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Enhancing Hazmat Logistics Safety through IoT: A Practical Study Focused on Oman

Ali al Kalbani
Ph.D. Candidate, Department of Mechanical and Industrial Engineering
Sultan Qaboos University, Muscat, Oman
Lecturer, College of Economics and Business Administration
University of Technology and Applied Sciences – Al Mussanah, Oman
S85169@student.squ.edu.om, ali.alkalbani@utas.edu.om

Hakan Gultekin
Associate Professor
Department of Mechanical and Industrial Engineering
Sultan Qaboos University
Muscat, Sultanate of Oman
hgultekin@squ.edu.om

Nasr Al Hinai
Associate Professor and Head
Department of Mechanical and Industrial Engineering
Sultan Qaboos University
Muscat, Sultanate of Oman
nhinai@squ.edu.om

Abstract

This study investigates how the integration of Internet of Things (IoT) technologies can enhance the safety and efficiency of hazardous materials (hazmat) logistics in the Gulf Cooperation Council (GCC), with a specific focus on Oman. Using a qualitative approach, the study draws insights from semi-structured interviews with key logistics and regulatory stakeholders, supported by an extensive literature review. The conceptual framework explores four key independent variables: IoT-based real-time monitoring, predictive analytics, technology adoption readiness, and regulatory and institutional support, along with the mediating role of operational visibility. Thematic analysis of stakeholder perspectives reveals that while IoT adoption in hazmat logistics is still in its early stages, it offers substantial benefits in enhancing visibility, tracking, emergency responsiveness, and proactive risk forecasting. Respondents highlighted real-time monitoring as the most immediately impactful application, especially for managing temperature-sensitive and volatile cargo. Predictive analytics was also recognized as a valuable tool, though its adoption remains limited due to a shortage of skilled personnel and lack of integrated data platforms. Regulatory ambiguity, budget constraints, and resistance to change were cited as common barriers across public and private sectors. The study presents practical recommendations for accelerating IoT-driven transformation in the region. These include: (1) introducing national regulatory frameworks specifically tailored for hazmat and IoT integration, (2) investing in workforce training programs to bridge the digital skills gap, (3) developing public-private collaboration to standardize technologies, and (4) adopting pilot projects to demonstrate value and scalability.

Keywords
Internet of Things (IoT), Hazmat Logistics, Operational Visibility, Technology Adoption, Regulatory Readiness

1. Introduction
Hazardous materials (hazmat) transportation is one of the most vital and sensitive businesses sectors in logistics, especially in regions such as the GCC, since industrial growth and broadening trade links has increased the movement of hazmat goods over national borders. The safe and effective handling of such logistics is critical, as even one failure could result in a disastrous impact on the environment, economy, and public health. Oman, as part of the GCC, has increasingly recognized the importance of modernizing its logistics systems, especially those involving high-risk cargo.

The emergence of the Internet of Things (IoT) offers promising avenues for addressing these challenges. IoT technologies can significantly enhance visibility, traceability, and responsiveness across supply chains by enabling real-time monitoring, predictive analytics, and automated alerts. These capabilities are particularly valuable in hazmat logistics, where early detection of incidents and continuous oversight are essential for safety compliance and operational efficiency.

Despite this potential, the adoption of IoT in the logistics sector across the GCC remains uneven, with multiple barriers such as regulatory inertia, technological readiness gaps, and insufficient workforce skills. Existing literature points to the need for context-specific strategies that consider the technological, organizational, and institutional realities in countries like Oman. While global case studies demonstrate the benefits of IoT in enhancing logistics safety, there remains limited empirical research examining its implementation in the GCC region's hazmat logistics landscape.

This study aims to fill that gap by exploring how IoT integration influences the safety and efficiency of hazmat logistics in Oman. Drawing on a combination of literature review and stakeholder interviews, the study identifies key factors such as real-time monitoring, predictive analytics, regulatory support, and technology adoption. Operational visibility is examined as a mediating variable that enables these factors to translate into improved logistics outcomes.

Through this investigation, the research contributes to both theory and practice by offering a conceptual framework and practical recommendations for enhancing logistics safety using digital technologies. The insights presented are intended to inform policymakers, industry leaders, and technology providers on how to better leverage IoT for safer hazmat transport in the GCC context.

