment studies, focusing on Bayesian Belief Networks (BBN), Graph Theory and Matrix Approach (GTMA), fuzzy-based models, and the Analytic Hierarchy Process (AHP). The synthesis shows that BBNs are good for figuring out what causes something to happen when you're not sure, GTMA is good for making hierarchical multi-criteria structures, but not so good for modeling uncertainty, fuzzy models are good when judgments are vague or linguistic, and AHP is a structured multi-criteria decision-making (MCDM) method. Finally, the review points out ongoing gaps, such as a lack of unified frameworks, not enough validation datasets, poor integration of real-time data, and weak hybrid probabilistic-structural models. This suggests a plan for making adaptability assessment tools that are stronger, more dynamic, and more integrated for making resilient e-business decisions.

## **Keywords**

E-business adaptability; probabilistic risk assessment; Bayesian Belief Networks; GTMA; fuzzy modeling; analytic hierarchy process; digital resilience.

## **1. Introduction**

Technological advancements, globalization, and the rapid evolution of digital platforms have accelerated the growth of e-business. Yet, with such growth comes substantial risk and uncertainty. Businesses face disruptions in the form of cyberattacks, supply chain failures, inconsistent customer trust, data breaches, regulatory changes, and technological obsolescence. E-business has been the best way for traditional markets to stay ahead of the competition during the global economic crisis. It is cheap, efficient, has a wide reach, and has other benefits. On the other hand, compared to traditional markets, the risk of e-business flexibility, like the higher risk of buying things online, has slowed its growth. The notion underlying traditional businesses is changing since the internet and mobile marketplaces are growing so quickly. Businesses that can't keep up with the changes in the new business model will find it hard to beat their competitors in this fast-changing market (Farida and Setiawan 2022).

Digitalization has reshaped organizational structures, business models, and customer engagement practices. As a result, e-businesses must continuously adapt to technological disruptions, market uncertainties, cybersecurity threats, and regulatory challenges. This paper provides a comprehensive review of e-business adaptability and probabilistic risk assessment methods, highlighting their significance in sustaining competitive advantage in volatile digital ecosystems. The review synthesizes recent literature on adaptability dimensions, risk drivers, and probabilistic frameworks such as Bayesian Belief Networks (BBN), Graph Theory and Matrix Approach (GTMA), fuzzy modeling, and hybrid multi-criteria techniques. Findings show that adaptability is multi-dimensional, shaped by technological capability, organizational readiness, customer trust, data security, supply chain dependency, and regulatory compliance. Adaptability refers to an organization's ability to respond to internal and external changes while maintaining operational performance. For e-businesses, adaptability is tied to technology readiness, operational flexibility, customer expectations and trust, cybersecurity and data protection, legal and regulatory alignment, and supplier and third-party reliability.

As digital environments are dynamic and unpredictable, the need for probabilistic risk assessment has become essential. Traditional risk assessment methods are largely deterministic, failing to capture uncertainty, interdependencies, and nonlinear relationships. Probabilistic models, especially Bayesian networks and GTMA, provide more accurate insight by modeling uncertainty and weighing multi-criteria structures. The objectives of this paper are as follows:

- i. To review e-business adaptability factors,
- ii. To examine and compare decision-making methods used in risk assessment and
- iii. To highlight gaps and propose future research directions.

Probabilistic assessment methods have gained traction because they address uncertainty, interdependence, and dynamic risk behavior. However, gaps remain in unified modeling, real-time data integration, cross-domain applicability, and hybrid probabilistic–structural frameworks. The review concludes by proposing future research directions and encouraging the development of integrated models to enhance e-business resilience and adaptability.

## **2. Related work**

The significance of probabilistic and multi-criteria techniques in assessing digital risk settings and e-business adaptation has been emphasized in recent work. Managing risk is the most crucial part of e-commerce, which is what both customers and businesses care about most. Risk managers at e-commerce organizations have a big job to do when it comes to making sure that information regarding online transactions is private, accurate, and valid (TOLEUULY, YESSENGELDIN et al. 2019).

