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VTIPJMRR | Journal of Multidisciplinary Research & Review
www.journal.vtinterpress.com

(Research Article)

Navigating Modern Volatility: The Renewed Importance of a Holistic PESTLE and All-Hazards Risk Framework for Mega-Projects

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Received: 01.08.2026	Accepted: 20.08.2026	Published: 30.08.2026

ABSTRACT

The new normal for mega-project development is now highly unpredictable due to the current environmental volatility. Volatility includes, inter alia, global pandemics; shock waves from inflation and interest rates; geopolitical conflicts; supply chain failures; cybersecurity breaches; and extreme weather events (climate). A common characteristic of these disruptions is their interconnectedness and ability to build on top of each other. However, traditional project risk management strategies based on discrete, internal to the project event-based registers, and/or probability–impact assessments of individual risks and contingency reserve approaches remain focused on discrete project-specific risks. In addition, while both PESTLE analysis and all-hazards thinking have been available for decades as tools to help address project specific risks they have received relatively little attention until recently. Under the present circumstances of high levels of uncertainty, it seems likely that both will gain renewed attention and be used together. As such, the authors conducted an integrated review of the literature concerning project management, strategic management, and emergency management, and a documentary analysis of eight major international mega-projects that were documented prior to the emergence of COVID-19. They applied the PESTLE analysis matrix and an additional matrix for hazards outside of the PESTLE categories. Technological factors and legal issues were identified as the source of disruption for the majority of the mega-projects studied, with seven out of eight experiencing significant impacts resulting from an exogenous hazard. All eight mega-projects active since 2019 experienced at least one exogenous hazard, primarily caused by either COVID-19 or climate related disasters. Based upon this data, the study recommends that a hybridized model combining PESTLE and all-hazards thinking be developed for use by sponsors of mega-projects and government agencies. The proposed model would allow for ongoing assessment of potential exogenous hazards through continuous external horizon scanning along with an evaluation of existing capabilities using a consequences-based approach across the entire lifecycle of a mega-project. Additionally, the model would include a composite measure of exposure (a combination of three measures) and an estimate of any gaps in capabilities that exist relative to the exposures faced by the mega-project. The recommended hybridized model should provide sponsors of mega-projects and government agencies a means to transition from reliance on risk controls toward developing proactive and resilient mega-project governance models in uncertain environments.

Keywords: *mega-projects; modern volatility; PESTLE analysis; all-hazards approach; holistic risk framework; polycrisis; resilience; infrastructure governance; Middle East; conflict-affected infrastructure*

I. INTRODUCTION

Risk registers were used to capture large amounts of information in a structured way and were commonly used in project risk management, including megaprojects. While useful for managing uncertainty in relatively predictable environments, the traditional risk register is generally designed to handle either low volumes of high-confidence data or high volumes of low confidence data. In most cases, megaprojects will have neither. This is particularly true given the fact that large numbers of megaprojects are being undertaken under highly uncertain conditions—conditions that are themselves constantly evolving. For example, megaprojects often take place over lengthy periods of time during which the economic, financial, technological, environmental and regulatory contexts may all shift significantly. As noted above, there are also many types of hazards affecting megaprojects today—climate change, cybersecurity, terrorism, pandemics—that affect not just megaprojects but entire systems of production and consumption. These factors contribute to create complex, dynamic, multi-risk environments. In such environments the task facing managers is not simply to identify and assess individual risks, but to understand how

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those risks interact with one another. This requires a much broader view of risk than is typical in current project-based approaches.

Risk management should focus on building resilience throughout a system rather than merely trying to predict every possible eventuality. This means designing systems so that they are able to absorb or recover from potential disturbances, whether caused by natural disasters, economic collapse or some other form of disruption. It also involves recognizing that risk is always relative to the goals and objectives of a system—and thus focusing on the risks that matter most to achieving those objectives. Traditional project management views risk primarily as something to be avoided or mitigated, whereas building resilience views risk as something to be managed proactively to achieve desired outcomes. Traditional risk assessments typically ask people to assign probabilities and impact scores to individual risks, then sum up these values to determine a total risk score. However, when we consider complex, interconnected systems like cities or transportation networks, this approach becomes impractical. We need better ways to assess the likelihood and severity of potential disruptions in order to plan accordingly. One alternative approach is called "all-hazard" thinking, which recognizes that many different hazards can produce similar effects. Instead of assessing risk separately for earthquakes and hurricanes, for example, we could look at what would happen if either type of disaster occurred. This allows us to anticipate more general problems (like loss of power) rather than having to guess ahead of time exactly which type of problem might occur. Another alternative is called PESTLE (Political Economic Social Technological Legal Environmental) analysis. PESTLE asks users to scan the surrounding political economy, society, technology and regulation in order to identify trends that could potentially disrupt operations. It focuses on understanding how big-picture forces shape business risks and opportunities, and can help organizations stay informed about changes in their environment before they lead to trouble. Both of these alternatives offer a broader perspective on risk than traditional methods. They recognize that some risks come from outside the organization itself, while others come from inside. And they allow users to think more systematically about how various types of risk fit together. In addition to providing a more complete picture of the overall risk situation, these approaches can also provide a basis for developing proactive strategies for dealing with major disruptions. By focusing on how risks interact with each other and with larger-scale forces outside the organization, managers can begin to identify early warning signs for potential disruptions, and take steps to mitigate or prepare for them even before they arise.

Modern volatility makes the combination of traditional project-based risk assessment and PESTLE/All-Hazards-style frameworks particularly important. Because megaprojects are so expensive, visible and dependent on government funding and public opinion, they are highly vulnerable to shifts in the underlying economic, political and environmental conditions in which they operate. At the same time, megaprojects are nearly guaranteed to experience multiple severe disruptions during their development process. Together, these facts suggest that managers of megaprojects will need to adopt a much more flexible and adaptive approach to risk assessment than is currently common. Using a single framework for identifying and prioritizing potential risks—such as the conventional risk register—is likely insufficient. Instead, we recommend using PESTLE/All-Hazards-type frameworks to analyze broad categories of potential hazards—such as climate change, cybersecurity breaches and geopolitical instability—and combining these analyses with detailed assessments of specific risks associated with each category. By doing so, we believe that managers can develop more comprehensive and resilient strategies for managing risks during megaproject development.

In terms of implementation specifics, our recommendation is simple: use PESTLE/All-Hazards-type frameworks to identify key sources of modern volatility that are likely to affect your megaproject, then supplement these analyses with a detailed review of historical and contemporary data regarding each source.

II. LITERATURE REVIEW

The literature relevant to this study spans three traditions that rarely cite each other: project and construction risk management, strategic environmental scanning, and emergency and disaster management. This section reviews each in turn and then identifies the gap that motivates the present work.

A. Conventional Project Risk Management and Its Limits

Contemporary Project Risk Management (PRM) has evolved through a family of standards and guides. ISO 31000 defines risk as an effect of uncertainty on objectives and outlines the principles, framework and process for any organization [5]. The Project Management Institute's (PMI) standards take the ISO definition and apply it specifically to projects using workshops to identify risks, probability/impact matrices, schedule/cost risk quantification, and assigning risk owners/responses [6], [7]. Enterprise Risk Management (ERM) frameworks, particularly COSO, expand the idea to the organizational level linking ERM to strategies and performance [13]. Practitioner texts provide a comprehensive description of the "toolkit" used for all types of risk management

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activities [14]; and empirical reviews of selecting techniques for risk assessments indicate that organizations typically use a limited number of established methods [15].

Empirical studies of construction and infrastructure projects generally support what such lists tend to record. Analyzing content of construction risk literature identifies the most frequently recorded risks associated with design changes, contractor capabilities, site conditions, funding, approvals, and productivities [16], [17]. While significant, these risks are internal to the project and generally well understood. A few researchers have suggested that the current paradigm is inadequate to address the deep uncertainty of large-scale projects. Ward & Chapman recommended shifting from "Risk Management" to "Uncertainty Management," indicating that concentrating solely on specific discrete events fails to acknowledge uncertainty relative to objectives, relationships among parties involved, and assumptions made regarding estimates [18]. Similarly, Perminova et al., separated uncertainty from risk, stating that managing uncertainty is best achieved by engaging in reflective learning vs. controlling uncertainty through only probabilities [19]. Aven's overview of risk assessment fundamentals identified limitations associated with using only probability as the metric for measuring uncertainty and advocated increasing attention to understanding both the quality of knowledge and surprise [20].

Research focused on mega-projects further develops the previous criticisms. Miller & Lessard conducted an examination of sixty large-scale engineering projects and determined that the largest risks faced were institutional/exogenous -- those created by regulatory bodies, government, markets and social acceptance rather than technical and that successful sponsors of mega-projects "shape" these risks over extended front-end timeframes [21]. Floricel & Miller indicated that mega-projects experience turbulence that cannot be fully anticipated or predicted and therefore require flexible strategic approaches and effective governance [22]. Sanderson examined alternative theories explaining mega-project failures and concluded that governance/institutional context play key roles, not secondary ones [23]. Kardes et al., defined complexity, multiple stakeholders and the international arena as characteristics typical of global mega-projects [24]; while Mok & Co. noted the critical role played by stakeholder interactions in mega-construction projects [25]. Collectively, these studies demonstrate that conventional PRM looks inwardly when external factors are usually driving forces responsible for the greatest impacts.