1.1 Objectives
This study aims to achieve the following objectives:
1. To examine the current state of IoT adoption in hazmat logistics in Oman and the broader GCC region.
2. To assess the influence of organizational readiness and regulatory frameworks on the successful implementation of IoT technologies in hazardous logistics.
3. To investigate the role of operational visibility as a mediating factor between IoT integration and logistics safety and efficiency outcomes.
4. To propose practical, policy-driven recommendations for accelerating IoT-based transformation in hazmat logistics across Oman and the GCC.

2. Literature Review
Hazardous materials (hazmat) logistics involve the transportation and storage of substances that pose considerable threats to public health, safety, and the environment. Within the context of the Gulf Cooperation Council (GCC), and specifically Oman, managing these risks has become increasingly critical as industrial activity grows. The literature supports a multifaceted understanding of the factors influencing safety and efficiency in hazmat logistics, particularly through the integration of Internet of Things (IoT) technologies.

Recent research acknowledges that the safety and efficiency of hazmat logistics depend on clear operational frameworks and adherence to risk mitigation protocols. For example, a GCC-based study by Sundarakani (2018) identified major safety compliance gaps among hazmat logistics providers and developed an initial risk-based safety framework. Although that study lacked detailed performance indicators, it highlighted foundational concerns such as the need for improved safety mechanisms and more proactive risk management strategies (Sundarakani, 2018).

2.1 IoT-Based Real-Time Monitoring in Hazmat Logistics
IoT-based real-time monitoring has emerged as a key enabler for improving both safety and efficiency in hazardous logistics. In the oil and gas sector, Ventulett and Villegas (2018) showed that IoT sensor networks can significantly improve emergency response and overall safety outcomes, a finding directly relevant to Oman's hazmat logistics context. This real-time monitoring through cloud-connected sensors enhanced situational awareness, particularly during hazardous incidents in remote operations. Similarly, Zhao et al. (2020) demonstrated that an IoT-enabled smart parking system with a genetic tracking algorithm enhanced vehicle monitoring and reduced congestion in a hazardous chemical logistics facility, achieving location tracking accuracy of around 96.7%. Both studies underline the value of integrating real-time IoT solutions with organizational procedures, resulting in tangible safety and operational benefits.

2.2 The Role of Predictive Analytics in Risk Forecasting
Predictive analytics plays a pivotal role in enhancing operational safety and efficiency across high-risk sectors, particularly logistics, transportation, and industrial operations. Wanasinghe et al. (2020), in a systematic review of IoT adoption in the oil and gas industry, demonstrated that IoT-enabled predictive maintenance solutions significantly reduce health and safety risks and lower operational costs through real-time monitoring. Similarly, Ghaffarpasand et al. (2022) emphasized the value of vehicle telematics in urban transport, supporting proactive safety interventions and eco-routing in congested logistics environments.

Recent advancements in artificial intelligence have further strengthened the predictive capabilities of safety systems. Chen (2024) demonstrated that an AI-based hybrid model integrating decision trees and neural networks reduced emergency response times by 20%. Acı et al. (2025) developed a hybrid deep neural network and random forest model that achieved 92% accuracy in predicting traffic crash severity. Complementing this, Soliani et al. (2025) applied machine learning techniques to fatigue-related data from self-employed truck drivers and achieved 85% accuracy in forecasting crash involvement. Together, these studies highlight the growing maturity and practical effectiveness of predictive analytics in anticipating and mitigating transportation risks.

2.3 Technology Adoption Challenges in the GCC
However, technology adoption across the GCC still faces systemic challenges. According to Al-Nabet (2021), a Technology-Organization-Environment (TOE) framework analysis in Qatar revealed that legal ambiguities, cybersecurity threats, and organizational inertia are major barriers to IoT deployment. Benayoune et al. (2022) further highlight human capital challenges, identifying a skills gap in Oman's logistics workforce and recommending closer alignment between educational outputs and industry needs for emerging technologies.

2.4 Regulatory and Institutional Support in Oman and the GCC
On the policy front, Masengu et al. (2024) note that Oman has made notable investments in port and logistics digital infrastructure (e.g., improving internet connectivity), yet IoT-specific regulatory frameworks remain underdeveloped. Importers and exporters still face challenges such as unclear documentation procedures, and overall digital adoption in logistics operations remains limited. Similarly, Al Kalbani, Masengu, and Al Habsi (2024) observe that infrastructure limitations and weak enforcement of digital transformation policies continue to hinder IoT adoption in Oman's logistics sector, underscoring the need for stronger governmental support. This regulatory inertia especially when contrasted with more structured international benchmarks indicates a need for tailored national frameworks to facilitate IoT integration in hazmat logistics.