(Chivatá Cárdenas, Al-Jibouri et al. 2012) show that Bayesian Belief Networks (BBNs) are becoming more popular for modeling uncertainty, causal linkages, and risk transmission in complicated socio-technical systems. Likewise, (Fenton and Neil 2012) illustrate the efficacy of BBNs in decision-making in uncertainty, rendering them particularly pertinent to dynamic e-business environments. (Mismar, Shamayleh et al. 2022) sorted hazards into groups, and the likelihood and seriousness of each danger are determined. This research utilizes a Bayesian Belief Network (BBN) model to discern the interdependence among hazards and to establish their ranking, while traditional ranking methodologies do not consider interdependence. There has also been more research on structural assessment methods. (Venkata Rao 2008) demonstrates that the Graph Theory and Matrix Approach (GTMA) facilitates hierarchical modeling and multi-criteria analysis, providing a predictable yet thorough methodology for assessing adaptation aspects. Since the GTMA considers the interdependencies and inheritance of the criteria, a complete mathematical analysis is required for establishing an order among the possibilities in a multi-criteria decision-making situation (Geetha and Sekar 2017).

Fuzzy-based approaches continue to play a significant role in addressing linguistic uncertainty in e-business risk assessment, in addition to GTMA and BBN. (Kahraman, Öztayşi et al. 2014) provide us with the basic ideas of fuzzy logic and fuzzy multi-criteria decision-making (MCDM). These ideas have been used to identify hazards when the data is unclear or not very clear. There is a lot of uncertainty in the risk assessment of information systems security (ISS) in an e-business setting (Feng and Li 2010). To deal with this, we use a hybrid method that combines evidence theory with fuzzy sets. The suggested method offers a fresh way to describe the basic belief assignment in fuzzy measure.

Hybrid vehicles have recently surfaced as a promising avenue. (Korb and Nicholson 2010) stress the strengths of both probabilistic modeling and rule-based inference systems. They suggest that structural analysis (GTMA) and

probabilistic reasoning (BBN) should be combined to make adaptability assessments that are more complete. Taken together, this research backs up the idea of using a BBN–GTMA hybrid framework to check how adaptable an e-business is.

### **3. Research methodology**

The most scientific, thorough, and repeatable review technique used in systematic literature review research (Inkinen 2016), which has gained widespread acceptance in the research community, was used in this work. The technique's general framework is depicted in Figure 1. Following the implementation of a risk determination approach to probabilistic risk assessment and e-business adaptability, the following stage:

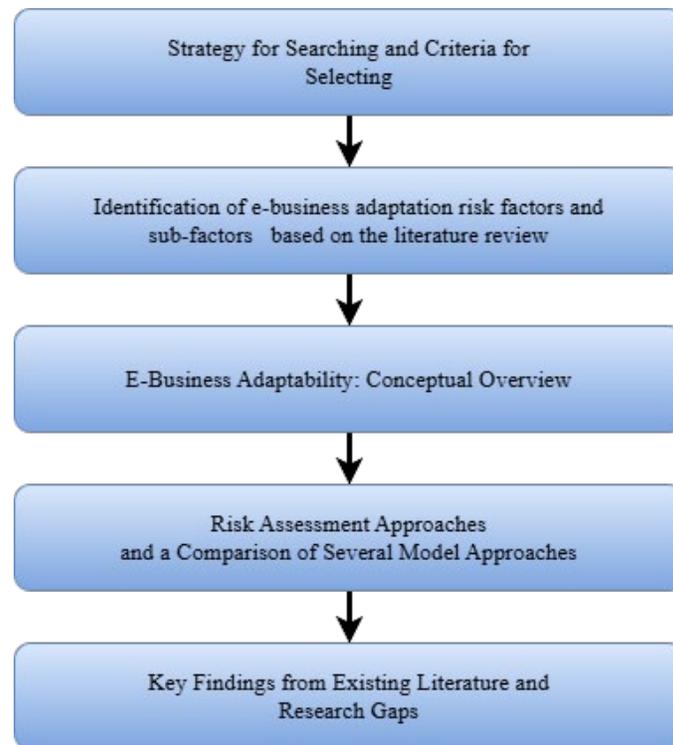


Figure 1. Research Methodology

#### **3.1 Strategy for Searching and Criteria for Selecting**

The literature study utilized a planned and systematic search technique to guarantee thorough coverage of pertinent studies regarding e-business adaptability and probabilistic risk assessment. We searched major academic databases like Scopus, Web of Science, IEEE Xplore, ACM Digital Library, and Google Scholar to find high-quality research that crossed disciplines. To find relevant publications, we utilized a mix of specific keywords, including e-business adaptability, digital adaptability, probabilistic risk assessment, Bayesian belief networks, GTMA, organizational digital resilience, and uncertainty modeling in e-business. The review concentrated on peer-reviewed journal publications released from 2000 to 2025, encompassing both foundational theories and contemporary methodological advancements. The studies examined had to utilize quantitative, probabilistic, multi-criteria, or hybrid analytical models. The main focus was on research that looked at digital business transformation, risk management, and adaptability assessment. Studies were eliminated if they focused on non-digital business environments, depended exclusively on qualitative discussion without analytical modeling, or failed to include a distinct methodological or evaluative element. This selection procedure ensured methodological rigor, applicability to e-business environments, and alignment with probabilistic and decision-analytic research aims. Figure 2 illustrates the operation of the screening and exclusion procedure. After the screening process, all relevant material was reviewed and analyzed to confirm that the findings aligned with current scholarly interests. During the identification phase, the search technique was used on all information sources, the articles were put into one database, and EndNote X9 was used to get rid of duplicates and examine the references again (Shupti, Hossain et al. 2024).

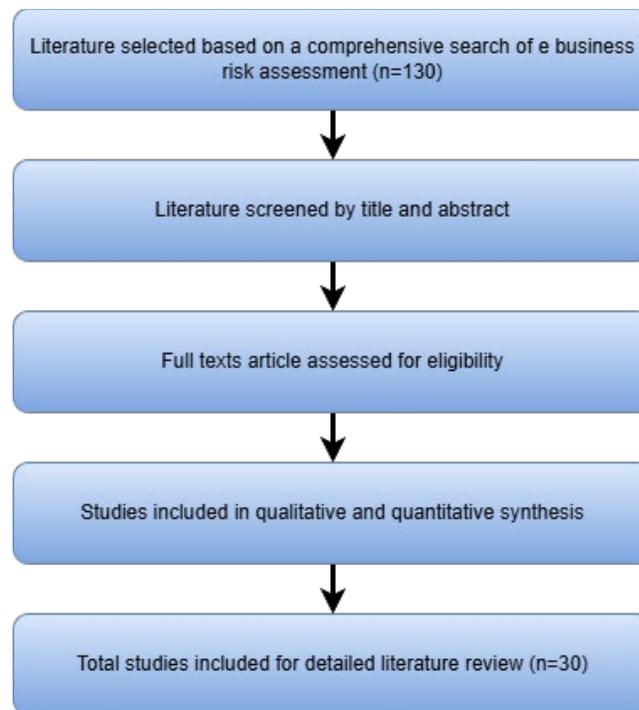


Figure 2. An overview of the searching and selection strategy

### 3.2 Identification of e-business adaptation risk factors and sub-factors based on the literature review

Businesses are looking at the recognized risk assessment of e-business adaptability-related concerns in an effort to lessen the impact of these problems on long-term business development. A literature review and input from stakeholders are used to identify several important transportation aspects for the business. A few important factors are listed. These include customer relationship hampered (Gupta, Das et al. 2019), legal concerns (Sinha 2020), poor planning (Sinha 2020), loss of reputation (Hsiao and Chen 2012), technological difficulties (Tian and Ren 2009), and dependency risks (Sukumar, Edgar et al. 2011).