The second limitation is based upon infrequent but very detrimental occurrences. Taleb described his "Black Swan" concept as events lying beyond normal expectation levels that produce extreme consequences and are explained only after their occurrence [26]. Wucker developed a parallel concept called "Gray Rhino," describing highly probable, high impact threats that are observable yet neglected [27]. Neither the Black Swans nor Gray Rhinos are effectively addressed using Probability-Impact Matrices (PIM), because PIM typically assign low weights/ratings to infrequent events and consider slow developing threats as background conditions. Studies examining High Reliability Organizations (HROs) and Resilience Engineering have demonstrated that HROs develop strong capacities to anticipate, absorb, adapt and recover from catastrophic events; suggesting that predictive precision is not the primary solution [28], [29].

A third limitation stems from the fact that mega-projects operate as complex adaptive systems. As such they consist of numerous organizations, technologies, and institutions interacting over extended periods; with small initial changes able to exhibit unpredictable and nonlinear behavior [24], [30]. Therefore, decomposing uncertainties into separate individual risks, each with its own risk owner/response team, may lead to a false perception of control. Risks interact; risk ownership change; boundaries between the project and the surrounding environment shift as attention increases/decreases due to political/public interest. Viewing mega-projects through this system lens explains how some mega-projects that appear to be well-managed individually will ultimately fail at the overall project level [3], [23] .

B. PESTLE Analysis as an External Scanning Tool

The contemporary PRM (Project Risk Management) is represented through a series of standards and guides. ISO 31000 provides a definition for risk as the effect of uncertainty on objectives. It also offers the risk management principles, a risk management framework and an iterative process that applies to all organizations. The PMI Standards then provide a translation of the risk management principles and practices specific to projects. The PMI Standards emphasize risk identification workshop sessions, qualitative probability-impact matrixes, quantitative schedule and cost risk assessments, and the assignment of risk owners and responses [1] [2]. ERM (Enterprise Risk Management) frameworks like COSO (Committee of Sponsoring Organizations of the Treadway Commission), build upon the PMI Standards and expand the concept of risk management to include organizational level risk management. ERM frameworks establish links to organization strategy and performance [8]. Practitioner texts outlining the tools available for practitioners also outline the same key tools [9]. Reviews of technique selections demonstrate that nearly all organizations use a limited number of established techniques [10].

Studies focused on empirical studies of construction and infrastructure projects generally support what these registers capture. Content analyses of construction risk literature identify the most commonly cited risks as design

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changes, contractor capabilities, geotechnical conditions, funding, permitting/ approval, and productivity [11] [12]. While these are significant risks, they are primarily internal to the project and are reasonably well understood.

Several researchers have criticized the conventional paradigm as being ineffective to address the larger uncertainties associated with large projects. Ward and Chapman noted that conventional paradigms represent "risk" as discrete event threats. This representation does not account for uncertainty regarding objectives, relationships, or bases for estimating values [13]. Perminova et al. differentiated between uncertainty and risk. They further indicated that managing uncertainty would require reflective learning and/or probabilistic control [14]. Aven's comprehensive review of foundational elements of risk assessment highlighted limitations inherent within the application of probability as the sole metric of uncertainty. He further called for greater consideration to be placed on knowledge strength and potential surprises [15].

Research focusing on mega-projects continues to sharpen the previous criticism. Miller & Lessard completed a comparative analysis of sixty large engineering projects. Their results indicated that those risks considered most detrimental were primarily institutional/exogenous in nature (i.e., regulator/government/market/social acceptability). Their findings also indicated that successful sponsors "managed" their risks over long periods prior to initiating their respective projects [16]. Floricel & Miller demonstrated that mega-projects experience turbulent environments that cannot be fully forecasted. Therefore, successful execution would require both strategic flexibility and governability [17]. Sanderson conducted a comparative analysis of alternative explanations for mega-project failures. His results indicated that both governance and institutional context are primary factors contributing to mega-project failures. [18]. Kardes & co-authors identified several characteristics common to mega-projects including complexity, multiple stakeholders, and international scope [19]. Mok & co-authors documented how critical stakeholder dynamics are to successful mega-construction projects [20].

Together, the collective results of these mega-project studies indicate that traditional approaches to PRM typically focus inwardly on risks whereas those risks most likely to result in project failure are located beyond the boundaries of a single project.

Secondly, another limitation concerns rare but potentially catastrophic events. Taleb's "Black Swan" concepts refer to events that lie beyond normal expectations, will produce extreme effects and are rationalized only after occurrence [21]. Taleb's "Gray Rhino" concepts refer to highly probable, high-impact threats that are observable but ignored until too late [22]. Both types of events are inadequately captured using traditional Probability-Impact Matrices since they tend to place rare events in lower score positions and treat the accumulation of threats over time as background noise. High-reliability organizations and Resilience Engineering research indicate that responding appropriately to Black Swans or Gray Rhinos should involve enhancing an organization's ability to predict, absorb, adapt to, and recover from such events rather than improving predictive accuracy [23][24].

Thirdly, there is a systemic aspect to mega-projects. Mega-projects are not merely large versions of typical projects. Rather, mega-projects are complex systems where numerous organizations, technologies, and institutions interact over considerable periods. Additionally, small perturbations can generate substantial nonlinear consequences in such systems [19], [25]. As such, the decomposition of uncertainty into lists of independent risks each having their own designated risk owner(s) and response(s) can contribute to creating an illusion of control. Moreover, risk interactions occur among owners change and project system boundaries shift due to fluctuating levels of political/public attention [1],[26]. From a systemic perspective, this explains why mega-projects that appear well-managed from an individual risk standpoint can still ultimately fail at the system level [3], [27].

C. All-Hazards Thinking in Emergency and Resilience Management

All-hazards thinking has been implemented into emergency management where the practice of developing separate plans for every possible event, proved to be both resource intensive and vulnerable. Therefore, planners have begun identifying the necessary functions/capabilities (warning/evacuation/continuity of services/comms/recovery) needed for virtually every emergency situation and develop plans that will allow them to provide those regardless of the hazard(s) causing the need for those functions/capabilities. In the U.S., this idea was codified through national preparedness policy and defined through core capabilities that would apply across all possible hazards/threats [12]. On an international basis, the Sendai Framework for Disaster Risk Reduction 2015–2030 utilized a multi-hazard approach including natural and manmade disasters along with environmental, technical and biological hazards [33]. As part of a routine process of conducting national risk assessments many countries utilize similar approaches. For example, the United Kingdom's National Risk Register utilizes a grouping method based on the commonalities of the consequences resulting from each group of risks. Additionally, India's first National Disaster Management Plan directly linked national planning efforts with the Sendai framework priorities [35].

The main benefit of using an all-hazards approach is a transition from thinking about causes to thinking about consequences. A project cannot predict if a project site will be shut down due to a flood, pandemic, civil unrest or cyber-attack; however, a project can prepare for the consequence that these events all have in common – lack

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of access to the project site. In addition, there may be numerous ways that a business could lose a key supplier (insolvency, sanctions, fire or a port shutdown); however, the required capability to address this issue (an alternate source of supplies) is the same. Consequence-based thinking is particularly effective in addressing disruptions associated with low probability-high impact events that conventional register methods often do not account for adequately [28] [29].

Table 1 compares the three perspectives on risk assessment showing how each perspective differs in terms of the primary questions asked; time horizons utilized; and blind spots inherent within each perspective.

Table 1. Comparison of Conventional PRM, PESTLE Analysis and All-Hazards Thinking.

Attribute	Conventional PRM	PESTLE Analysis	All-Hazards Thinking
Origin	Project and engineering management standards [5], [7]	Strategic management and environmental scanning [10]	Emergency management and civil protection [11], [33]
Primary question	What specific events could affect project objectives?	Which external forces could change the assumptions behind the project?	What capabilities are needed to cope with any disruption?
Unit of analysis	Discrete risk event	Macro-environmental driver or trend	Consequence and required capability
Time horizon	Project phase or baseline period	Medium to long term, often beyond delivery	Immediate response through to recovery
Typical tools	Risk register, probability–impact matrix, Monte Carlo analysis, contingency	Horizon scanning, driver mapping, scenario building	Hazard identification, consequence planning, business continuity, exercises
Main strength	Precise, auditable control of known risks	Breadth; reveals structural and slow-onset drivers	Robustness to surprise and to compound events
Typical blind spot	External, systemic and rare events	Weak link to quantified responses and ownership	Limited attention to commercial and strategic drivers

D. Modern Volatility and the Case for a Holistic Approach

Management writers have been using the term VUCA (volatile, uncertain, complex and ambiguous) for some time now to describe environments where organizations experience an increasingly unstable operating environment and argue that each condition requires a specific type of organizational response; specifically, volatility is best addressed with the use of buffers and agility rather than enhanced predictive capabilities. As noted above, prior research related to systemic and emerging risks has cautioned that today's society faces risks that transcend individual sectors and borders and cannot be effectively managed by any single organization or discipline. More recently, authors who write about polycrisis argue that formerly discrete global shocks (such as pandemic, climate change, financial fragility and geopolitical conflict) now interact through interconnected causal pathways creating synergistic effects among previously isolated stressors (i.e., a shock in one area increases stressors in other areas). Risk assessments conducted internationally show the same pattern of interconnection among the five major categories of risk: economic, environmental, geopolitical, social/societal and technological [8].