2.5 Operational Visibility as a Mediating Factor
Finally, operational visibility emerges as a critical link between IoT deployment, policy implementation, and safety performance. Studies by Thibaud et al. (2018) and Ghaffarpasand et al. (2022) demonstrate that real-time data visibility achieved through IoT sensors, unmanned aerial vehicles (drones), and advanced vehicle telematics markedly enhances situational awareness and emergency readiness. These technologies not only improve driver behavior and fleet safety but also support greater organizational learning and responsiveness in high-risk scenarios.

2.6 Synthesis and Research Gaps

In sum, the literature confirms the transformative potential of IoT in hazmat logistics, especially when combined with predictive analytics and supported by enabling policies. However, IoT adoption across the GCC remains uneven, hindered by regulatory, technological, and human capital challenges. Addressing these gaps through targeted interventions such as updated national policies, workforce training programs, and the implementation of performance-based IoT frameworks could significantly enhance logistics safety and resilience in Oman and across the broader region.

The conceptual framework for this study is based on insights from the literature and interview data. It proposes that IoT real-time monitoring, predictive analytics, technology adoption, and regulatory support influence hazmat logistics safety and efficiency, with operational visibility acting as a mediating factor. The relationships are outlined through five hypotheses (H1–H5), as shown in Figure 1.

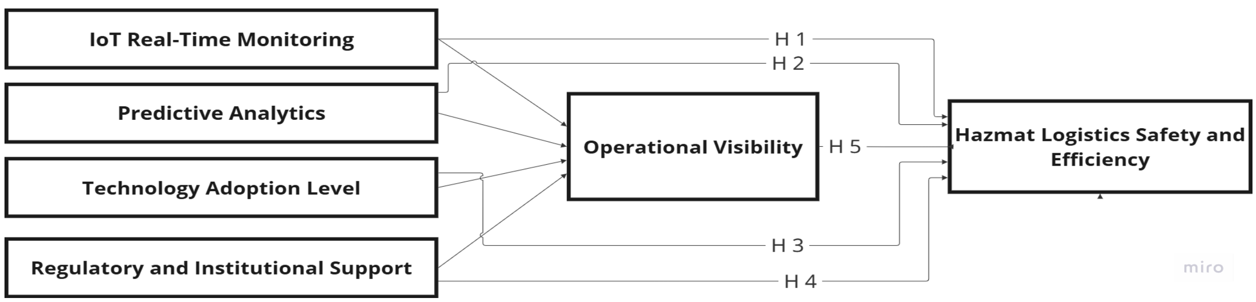

Figure 1. Conceptual framework diagram

3. Methods

This section outlines the research methodology employed to explore how IoT integration enhances safety and efficiency in hazmat logistics within the GCC region, with a particular focus on Oman. The study investigates the relationships between four independent variables IoT monitoring, predictive analytics, technology adoption, and regulatory support and the dependent variable of logistics safety and efficiency, mediated by operational visibility.

3.1 Research Design

A qualitative, exploratory research design was adopted to examine the use of emerging technologies within complex, real-world logistics environments. This approach allowed for capturing rich, contextual insights from practitioners and policymakers particularly important given the limited availability of empirical data in the Omani context.

3.2 Data Collection Methods

Semi-Structured Interviews, Primary data was collected through semi-structured interviews with logistics professionals, regulatory officials, and technology providers in Oman. Interview questions were aligned with the study's conceptual framework to explore perceptions, practices, and experiences related to IoT-based hazmat logistics. A total of eight stakeholders were interviewed, including representatives from seaports, transport authorities, oil and gas companies and private logistics firms.

Document and Literature Review, Secondary data was gathered through an extensive literature review of publications from 2019 to 2024. Key sources included journal articles, technical reports, policy documents, and conference proceedings accessed through platforms like Elicit and Semantic Scholar. This literature informed the theoretical foundation and supported the triangulation of interview findings.