### 3.3 E-Business Adaptability: Conceptual Overview

A variety of internal and external factors impact adaptability, which has various dimensions. Adaptability, according to the literature, includes:

**Adaptability in Technology:** Scalability of IT infrastructure, Updates and integration of technology, and cybersecurity preparedness.

**Strategic and organizational preparedness:** Leadership vision, staff digital literacy, innovation culture, and resource flexibility.

**Customer-Centric Adaptability:** Trust and openness, resolution of disputes, assurance of product quality, and consistency of services.

**Compliance with laws and regulations:** Validity of websites, data protection laws, e-payment guidelines, and intellectual property laws.

**External Dependency Risks:** Dependability of suppliers, hazards associated with outsourcing, contractor proficiency, platform dependence, market failure risks, product mismatches, pricing irregularities, and unsuccessful promotional strategies.

### 3.4 Risk Assessment Approaches and a Comparison of Probabilistic Approaches

#### **Risk Assessment Approaches**

Probabilistic models quantify uncertainty, allowing researchers to analyze risk interactions and estimate adaptability outcomes.

### **Bayesian Belief Networks (BBN)**

Bayesian Belief Networks (BBNs) are graphical probabilistic models that use directed acyclic graphs to depict cause-and-effect interactions between risk factors (Hossain, El Amrani et al. 2020). They are particularly useful in situations where data may be ambiguous, missing, or changing quickly—all of which are typical features of e-business operations—and they use conditional probability tables (CPTs) to record uncertainty. Complex interdependencies between operational, legal, technological, and customer-related hazards can be reflected by BBNs. Their design enables analysts to carry out sensitivity analysis to pinpoint important risk factors, run scenario simulations (e.g., "What if customer trust declines?"), and dynamically adjust system probabilities in response to fresh information or evidence. Cybersecurity risk forecasting, technology adoption analysis, supply-chain vulnerability modeling, service dependability evaluation, and more general adaptation or resilience measurement are examples of applications in e-business. Because of these characteristics, BBNs are especially well-suited for probabilistic risk assessment in digital business environments (Abdalla, Apramian et al. 2018).

#### Advantages

- Models uncertainty using conditional probabilities
- Captures causal dependencies and risk propagation
- Supports continuous learning as new data updates node beliefs
- Dynamic and flexible, enabling scenario-based analysis

#### Limitations

- Requires expert judgment to construct CPTs when data is limited
- Scalability challenges, as very large networks become computationally complex.

### **Graph Theory and Matrix Approach (GTMA)**

A structural multi-criteria approach known as the Graph Theory and Matrix Approach (GTMA) depicts factors as nodes in a graph and their connections as directional links. These graphs are transformed into matrix forms, where factors' relative importance and interdependencies are measured. GTMA creates a single performance or adaptability index by calculating the permanence of this matrix (Shupti, Hossain et al. 2024). Because of this, it can be used to assess system complexity, organizational competency, supply-chain vulnerability, and digital readiness.

Maintaining hierarchical structures, managing several criteria at once, and generating methodical, quantitative evaluations are some of GTMA's advantages. Compared to straightforward weighting techniques, it successfully integrates interactions between criteria, enabling a more comprehensive evaluation. However, it cannot simulate uncertainty or probabilistic behavior and only works with fixed numerical values. Because of this, its accuracy is highly dependent on expert grading, and it is unable to replicate dynamic "what-if" situations. Because of these drawbacks, probabilistic models are frequently used in conjunction with GTMA to provide a more thorough risk assessment.