A second factor regarding climate change adds a significant structural dimension to what may otherwise be considered simply another form of external disruption (PESTLE). Specifically, the Intergovernmental Panel on Climate Change (IPCC) notes that extreme temperatures, heavy rainfall events and increased frequency/intensity of droughts have become more prevalent in many parts of the world. Moreover, as global temperatures continue to rise, it can be anticipated that the number and severity of climate-related disasters will continue to grow [38]. For infrastructure that was originally designed to operate for 50+ years under a stable environmental baseline, this new reality implies that the environmental baseline upon which original designs were based is no longer static. Therefore, climate change represents both a slow onset PESTLE driver affecting regulations, design standards and resource availability as well as a rapid onset hazard generator (floods, heat waves, droughts etc).

As such, these factors contribute significantly toward explaining why a holistic perspective is necessary to address the rapidly changing nature of uncertainty. No single lens exists to capture the full scope of the uncertainty created by modern volatility. Traditional PRM addresses internal risks that are known while PESTLE identifies changes in the external environment that create structural shifts. All-hazard thinking provides the capability to respond to any sudden disruption regardless of its source. A holistic framework would provide a common register where

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these lenses are integrated into a common governance process (and single governance cycle), and where there is shared ownership.

E. Research Gap

Three gap areas are identified within this literature review. Firstly, whilst mega-project scholars have consistently stated that external and institutional risks are major threats to mega projects (i.e., [21][23][24]), surprisingly little advice or guidance exists regarding how information gathered during an external scan (e.g. PESTLE) can be formally integrated into the project's overall risk management processes. Secondly, although all-hazards approaches to risk assessment and response are clearly established and well used in public safety domains (e.g. emergency planning), they have had limited translation into the realms of project and program management; indeed, it appears that business continuity planning is primarily seen as an operational issue rather than one that falls under the remit of governance in many organizations. Finally, very few studies examine both perspectives on documenting mega-project experiences simultaneously. Additionally, even fewer have assessed the extent to which recent increased volatility may have altered the comparative weights given to external and hazard related drivers. The purpose of this research is to address each of these three gaps via a combination of an integrative review with a structured case study and propose a holistic framework.

III. METHODOLOGY

The study follows a qualitative, interpretive design suited to a field in which concepts are drawn from several disciplines and in which the phenomena of interest, external drivers and rare disruptions, are not easily captured by large quantitative datasets. It combines an integrative literature review with a structured, multiple-case documentary analysis and a conceptual modelling step.

A. Research Design

An integrative review was chosen as opposed to a narrow systematic review in order to allow for integration of all three (project management, strategic management, and emergency management) disciplines' vocabulary to be integrated together with respect to the research question. The results of this integrative review helped develop the analytical categories to use during the case study; specifically, the 6 PESTLE categories and an additional dimension of exogenous hazards. After developing these categories, a multiple-case design was selected as it allows the researcher to compare cases and look for patterns in each category which would likely not have been visible using single cases [30], ultimately helping to synthesize the findings into a conceptual framework and two simple index tools to aid practitioners.

B. Data Collection

Academic literature was identified via major academic database search using various combinations of search terms (e.g., "megaproject," "large engineering project", "risk management", "uncertainty", "PESTLE" or "PEST", "all-hazards", "resilience") with supplemental use of backward citation tracking for prominent studies [1], [21] , [23]. In addition to academic literature, standards and policy statements from ISO, PMI, COSO, FEMA, the United Nations, and government agencies were used due to their role in establishing general best practices [5], [7], [11], [13], [33].

The eight mega-projects examined in this study were selected on a purposeful basis based upon four factors: A) a cost greater than $one billion; B) a body of significant public documentation (audit reports, reports of parliamentary or legislative inquiry, court records, etc.) documenting each project's performance; C) sufficient time elapsed since the initiation of each project to allow the impacts of changing environmental conditions to be assessed; D) projects located in different sectors and regions. The eight mega-projects examined are: the Boston Central Artery/Tunnel Project, the Channel Tunnel Project, Berlin Brandenburg International Airport, Crossrail (Elizabeth Line), the Panama Canal Expansion Project, Hinkley Point C Nuclear Power Plant, HS2 High Speed Railway, and the Mumbai-Ahmadabad High-Speed Railway. These mega-projects represent completed and ongoing projects in the transportation, energy, and water infrastructure sectors. This sample includes an Indian case to reflect the rapid growth of mega-project investments in emerging economies. Additionally, this sample represents two distinct time frames: Two mega-projects were completed prior to 2010 (Channel Tunnel and Boston Central Artery/Tunnel); Six mega-projects have been under construction/opening/operating as new assets subsequent to 2019 providing preliminary evidence of comparisons between two periods of relative stability and volatility.

C. Analysis Procedure

Each of these cases were analyzed from the publicly available data, and all of the primary reasons for increased costs, delays, re-scope changes, or disruptions were identified. The primary reason for each driver was then assigned to either one of the PESTLE categories or an Exogenous-Hazard category. An Exogenous-Hazard is

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defined as an unplanned-for occurrence that occurs beyond the control of the project and its stakeholders. Examples include pandemics, extreme weather events or accidents occurring at other locations. For each case and each dimension, the impact of each driver was quantified using an ordinal scale: 2 (Primary), where the dimension had been cited by multiple credible sources as the most significant cause of cost, time, or scope change; 1 (Secondary), where there was evidence the dimension had made some contribution to the problem, but it had not been the defining factor; and 0 (No Material Influence), where there was no indication of influence based upon a review of the documents.

To translate the conceptual findings into a usable form, two indices are proposed. The first is an Integrated Exposure Index (IEI) for a project *p*, which aggregates exposure across PESTLE dimensions while explicitly incorporating vulnerability:

$$IEI_p = \Sigma_{d \in D}\, w_d \cdot \Sigma_k \left(L_{k,d} \times C_{k,d} \times V_{k,d} \right) \qquad \ldots\ldots(1)$$

Where $D = \{P, Ec, S, T, L, En\}$ is the set of PESTLE dimensions, w_d is a weight reflecting the strategic importance of dimension *d* for the project, $L_{k,d}$ is the assessed likelihood or plausibility of driver *k* within dimension *d* over the project horizon, $C_{k,d}$ is its consequence for project objectives, and $V_{k,d}$ is a vulnerability factor between 0 and 1 representing how far existing controls fail to buffer the driver. The vulnerability term distinguishes the IEI from a conventional probability–impact product, because two projects facing the same external driver may be very differently exposed.

The second index is an all-hazards Capability-Gap Score (CGS), which moves the focus from causes to consequences:

$$CGS_p = \Sigma_{c \in K}\, max\,(0, R_c - A_c) \qquad \ldots\ldots(2)$$

Where *K* is a set of consequence categories common to many hazards (for example loss of site access, loss of key workforce, interruption of critical supply, loss of digital systems, and loss of public or regulatory confidence), R_c is the required level of capability to maintain or recover project functions for consequence *c*, and A_c is the capability actually available. Both are scored on a common ordinal scale through structured expert judgement. A rising IEI signals growing structural exposure in the external environment, while a positive CGS signals where the project would be unable to cope with a disruption whatever its cause. Figure 1 shows how the two lenses and the conventional register combine.

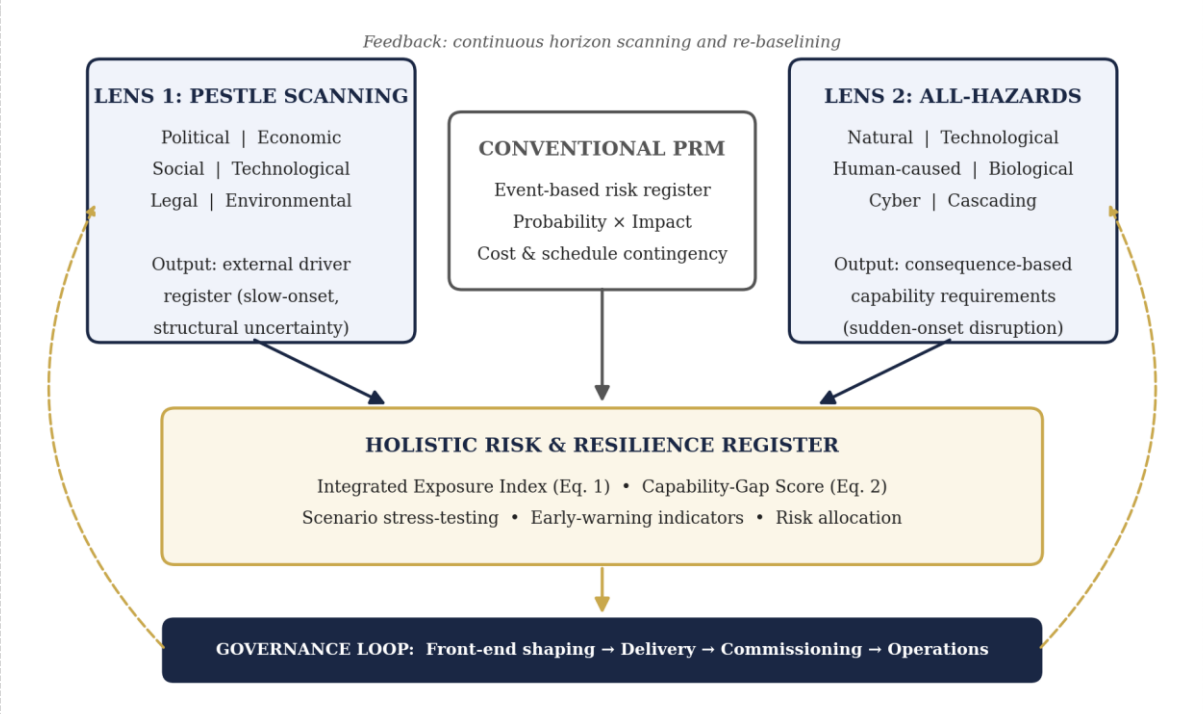


Figure 1. Holistic PESTLE and all-hazards risk framework for mega-projects under modern volatility.

IV. RESULTS

This section reports the case findings in four steps: a profile of the documented drivers in each project, a cross-case comparison of their distribution across the PESTLE and hazard dimensions, a set of recurring patterns that conventional PRM appears to have under-weighted, and an illustrative application of the proposed indices.

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A. Case Profiles

Table 2 summarises the principal documented drivers in each project. The descriptions are deliberately concise and are restricted to features widely reported in public sources.

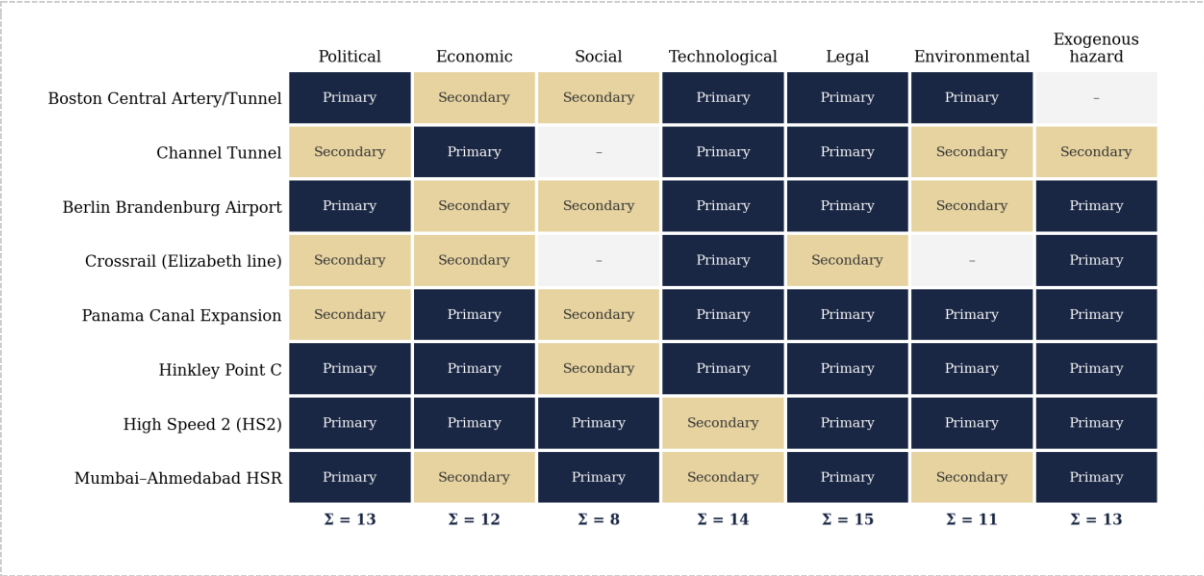
Table 2. Profile of the Eight Mega-Project Cases and Their Principal Documented Drivers.

Project	Location / delivery period	Principal documented drivers of cost, schedule or scope change	Dominant dimensions
Boston Central Artery/Tunnel	USA, c. 1991–2007	Large escalation from early estimates; extensive environmental and community mitigation commitments; complex federal–state funding politics; construction defects, litigation and a fatal 2006 tunnel ceiling-panel failure.	P, T, L, En
Channel Tunnel	UK–France, 1988–1994	Substantial cost overrun; evolving safety requirements from the binational regulator; contractual disputes between owner and contractor; financing stress and traffic shortfall; a 1996 fire during early operations.	Ec, T, L
Berlin Brandenburg Airport	Germany, 2006–2020	Opening planned for 2011–2012 cancelled weeks beforehand over fire-protection system deficiencies; politically constituted supervisory governance; design changes during construction; legal and noise-protection issues; opened in October 2020 amid the COVID-19 pandemic.	P, T, L, hazard
Crossrail (Elizabeth line)	UK, 2009–2022	Planned December 2018 opening deferred to May 2022; difficulties integrating signalling, train and station systems; governance and reporting weaknesses; COVID-19 restrictions during the final testing phase.	T, hazard
Panama Canal Expansion	Panama, 2007–2016	Approved by national referendum; opening about two years late; prolonged contractor claims and arbitration; concrete and gate-related technical issues; water-supply constraints, with severe drought restricting transits in 2023.	Ec, T, L, En, hazard
Hinkley Point C	UK, 2016–ongoing	First-of-a-kind EPR construction in the UK; repeated cost and schedule re-estimates; government contract-for-difference and national-security scrutiny of foreign investment; marine-ecology mitigation; pandemic and inflation effects.	P, Ec, T, L, En, hazard
High Speed 2 (HS2)	UK, 2017–ongoing	Major cost growth; hybrid-bill consenting and legal challenges; sustained community and environmental opposition; cancellation of the northern leg in 2023; pandemic and inflation pressures.	P, Ec, S, L, En, hazard
Mumbai–Ahmedabad HSR	India, 2017–ongoing	Land acquisition delays, particularly in Maharashtra; shifting state-level political support; farmer and community concerns; environmental clearances in sensitive coastal and wildlife zones; COVID-19 disruption; international technology and financing partnership.	P, S, L, hazard

B. Cross-Case Distribution of Drivers

A total sum of all ordinal ratings per case is possible to reach up to 16 points for each of the dimensions. The legal drivers have the largest amount of points with a sum of 15, then follow the technological drivers with an amount of 14, as well as political drivers and external risks both with an amount of 13. Economic drivers had the smallest number of points with an amount of 12, followed by environmental drivers with 11 and finally social drivers with an amount of 8. As it can be seen in figure 2, legal drivers were rated as the most important driver in seven out of eight projects. This demonstrates how often legal issues such as consenting regimes, contractual disputes or litigation occur when delivering mega-projects. In addition, technological drivers are ranked as the second most important driver in six cases. This is due to the fact that many of these projects contain first-of-a-kind engineering and/or system integrations. Finally, political drivers were ranked as the third most important driver in five of the eight cases and as the fourth most important driver in the remaining three cases. Therefore, there are no mega-projects among the studied projects which are completely unaffected by political factors.

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	Political	Economic	Social	Technological	Legal	Environmental	Exogenous hazard
Boston Central Artery/Tunnel	Primary	Secondary	Secondary	Primary	Primary	Primary	–
Channel Tunnel	Secondary	Primary	–	Primary	Primary	Secondary	Secondary
Berlin Brandenburg Airport	Primary	Secondary	Secondary	Primary	Primary	Secondary	Primary
Crossrail (Elizabeth line)	Secondary	Secondary	–	Primary	Secondary	–	Primary
Panama Canal Expansion	Secondary	Primary	Secondary	Primary	Primary	Primary	Primary
Hinkley Point C	Primary	Primary	Secondary	Primary	Primary	Primary	Primary
High Speed 2 (HS2)	Primary	Primary	Primary	Secondary	Primary	Primary	Primary
Mumbai–Ahmedabad HSR	Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary
	Σ = 13	**Σ = 12**	**Σ = 8**	**Σ = 14**	**Σ = 15**	**Σ = 11**	**Σ = 13**

Figure 2. Coded influence of PESTLE dimensions and exogenous hazards across the eight mega-project cases (Σ = aggregate score, maximum 16).

A special emphasis should be placed on the exogenous-hazard dimension. An outside event significantly impacted seven of the eight projects. Six (Berlin Brandenburg Airport, Crossrail, Panama Canal Expansion, Hinkley Point C, HS2, and Mumbai-Ahmedabad HSR) had their exogenous events coded as primary; for example, due to the COVID-19 pandemic. In addition to the effects of the COVID-19 pandemic, the 2018 climate-related drought that restricted operation of the completed Panama Canal Expansion asset was also considered as primary. The 1996 fire in the Channel Tunnel that occurred after it opened resulted in significant operational and financial consequences and was therefore coded as secondary. Only the Boston project did not have a notable exogenous-hazard based on the reviewed sources; Boston's main failure was a technology flaw internally related to the project when it failed in 2006.