#### Advantages

- Quantitative and systematic
- Preserves hierarchical structure
- Handles multiple criteria
- Deterministic (no uncertainty modeling)
- Requires integration with probabilistic tools

#### Limitations

- Deterministic (no uncertainty modeling)
- Requires integration with probabilistic tools

### **Fuzzy Model**

In situations where information is ambiguous, qualitative, or conveyed linguistically, fuzzy models offer a means of assessing systems. They use membership functions to interpret expert words like high risk, medium adaptability, or poor trust rather than demanding precise numerical values. Because of this, fuzzy logic works well in situations where human judgment—rather than chance—causes uncertainty. Fuzzy MCDM techniques, such as fuzzy AHP, fuzzy TOPSIS, and fuzzy inference systems, may handle several criteria at once and reflect hierarchical structures

(Aishwarya, Ekren et al. 2025). They do not, however, simulate causation or probabilistic propagation, even though they are capable of expressing uncertainty in linguistic form. For decision-making, their outputs are usually fuzzy scores that can be defused. All things considered, fuzzy models are excellent at capturing subjective evaluations, but they cannot take the place of probabilistic models for dynamic risk assessment.

**Advantages**

- Excellent for ambiguous
- Flexible modeling of expert linguistic terms
- Imprecise human assessments
- Compatible with other MCDM techniques
- Requiring less data

**Limitations**

- No explicit probabilistic interpretation
- Cannot model causal propagation
- Complexity can arise in rule-based systems

**Analytic Hierarchy Process (AHP)**

Thomas L. Saaty created the Analytic Hierarchy Process (AHP) in 1980. It is a structured multi-criteria decision-making (MCDM) method that breaks down difficult decisions into a list of goals, criteria, sub criteria, and choices (Saaty 2013). It figures out priority weights and the relative importance of factors by means of pairwise comparisons. AHP is used a lot in digital transformation, e-business evaluation, risk prioritization, and organizational decision-making because it uses experts' opinions and creates numerical rankings (Table 1).

**Advantages**

- Complex challenges are ranked in structured decision-making.
- Integrates subjective judgments with quantitative data.
- Prioritization and ranking—weights and ranks criteria and alternatives.
- Consistency check, checks judgment reliability.
- Facilitates group decision-making by aggregating expert perspectives.

**Limitations**

- Subjectivity—human judgment can be prejudiced.
- Scalability issues—many criteria/alternatives complicate comparisons.
- Ranking reversal: adding/removing alternatives changes rankings.
- It's hard to make consistent decisions for complex problems.

Table 1. Summary of Decision-Making and Risk Assessment Methods

<b>Author</b>	<b>Method</b>	<b>Application Domain</b>	<b>Validation Method</b>
(Hossain, El Amrani et al. 2020)	BBN	Risk assessment	Case study + sensitivity analysis
(Gupta, Das et al. 2019)	GTMA	E-business risk	Expert validation
(Kahraman, Onar et al. 2015)	Fuzzy MCDM	Digital readiness	Comparative evaluation
(Alkan and Kahraman 2023)	AHP	Digital transformation	Consistency ratio + survey

**Comparative Analysis of Several Model Approaches**

The literature review helped uncover several models, and specialists at the organization being evaluated gave information that can be seen in Table 2.