The time at which these hazards occurred provides some additional insight into this data. All three projects that were completed prior to 2010 received exogenous-hazard scores of 0 or 1. Conversely, five of the six projects that were either still under construction, opening, or operating as a new asset after 2019 received an exogenous-hazard score of 2. That is, each of the six projects that were under construction, opening, or operating as a new asset after 2019 experienced an external hazard as one of the primary drivers of disruptions. Although the sample size is limited and there is no basis for statistical comparison between these groups, the pattern observed here supports the notion that increasing levels of volatility since 2019 have increased the relevance of external hazards relative to those that exist within a project and/or its institutional framework.

In terms of overall project-level scores, they varied from a low of 7 (Crossrail) up to a high of 13 (both Hinkley Point C and HS2). The two highest scoring projects are currently ongoing, long-duration projects with significant public funding/guarantees and a high policy profile. This supports the assertion that as project duration increases and/or as projects become increasingly relevant to politics, so too does exposure to elements of the external environment [1], [21]. Crossrail is representative of a project that was primarily affected by problems integrating technologies, while its principal external disruption was a result of a generalized pandemic (not project-specific)

C. Recurring Patterns

Four of the identified patterns are common among the case studies. The first of those patterns is compound impact; external factors normally do not act singly. Both the technical failures of the Berlin Brandenburg airport (technical problems) and the political decisions surrounding the cancellation of the northern part of the High Speed Rail link (political) in conjunction with the costs associated with building the high-speed rail system (cost inflation), and the subsequent delays caused by the various court actions taken against the project (legal process), acted upon one another. As well, many technical issues have been made worse by government policies that make it difficult to assign responsibility for those technical issues. A traditional register that assesses individual risks does not take into account how individual risks interact. Another illustration of this interaction can be seen at a local level in the wake of the 2026 war between Iran and its neighbors, when the closure of the Strait of Hormuz, which has historically served as a choke-point for nearly 20% of world-wide petroleum imports, impacted the ability of Iraq to export oil from its southern fields. With those exports came the loss of Iraqi revenue on which the Iraqi government's own large-scale construction program was dependent.

The second identified pattern is slow onset. Many of the most significant contributing factors toward their respective disasters took place slowly and cumulatively over time. For instance, the development of new public

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support for the northern portion of the UK's High-Speed Rail line took years, as did the accumulation of land acquisition problems for India's proposed Mumbai-Ahmedabad bullet train, and the gradual diminishment of available fresh-water resources in Panama. While each of these was observable as "gray rhinos" i.e., foreseeable but ignored until too late -- rather than "black swans," which would have come without warning [27] they tend to be considered only as implicit backdrops rather than explicitly recognized as managed risks. Similarly, Iran's threat to block the Strait of Hormuz, through which flow about one-fifth of global crude oil shipments [43], had been debated for decades prior to being realized in 2026.

The third identified pattern is life cycle span. External factors often impeded or otherwise negatively influenced a project at some point beyond when typical attention regarding the project's risks, via PRM, tends to fade. For example, while operational registers might recognize risks related to a mega-project's operations phase, neither they nor delivery-phase registers may capture fully the extent of a mega-project's risk exposure post-delivery. An illustration of this is provided by the Panama Canal droughts and the fire that damaged the Channel Tunnel. Each occurred while the relevant assets were in operation. More starkly still is Sudan's Merowe Dam, Sudan's single largest hydroelectric power plant. During Sudan's civil war which began in early April 2023, it was attacked by drone’s multiple times, resulting in blackouts for several states throughout Sudan long after it entered commercial operation [44], [45].

The fourth identified pattern is similarity in impact despite differences in hazard type. A pandemic, labor disputes and regional disasters alike will similarly hinder access to critical workforce and/or restrict site access. These impacts were also those in which the projects under study experienced their greatest losses. This is precisely what all-hazard planning seeks to mitigate [11]. For example, while there are many differences between a pandemic and a regional conflict such as cause, scope and severity -- both resulted in restrictions on labor mobility and materials availability and forced delay of programs and/or invocation of force majeure provisions in the Gulf region [39], [46].

Table 3 synthesises how these patterns map onto the respective strengths of each analytical lens.

Table 3. Mapping of Observed Patterns to Analytical Lenses.

Observed pattern	Conventional PRM	PESTLE analysis	All-hazards thinking
Compounding of drivers	Weak: risks scored independently	Moderate: reveals interdependent external drivers	Moderate: plans for combined consequences
Slow-onset drivers	Weak: treated as background assumptions	Strong: designed for trend and horizon scanning	Weak: focused on sudden disruption
Life-cycle reach	Moderate: phase-bound registers	Strong: long-term outlook	Strong: continuity extends into operations
Consequence convergence	Weak: cause-specific responses	Weak: driver-focused	Strong: capability-based planning
Known technical risks	Strong: precise quantification and control	Weak: not its purpose	Moderate: only where disruptive

D. Illustrative Application of the Proposed Indices

To illustrate how Equations (1) and (2), as outlined, may be used practically in terms of quantifying them, an illustration was made using a hypothetical high speed rail case that somewhat reflects the identified transport trends. As such, all values illustrated here are strictly hypothetical and should not be taken as indicative or representative of any specific existing development. Likewise, likelihood (L) and consequences (C) were assigned scores ranging from 1–5; vulnerability (V) scores ranged from 0–1; and dimension weights (w) total to 100% so as to be normalized. A single most significant factor was assumed for each dimension. The results of these calculations are shown in Table 4

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Table 4. Illustrative Calculation of the Integrated Exposure Index for a Hypothetical High-Speed Rail Project.

Dimension	Dominant driver (illustrative)	w	L	C	V	w·L·C·V
Political	Change of government leading to review of later phases	0.20	4	5	0.6	2.40
Economic	Sustained construction cost inflation	0.20	4	4	0.5	1.60
Social	Land acquisition resistance in peri-urban districts	0.15	3	4	0.7	1.26
Technological	Signalling and systems integration with imported technology	0.15	3	4	0.4	0.72
Legal	Challenge to environmental or land consents	0.20	4	4	0.6	1.92
Environmental	Extreme rainfall affecting earthworks and schedule	0.10	3	3	0.5	0.45
Total	Integrated Exposure Index (maximum possible = 25)	1.00				8.35

To illustrate how Equations (1) and (2), as well as the Indices shown below them, could be operationalized an Index-based hypothetical High-Speed Rail Project with characteristics similar to those illustrated in the transportation examples described previously was created. All values within these examples are illustrative and should NOT be interpreted as actual estimates for a real project. Values for the likelihood (L) and consequence (C) components are based on a scale of 1–5; while the Vulnerability (V) component will be scored from 0 – 1. Each of the Dimension Weights (w) will also sum to 1. In order to simplify the calculation process, we have identified a single dominant driver for each of the Dimensions. The Calculation Process is outlined in Table 4. The Total IEI Value of approximately 8.35 represents slightly less than one-third of the Maximum Possible Value, with three of the four Dimensions being Political, Legal and Economic contributing approximately 71% to the total value. There are two items worthy of note. Firstly, the Social Driver is ranked higher than the Technological Driver (despite both having the same Likelihood and Consequence Scores), due to the fact that the project has weaker Controls for Land Acquisition (V=0.7) compared to Systems Integration (V=0.4). This is an item that a traditional Probability-Impact Matrix would not have been able to identify. Secondly, the Index points out Drivers that are primarily owned by Sponsors/Government (as opposed to the Delivery Team) indicating support for Sponsor-Level Ownership as suggested in Section V.

The same hypothetical project was then used to assess five different Consequences using a 1–5 Scale to represent Required (R) vs. Available (A) Capability, with the following Illustrative Scores:

* Loss of Site Access (Required Capability R = 4, Available Capability A = 3, Gap = 1)
* Loss of Key Workforce (Required Capability R = 4, Available Capability A = 2, Gap = 2)
* Interruption of Critical Supply (Required Capability R = 5, Available Capability A = 3, Gap = 2)
* Loss of Digital & Control Systems (Required Capability R = 4, Available Capability A = 4, Gap = 0)
* Loss of Public/Regulatory Confidence (Required Capability R = 4, Available Capability A = 2, Gap = 2)

This resulted in a CGS Value of 7; indicating that the project would be most susceptible to Disruptions regardless of Cause, associated with removing Skilled Workers, Disrupting Specialized Supplies and/or Eroding Public Trust. It is precisely these types of Consequences that were produced in many of the Real Cases during the Pandemic and subsequent Inflation Shocks and Local Opposition, illustrating how the All-Hazard Lens produces a Short List of Priorities for Capability across Diverse Hazards.

V. DISCUSSION

The results confirm a key argument of this paper that conventional Project Risk Management (PRM) is important but insufficient to ensure successful mega-project delivery. It also demonstrates that the limitations of conventional PRM are systemic and not merely a matter of chance. In this section, I will explain what the research

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found; how both perspectives have become even more important; how we can apply the overall framework practically; and how far it falls short as an academic contribution.

A. Why Conventional Practice Falls Short

The results show that the central idea behind this paper holds; whilst conventional PRM is required it is insufficient for mega-projects. Furthermore, the shortcomings of conventional PRM are inherent (systematic) as opposed to simply being the result of poor application or luck.

This section provides an interpretation of the findings. It discusses why the importance of both lenses has been revitalised. It outlines the holistic framework within which to provide a practical approach to risk management in mega-projects. Finally, it addresses the study's constraints.

It can be seen that legal, political and technological aspects dominate the case matrix. Miller and Lessard found that institutional and external risks are the greatest threats to large engineering projects [21]. It should also be noted that there are two additional observations from the current work; seven of the eight projects had material impacts resulting from an external event, and six of those same projects were impacted primarily due to that event. In many cases these events would likely be included on the risk register at best only as rare occurrence-type entries. As a result, contingency planning will likely focus solely upon other types of events and/or their likelihoods/impacts. Because the probability – impact matrix is designed to reduce such events to the lower priority regions, and because the scores used in the matrix are typically based upon historical data that does not account for the specific hazards associated with a given project, [20], [26].

In addition, it appears that part of the issue lies with how organisations function. Project delivery teams typically maintain ownership of risk registers, but do so under limited remits and authorities that usually stop at the point where responsibility transitions to a higher level entity (e.g., a ministry). Sponsors and ministerial boards, however, control political/legal/macro-economic drivers. Where these drivers are not formally allocated, they may exist outside of either the sponsor or project delivery teams' areas of responsibility. This is consistent with prior literature regarding governance and stakeholder management as major contributors to success/failure of mega-projects [23], [25]; and with prior literature demonstrating that forecasting errors related to large-scale construction projects are attributable as much to behaviour/politics as to technology [2], [4].

B. Why the Importance of PESTLE and All-Hazards Thinking Has Been Renewed

Three major reasons support the notion that both lenses will be relevant today much more so than they were recently. The first lens is about the compression of change. Where before changes to the macro-environment occurred over decades (such as changing interest rates, energy price trends, international trade agreements, or shifting climate baseline) these changes are occurring during the time frame of a single project's implementation. In an era when we had relative stability in our macro environment, a PESTLE analysis developed to inform the business case for a particular project would likely be good for many years. However, with modern instability a PESTLE analysis may become outdated within just a few months. Therefore, instead of continuous scanning being seen as a "refinement" of this type of analysis, it has evolved into an absolute necessity.

The second lens describes how recent shocks are not coming singly but rather as a combination of disruptions. For example, the COVID-19 pandemic caused labor shortages and disruptions to supply chains; which contributed to inflationary pressures; which then increased the cost of financing projects and heightened political scrutiny of project budget expenditures. As stated above, this is what is referred to in the literature as the polycrisis dynamic [8] [9]; and it is clearly demonstrated by examples from both HS2 and Hinkley Point C. To identify such interdependent chains and to develop all-hazards planning strategies to mitigate the impact of such chain reactions, holistic multi-dimensionality analysis is necessary.

A fourth link to these types of chain reactions was added in June 2026 when an Iran war occurred in the Gulf region. A single security shock impacted energy supplies, shipping, labor mobility and investor confidence simultaneously (Section V.F).

The third lens demonstrates how the buffers we use to manage risk have been exhausted. Contingency reserve accounts and schedule floats are designed to absorb variability in the risks we know. When multiple significant external shocks occur at the same time, contingency reserve accounts and schedule floats are quickly depleted leaving any additional disruptions to flow directly to costs and/or completion dates. Capability based resilience provides a secondary layer of defense against unanticipated events [29]; and since capability based resilience is independent of predicting the occurrence of a specific event, together these three lenses provide strong rationale

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for why those tools that were previously relegated to secondary status will again occupy center stage in mega-project governance.

C. Complementarity of PESTLE and All-Hazards Thinking

PESTLE and all-hazards thinking represent different aspects of the uncertainty continuum. The PESTLE tool is best suited to situations that have slow changing conditions and are structurally based; i.e. the evolution of a new policy direction, the onset of inflationary trends, changes in legal precedents or changes to the climate. On the other hand, all-hazards thinking will be most effective in situations characterized by rapid and unpredictable change; e.g. pandemics, cyber-attacks, floods, etc. Conventional PRM falls somewhere in the middle of this continuum with respect to specificity. The combination of PESTLE and all-hazard thinking allows us to consider uncertainty across a broader spectrum than would either alone. A combination of these approaches represents a whole system perspective on uncertainty.

It is critical to note that PESTLE and all-hazards thinking complement each other. The PESTLE process produces potential future "scenarios" that serve as the basis for testing all-hazards preparedness and response capabilities; e.g., a scenario representing high inflation rates combined with a change in government leadership and adverse seasonal weather provides a real-world assessment of workforce, supply chain and access-to-site preparedness. In addition, all-hazards consequence analysis provides a tangible endpoint for PESTLE-generated information. In turn, it converts the abstractions generated through PESTLE into specific capability, contingency and contractual flexibility needs. It is this interdependency of the two approaches that makes them truly integrated rather than simply co-existent.

D. A Holistic Framework Across the Project Life Cycle

Building on Figure 1, Table 5 sets out how the holistic framework can be applied across the main phases of a mega-project. The framework is deliberately designed to sit alongside ISO 31000 and the PMI standards rather than to replace them, so that organisations can adopt it within existing governance structures [5], [7].

Table 5. Application of the Holistic Framework Across the Mega-Project Life Cycle.

Life-cycle phase	PESTLE activity	All-hazards activity	Key outputs
Front-end and business case	Full PESTLE scan; driver mapping; long-horizon scenarios; reference-class checks of economic assumptions [3]	Hazard screening for the site and supply chain; definition of consequence categories	Baseline IEI; scenario set; preliminary CGS; risk-informed options appraisal
Procurement and contracting	Allocation of political, legal and economic risks between owner, state and contractors	Continuity obligations, force-majeure scope and step-in rights written into contracts	Risk-allocation matrix; resilience clauses; insurance strategy
Delivery	Periodic re-scanning (e.g. quarterly); early-warning indicators linked to the register	Capability exercises; supplier and workforce continuity plans; cyber resilience	Updated IEI and CGS; dashboard; re-baselining triggers
Commissioning and handover	Review of regulatory and public-acceptance drivers for operations	Integrated testing under disruption scenarios; transfer of continuity plans to the operator	Operational risk and resilience file
Operations	Continuing horizon scanning of policy, demand and climate trends	Adaptive maintenance; climate-resilience upgrades; incident learning	Asset resilience plan; feedback to future projects

Three key practical design considerations arise from this evidence. Firstly, owner of the external PESTLE factors should always align with the owner of the driver. Political/ Legal Risks should therefore be escalated to either Sponsor or Board Level when they occur, to remove responsibility from those who cannot take action. Secondly, scanning must be continuous. Preparing a PESTLE Analysis as part of your Business Case preparation is insufficient over the life of a project (10 – 15 years) to provide you adequate protection. Scanning should be regularly reviewed/renewed based on lead indicators, and whenever changes occur. Thirdly, all capability development must be exercised. Plans developed to address all hazards will only be effective if exercise(s) have been conducted using Table Top and Live Exercises. This is common in Emergency Management, however is less frequent in Project Delivery [11].

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Table 6. Illustrative Early-Warning Indicators by PESTLE Dimension.

Dimension	Example mega-project driver	Leading indicator	Typical pre-planned response
Political	Change of government or policy priority	Election calendar; manifesto commitments; parliamentary or assembly debates	Cross-party engagement; phased commitments; review points built into approvals
Economic	Construction cost inflation and interest-rate changes	Construction price indices; central-bank guidance; commodity prices	Indexation clauses; hedging; staged procurement
Social	Community opposition or land acquisition delay	Grievance volumes; protest activity; acquisition progress against plan	Early benefit-sharing; independent mediation; route or design flexibility
Technological	Systems-integration failure or obsolescence	Integration test pass rates; supplier technology roadmaps	Incremental integration; modular architecture; technology refresh options
Legal	Consent challenge or regulatory change	Judicial review filings; draft regulations; regulator consultations	Legal readiness plans; design margins; regulator engagement
Environmental	Extreme weather, water stress or ecological constraint	Climate projections; seasonal forecasts; monitoring of protected species	Climate-adjusted design standards; seasonal scheduling; adaptive mitigation

The framework will also easily map into the structure of currently accepted standards, thereby making easier the transition. For example, in ISO 31000, the first phase includes developing the scope, defining the context and identifying the criteria for conducting a risk assessment [5]. This context-setting phase is performed in a methodical manner using PESTLE when considering the external aspects of this task. The IEI will provide documentation on how these contexts evolve over time. Similarly, ISO 31000 has defined risk treatment and continuous monitoring/review processes. Both of these are directly related to the concept of all-hazards capability development. Any capability gaps identified through equation (2) represent nothing other than treatment requirements stated in terms of consequences versus causes. Similar to ISO 31000, the PMI standard recognizes both threats and opportunities and defines both event-based and non-event based risks. Therefore, there is a foundation for formally documenting slow-onset external factors within the register. When viewed at the enterprise level, COSO integrates risk with strategy and performance. This serves as an anchor for sponsors who will ultimately be accountable for the environmental drivers identified via PESTLE [13].