Table 2. Comparative Analysis of Several Model Approaches

Criteria	BBN	GTMA	Fuzzy Models	AHP
Uncertainty Handling	Probabilistic uncertainty modeling (Fenton and Neil 2014)	Deterministic (Rao 2007)	Linguistic uncertainty (Zimmermann 2012)	Limited—crisp comparisons (Saaty 2013)
Structural Hierarchy	Supports multi-level causal structures (Koller and Friedman 2009) (Hossain, El Amrani et al. 2020)	Strong hierarchical MCDM (Rao 2010)	Hierarchical fuzzy AHP/TOPSIS (Kahraman, Onar et al. 2015)	Designed for hierarchical decision systems (Saaty 2013)
Causal Modeling	Explicit cause–effect propagation (Korb and Nicholson 2010)	No causality (only relational) (Rao 2007)	No causal propagation (rule-based only) (Mendel and Wu 2002)	No causal reasoning (Saaty 2013)
Expert Knowledge Integration	Experts define CPTs (Koller and Friedman 2009) (Hossain, El Amrani et al. 2020)	Weight & relationship assignments (Rao 2007)	Linguistic expert input (Mendel and Wu 2002)	Pairwise expert judgments (Saaty 2013)
Quantitative Output	Probability values (Fenton and Neil 2014)	Permanent Index (Rao 2007)	Fuzzy scores / defuzzified values (Kahraman, Onar et al. 2015)	Priority weights/consistency index (Saaty 2013)
Scenario Analysis	Strong – network-based propagation (Fenton and Neil 2014)	Weak – requires manual recalculation (Rao 2007)	Moderate – rule-based simulation (Mendel and Wu 2002)	Weak–Moderate – limited what-if ability (Saaty 2013)
Computation Complexity	Medium–High (Koller and Friedman 2009)	Low–Medium (Rao 2007)	Medium (Kahraman, Onar et al. 2015)	Medium (Saaty 2013)
Data Requirements	High (probabilities, expert input)	Low (weights & matrix data)	Moderate (expert linguistic input)	Low–Moderate (pairwise comparisons)
Best Use Case	Uncertainty, causality, risk propagation (Koller and Friedman 2009)	Structural ranking, multi-criteria evaluation (Rao 2010)	Subjective, vague, qualitative environments (Zimmermann 2012)	Clear hierarchical decisions with consistent expert judgments (Saaty 2013)
Main Limitation	Hard to scale to large networks (Korb and Nicholson 2010)	Cannot model uncertainty (Rao 2007)	Lacks causal depth (Mendel and Wu 2002)	May suffer consistency issues in pairwise comparisons (Saaty 2013)

### 3.5 Key Findings from Existing Literature and Research Gaps

#### Key Findings from Existing Literature

Risk-related factors (customer relationship hampered, legal concerns, poor planning, loss of reputation, technological difficulties) interdependently affect adaptability. E-business viability depends on customer trust and data security. Probabilistic techniques prevail over deterministic ones due to inherent uncertainty. BBN is commonly used but not often combined with structural models like GTMA. Although GTMA is helpful for hierarchical adaptation, it cannot model uncertainty alone. Hybrid probabilistic-structural models are evolving and yet underdeveloped. BBN is the best at predicting adaptability risk, causal propagation, and probabilistic reasoning. GTMA is the best option for adaptability indexing and hierarchical structural evaluation. When data is

ambiguous and there is linguistic uncertainty, fuzzy models are most effective. ANP is best suited for representing interdependent criteria in intricate digital ecosystems. The most effective method for simulating uncertainty and causal propagation is BBN. When it comes to multi-criteria structural modeling with graph-based permanents, GTMA is excellent. Although they lack causal depth, fuzzy models offer flexible thinking in ambiguous situations. The most thorough probabilistic adaptability evaluation is provided via a hybrid BBN–GTMA framework.

### **Research Gaps**

- No uniform frameworks for probabilistic adaptation.
- Lack of sufficient data sets to test adaptation models.
- Few studies have looked at how BBN and GTMA work together to make e-business more adaptable.
- Relying too much on expert judgment makes models less resilient.
- Most research does not consider dynamic adaptation (time-dependent).
- Few models incorporate real-time data (from IoT, ERP systems).

### **4. Conclusion**

Adaptability in e-business is essential for thriving in ever-evolving digital environments. A key component of comprehending uncertainties, interdependencies, and system behavior is probabilistic risk assessment. While GTMA gives good structural evaluation, Bayesian Belief Networks offer robust causal and probabilistic modeling. Although integrated adaptation frameworks are still uncommon in the literature today, both approaches are complementary to one another. In order to improve e-business resilience and competitive advantage, this paper emphasizes the necessity of hybrid methodologies, real-time modeling, and sophisticated probabilistic techniques.

### **Future Research Directions**

- Develop BBN-GTMA hybrid models that combine probabilistic and structural reasoning.
- Generating CPTs automatically for BBN using machine learning.
- Incorporate real-time digital data to assess dynamic adaptability.
- Utilize probabilistic models in developing fields such as digital logistics, financial technology, and e-health.
- Create standards for flexibility so that different industries can be compared.
- Implement probabilistic adaptation indices to inform the development of decision-supporting technologies.

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