Practically speaking, integration does not require duplication of efforts or establishment of a redundant organization. One registry can contain entries representing three types of information: conventional project-related risk exposures with corresponding probability-impact values; external driver-related information such as lead indicators associated with the results of a PESTLE scan and the owner of each driver; and/or consequence category requirements derived from an all-hazards analysis with required and available capability levels. Reporting will enable boards to view project-related risk exposure along with the results of the IEI and CGS analyses side-by-side. Thus, boards will have visibility regarding not only the remaining contingency value, but also the degree to which the project is exposed to its operating environment and the potential impact of any shocks experienced. Furthermore, as additional data accumulates across multiple projects, it may be possible to establish reference classes for external drivers, thereby expanding reference class forecasting beyond traditional application areas of cost and schedule to include broader elements of the overall risk environment [3].

E. Implications for Emerging Economies and India

The model applies particularly to new (emerging) economies that have a large number of mega-projects being invested in at this stage in their economic development as well as when institutions related to the delivery of such projects are still evolving. For example, both India's National Infrastructure Pipeline and the PM Gati Shakti National Master Plan represent a massive programmatic commitment to invest in transportation infrastructure, energy supply, logistics and urbanization. The Mumbai-Ahmedabad case study shows how four key issues (land acquisition, centre-state politics, social acceptability and environmental approvals) can be the determining factors in terms of project success more often than technical/ engineering risks. In addition to these challenges, India also has a significant risk of experiencing disasters including flooding, cyclones, heat waves and earthquakes. Project level all hazards planning aligned with the National Disaster Management Plan that followed the Sendai Framework would provide project investors with access to established hazard data, early warning systems and institutional arrangements. [33] [35]. A PESTLE analysis conducted specifically for the Indian context will require

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consideration of specific aspects including; land acquisition/rehabilitation laws, centre state coordination, monsoonal seasonal environmental restrictions and currency fluctuations affecting international funding projects.

F. Illustrative Evidence from the Middle East and North-East Africa

Emerging economies offer unique opportunities to apply the framework due to rapidly increasing investments in mega-projects and constantly changing institutional conditions. Mega-transport, energy, logistics and urban development investments of unparalleled scale are underway via India's national infrastructure pipeline (NIP) and the pm gati shakti national master plan. The example of the Mumbai-Ahmedabad mega-project demonstrates that land acquisition, centre-state political relationships, social acceptance and environmental approvals can lead to greater influence on outcomes than engineering risks. Additionally, india is vulnerable to numerous natural hazards such as flood, cyclone, heatwave and earthquake. Allowing project sponsors to utilize the existing hazard data, early warning systems and institutional frameworks as part of the National Disaster Management Plan (NDMP), which follows the sendai framework, will allow for all-hazard planning at the project level to occur. A PESTLE scan in relation to india should therefore place a high degree of emphasis upon laws relating to land and rehabilitation, centre-state co-ordination, monsoon related environmental limitations and foreign currency based funding for internationally funded mega-projects.

To assess whether similar trends exist where volatility is even higher, we refer to documented examples from the Middle East and north-eastern Africa. We selected examples from these regions because they were not included in the eight coded cases used in figure 2 but may serve as illustrative examples rather than as supplementary examples. Examples include the COVID-19 pandemic, ongoing conflicts in Sudan, Syria, Iraq and Yemen and the 2026 Iran war, which are summarized in terms of their alignment with the PESTLE lens and all-hazards lens in Table 7 below.

COVID-19 pandemic. The COVID-19 pandemic was the first wide-scale test of all-hazards preparedness for mega-project stakeholders in the gulf region. Prior to the outbreak of COVID-19, it was anticipated that expo 2020 Dubai would open in October 2020. Due to the COVID-19 pandemic, however, the member states of the Bureau International des Expositions agreed to postpone the start date of expo 2020 by one year to October 2021-March 2022 [39] at the request of the uae government. This example provides insight into how a large-scale fixed-date event mega-project is subject to a hazard that likely would not have ranked high on a project-specific list of hazards, but also serves to illustrate how consequence-based planning is effective. Specifically, although COVID-19 had many potential consequences for an event like expo 2020 (e.g., travel restrictions for attendees from abroad, limits on workers' ability to travel, limits on visitors), those consequences are equivalent to some of those that could arise from a regional conflict.

Sudan. The war that broke out in April 2023 between the Sudanese Armed Forces and the Rapid Support Forces shows what occurs when the political component of PESTLE fails completely. In addition to stopping new investments, the conflict has made infrastructure under construction or recently completed targets. Drone strikes against the Merowe Dam power station in January 2025 resulted in blackouts throughout parts of sudan including Port Sudan, Atbara, Dongola and Omdurman [44]. Further strikes against transformers servicing the northern state occurred in April 2025 [45], despite continued repair work being carried out. As such, mega-project investors in fragile environments need to ensure that their all-hazards plans incorporate physical asset protection, redundant power supplies and rapid response capabilities from day one instead of waiting until handover.

Syria. Over thirteen years of conflict have led Syria to require significant levels of post-conflict reconstruction; the World Bank estimates required investments amounting to approximately $us216 billion ($us140-$us345 billion) with approximately $us82 billion allocated towards infrastructure alone; in comparison the central estimate is roughly ten times larger than Syria's forecasted 2024 gdp [47]. An added layer of complexity for investors interested in reconstructing Syria is that there is a legal aspect to conflict risk. Lafarge operated a cement plant in northern Syria (at a cost of approximately $us680 million) during the conflict; lafarge subsequently entered into a plea agreement with u.s. Authorities admitting to conspiracy to provide material support to designated terrorist organizations regarding that operation; and in doing so agreed to pay approximately $us778 million in penalties [48]. Therefore, investors currently evaluating options for reconstruction projects in Syria must therefore evaluate them using a PESTLE scan that covers sanctions regimes, anti-terrorism legislation and actions taken by local partners in addition to conventional economic and political factors.

Iraq. The proposed grand faw port and associated Development Road is a transportation corridor spanning over 1200 kilometers at an estimated cost of approximately $us17 billion connecting Basra, Turkey and Europe; among its goals is to reduce reliance on oil revenues for at least 90% of the iraqi government's income [49], [54]. The war with iran in 2026 revealed both the rationale behind developing this strategy and the vulnerability of that strategy. When the Strait of Hormuz was closed down by iran for several months prior to march 2026, Iraq's exports of crude oil through that strait dropped from an average of about 93 million barrels per month prior to the

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war with iran to less than 10 million barrels in April 2026 [50], thereby reducing public sector funds upon which the corridor depends. Analysts also noted that while the closure strengthened the strategic justification for building an overland route it undermined its commercial basis as grand faw can only function as a port if vessels can navigate the northern gulf safely [49]. Consequently, a single external event simultaneously altered the political, economic and security assumptions underlying a single project in opposing directions. This represents exactly the type of compound impact that a static business-case approach incorporating only a traditional PESTLE analysis cannot address.

Yemen & red sea. Since late 2023, attacks on commercial shipping by Yemen's houthi movement demonstrate how instability in one country can undermine business case viability for mega-projects in another. As reported by the Suez Canal Authority, revenue generated by ship transit through the canal decreased from a record $us10.25 billion in 2023 to $us4 billion in 2024 while the number of ship transits decreased by more than half [40]. Egypt expanded the canal in 2015 anticipating increased volumes; a previously valid demand assumption regarding future volume was thus negatively impacted by a security incident beyond Egypt's control. The same crisis extended delivery routes, increased freight rates and insurance premiums for projects located throughout the region; an all-hazards plan would merely document this as interruptions to key supplies.

Iran war. Beginning on February 28th 2026 with u.s. And Israel airstrikes against Iran followed shortly thereafter by Iranian missile and drone attacks against all six gcc countries [41], is perhaps the most recent and severe regional testing point for our framework [41]. Within weeks Bahrain declared force majeure after Bapco's energy operations were halted; deliveries from ega ceased after its al-taweelah smelter was attacked; Qatar reportedly suffered losses equating to approximately 17% of its LNG production for up to five years; and repair costs for damage incurred by gulf energy infrastructure were estimated at $us58 billion [41], [42], [46], [51]. Following this shock waves spread to construction. Legal advisors reported that force majeure became a viable consideration for engineers who procure construction services for contracts dependent on cross-border labor and logistics [46]; and monthly contract awards in the gulf declined from an average of $us32 billion during the second half of 2025 to $us17 billion in May 2026 [52]. In Saudi Arabia cancellation of Webuild's contract for a lake at Trojena (a ski resort) as well as termination of high speed rail contract during the first half of 2026 also indicate how widespread and severe the effects of the Iran war were [53]. How much of those cancellations were due specifically to the war versus previous cost concerns remains unclear? Together these incidents present all four patterns illustrated in section iv: compounding (security/energy/financial/labour shocks mutually reinforcing); slow onset (the hormuz threat has existed for decades); life cycle reach (refineries/LNG trains/smelters were damaged long after completion); and consequence convergence (very different causes produced virtually identical disruptions in supply/worker/site).

Table 7. Illustrative Middle Eastern and North-East African Examples Mapped to the PESTLE and All-Hazards Lenses.

Example	Country / period	Principal disruption	Dominant dimensions	Main all-hazards consequence
Expo 2020 Dubai	UAE, 2020–2022	One-year postponement approved because of the COVID-19 pandemic [39]	P, Ec, hazard	Loss of participant, workforce and visitor access
Merowe Dam and national grid	Sudan, 2023–ongoing	Repeated drone strikes on an operating hydropower asset during civil war [44], [45]	P, S, T, hazard	Loss of power supply; damage to operating assets
Post-conflict reconstruction	Syria, 2011–ongoing	Reconstruction need of about US$216 billion; sanctions and criminal-law exposure of investors [47], [48]	P, Ec, L, hazard	Loss of site access; legal and reputational exposure
Grand Faw Port and Development Road	Iraq, 2020s–ongoing	Hormuz closure cut oil exports and revenue while raising the strategic case for the corridor [49], [50]	P, Ec, hazard	Loss of funding; interruption of maritime access
Suez Canal (2015 expansion)	Egypt / Yemen, 2023–2025	Houthi attacks roughly halved transits and cut revenue by about 60 percent [40]	P, Ec, hazard	Loss of demand; interruption of supply routes
Gulf energy and construction programmes, including NEOM	GCC states, 2026	Strikes on energy assets; force majeure; fall in contract awards; termination of NEOM contracts [41], [46], [52], [53]	P, Ec, L, hazard	Interruption of critical supply; loss of workforce; contract frustration

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Three lessons to apply to this framework are shown by this example.
Firstly; where there has been conflict in an area then both the legal/ political aspects of your PESTLE will need to include sanctions, security laws, terrorism legislation etc. In addition, you will want to refresh your PESTLE as often as possible based upon changes to regional data (i.e. when conditions change) and not just every couple of years as originally suggested.
Secondly; the capability gap score should provide some weighting to protect your operational assets and also potential alternatives for your supply chain (energy, raw materials and export markets). As many of the biggest losses have happened post project delivery and particularly at maritime choke points (e.g. Hormuz, Bab el-Mandeb, Suez).
Thirdly; when drafting force majeure provisions, step in rights and price adjustments (as listed in Table 5), you should assume a full-scale war in the region during the lifetime of a mega-project in the Middle East is possible, not just pandemics or natural disasters.

G. Barriers to Adoption and Enabling Conditions

A number of barriers (see Cases) explain why if the case for integrating is so compelling, why then is it not now a standard part of most organizations' practices? The first was the issue of incentives. Those who seek to gain approvals to develop a new facility (i.e., promoters) are interested in demonstrating their project has minimal risk. To acknowledge that they also expose many stakeholders to a broader array of externalities could weaken the business case for the development. In addition, the political discomfort associated with a thorough and objective assessment of external factors may make some developers reluctant to conduct a comprehensive PESTLE analysis; especially when it reveals dependence upon continued governmental support. As stated earlier, Reference Class Forecasting is one tool that can help mitigate these biases. This method compares the projected performance of a project against the results of previous like projects (Reference Projects).

The second barrier was discipline-based fragmentation. That is, those individuals responsible for managing or developing strategies related to risk management, emergency planning, and business continuity were typically educated in very different disciplines, utilize different terminology and usually report to different divisions within an organization. Thus, there exists a need for purposeful organizational design to integrate these separate functions and allow them to collectively work towards addressing a single set of problems. For instance, the development of a jointly-owned risk/resilience function and having this function report directly to the Sponsor Board would be essential in creating an environment that facilitates integrated thinking. Membership of this function should include representatives from each of the individual disciplines mentioned above.

The third barrier is measurement. Quantifiable measures produced through traditional PRM are easily incorporated into conventional financial approval processes. Conversely, qualitative measures produced through PESTLE assessments and All-Hazard analyses tend to provide little evidence of rigor. Some of the indices outlined in Section III were developed specifically to address this particular issue. These indexes were designed to quantify both external exposures and capability deficiencies/shortcomings in a manner that allows them to be audited and measured over time. Furthermore, the indexes also clearly articulate the subjective nature of these judgments [20].

Lastly, the cultural environment surrounding mega-project organizations can hinder the ability to successfully implement integrated approaches to managing risk and resilience. Literature on High Reliability Organizations (HROs) highlight preoccupation with failure, reluctance to oversimplify complex issues, and sensitivity to operations as key characteristics of HROs that are able to effectively manage uncertainty [28]. On the other hand, mega-project organizations often find themselves under significant pressure to demonstrate forward momentum and protect budget allocations. Therefore, leadership at these organizations that views warning signs as potential sources of valuable information instead of being viewed as bad news will create a necessary culture that will facilitate the successful implementation of integrated risk and resilience management methodologies.

H. Limitations

The results from this project are subject to several important limitations. First, the case study was developed from secondary data. As a result, the assignment of weights (ordinal coding) to each of the driver categories for the nine projects is subjective and can vary depending on how an analyst weighs the importance of these categories. Second, there is a very small sample size of eight projects with most being large-scale, high-profile transportation and energy projects. While these eight projects are representative of many other similar projects around the world, it does limit our ability to make statistical generalisations about all construction projects. Third, because we relied on only two previous studies (the EPC/Turnkey projects in France and Canada), it would be unwise to treat the comparisons we made between earlier and more recent construction projects as anything more than illustrative or suggestive. Fourth, ongoing projects (Hinkley Point C, HS2 and the Mumbai-Ahmedabad High Speed Rail Project) may experience future changes due to new developments. Fifth, while the proposed five project delivery system indices have been identified through extensive reviews of current practices and conceptual frameworks related to project delivery systems, no empirical testing has been conducted using these proposed indices. As a

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result, the utility of these proposed indices will ultimately rest on the quality of the expert judgment used to develop them. Sixth, the inclusion of Middle Eastern and North East African examples in Section V.F are based on official government statements, reports published by international organizations and contemporary newspaper articles covering the 2026 Iran War and subsequent developments. These examples were not included in Figure 2 and should therefore be viewed as illustrative examples rather than as additional case studies.

VI. CONCLUSION

This paper argues that modern volatility has revealed a gap between the traditional tools used in managing project risk and the type of uncertainty faced by mega-projects. Traditional project Risk Management (PRM) continues to be appropriate for known risks which are internal to the project. However, there is a tendency for PRM to ignore low frequency/low probability events (structural changes) occurring in the external environment and those caused by other external factors, which are becoming increasingly common and complex. There is empirical evidence from eight mega-projects that suggest that political, technological and legal influences were the most significant sources of disruption, that 7 out of the 8 projects studied had their development affected significantly by exogenous hazards and that every project currently being developed was influenced by at least one of these hazards as its key source of disruption. Empirical examples of this trend from MENA (Middle East and North Africa), e.g., delays caused by COVID-19 for the opening of Expo 2020 Dubai; physical damage resulting from conflict in Sudan, Syria, Iraq and Yemen and ongoing civil unrest/war in Iran since 2026, reinforce this point.

Therefore, the application of PESTLE analysis and All-Hazards thinking needs to be revitalized. PESTLE provides an expanded scope to consider the many Political, Economic, Social, Technological, Legal and Environmental factors that may change during a project's lifetime. All Hazards Thinking enables consideration of the impact of various different hazards rather than considering each hazard individually. Neither methodology will be enough on its own. The holistic framework outlined below integrates these two methodologies with established industry standards using a Common Register, Sponsor Level Ownership, One Governance Cycle, integrated with an Integrated Exposure Index and Capability-Gap score. The new methodology applies across the entire lifecycle of a mega-project. Its main contribution is to assist mega-project governance transition from an overly focused emphasis on controlling risk to developing greater capabilities for anticipating potential risks or threats and developing resiliency when operating in uncertain/volatile environments.

There are many avenues for future research. These include calibrating and validating the two proposed indexes (Integrated Exposure Index and Capability-Gap score) against actual data from current mega-project activities. Additionally, expanding the number of mega-projects examined and increasing geographical diversity of mega-projects analyzed in particular from Asia, Africa and Latin America. Another area for additional research includes investigating if the increase in external hazards impacting mega-projects has accelerated over time. It is also important to study how contractual and financing arrangements should appropriately apportion external and hazard-based risks. Future studies could also evaluate how use of Digital Tools (including Data Driven Horizon Scanning and Digital Twins) could facilitate real-time monitoring of PESTLE Analysis and All-Hazards Scenario Planning. Finally, replication of the coding methods utilized in this study by independent researchers would provide greater assurance in regards to the patterns identified above.

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