3.3 Sampling Strategy

Purposive sampling was used to identify participants based on their professional roles, experience, and relevance to hazmat logistics and IoT deployment. The selection ensured a diverse range of perspectives across public and private sectors, covering both operational and policy-level actors.

3.4 Data Analysis Techniques
Interview transcripts were analyzed using thematic analysis. Manual coding was applied to identify patterns and themes aligned with the study's variables. Document analysis employed content coding to extract themes related to policy frameworks, technology implementation, and safety outcomes. The analysis emphasized linking the independent variables (e.g., IoT monitoring, predictive analytics) to operational visibility and the resulting impacts on safety and efficiency.

3.5 Ethical Considerations
The research adhered to ethical guidelines, including informed consent, participant anonymity, and confidentiality. All interviewees were briefed on the voluntary nature of their involvement, and institutional approval was secured prior to data collection.

3.6 Trustworthiness and Validity
To enhance trustworthiness, the study employed methodological triangulation by combining interview data with document analysis. Peer debriefing and member checking were conducted to validate interpretations. Comprehensive documentation of the research process was maintained to support transparency, consistency, and credibility.

4. Findings and Discussion
4.1 IoT-Based Real-Time Monitoring
Interview participants overwhelmingly underscored the importance of real-time IoT monitoring for hazmat operations. Many noted that current usage in Oman is still basic – for example, a logistics manager explained that "for us it is at an acceptable level as we are using only basic monitoring tools" . This reflects a general trend that most firms rely on rudimentary GPS trackers and simple environmental sensors (e.g. temperature or gas detectors). A few larger operators, however, have piloted comprehensive multi- sensor systems. An experienced HSE specialist observed that such deployments "transform Hazmat logistics from a reactive to a proactive discipline, where safety decisions are made on the basis of live data…[leading to] fewer incidents, quicker response times, and a stronger safety culture" . In practice, these early adopters use networks of sensors (GPS, humidity and gas detectors, geofencing, etc.) to gain much higher situational awareness and faster incident response.

These practitioner insights align closely with existing literature. Prior studies in high-risk industries show that cloud-connected sensor networks can significantly improve emergency response and overall safety outcomes. For example, Ventulett and Villegas (2018) found that real-time IoT monitoring in oil and gas operations greatly enhanced situational awareness during remote incidents. Likewise, system designers have demonstrated smart-tracking solutions that achieve over 90% location accuracy and reduce chemical transport delays (e.g. Zhao et al., 2020). Our interviewees' reports of early leak detection and streamlined hazard communications echo these findings. One logistics manager noted that even basic tracking data helped "streamline safety processes" by providing hard evidence on shipment conditions (paraphrased from interviewee). This confirms the literature's claim that IoT monitoring produces tangible safety and operational benefits.

However, the interviews extend our understanding by highlighting a notable gap: while the potential of real- time IoT monitoring is widely acknowledged, actual uptake in Oman remains nascent. Except for a few large oil-and-gas firms, most companies have "minimal usage" of IoT – a fact our participants did not seem surprised by. Indeed, one expert pointed out that only about 1–2% of Omani logistics firms were fully digitized as of 2023, underscoring how much room there is for growth. This challenge is consistent with regional reports that overall digital adoption in GCC logistics lags global benchmarks. Thus, our findings suggest that while literature predicts clear safety gains from real-time monitoring, realizing those gains in Oman will require overcoming inertia and expanding basic IoT capabilities.

Implications: In the Omani context, the clear consensus is that expanding IoT monitoring should be a priority. Policymakers and industry bodies could promote this by raising awareness of the proven safety benefits (as our interviews highlight) and by providing support for initial deployments. For example, subsidies or shared-service sensor platforms might make adoption more feasible for smaller firms. Training programs could also help companies move beyond "rudimentary tracking" to advanced monitoring. If more organizations follow the lead of early adopters – leveraging live data to anticipate issues – Oman's hazmat transport sector can shift from the reactive stance most participants described to the proactive, prevention- focused model shown to reduce accidents .

4.1 Predictive Analytics for Risk Forecasting

While IoT monitoring emphasizes real-time visibility, predictive analytics extends its value by leveraging that data to anticipate and mitigate future hazards. Across interviews, most participants acknowledged that predictive tools remain in their infancy within Oman's hazmat logistics sector. Several reported that their organizations are "not yet" utilizing specialized analytics or AI technologies for incident forecasting. Instead, decision-making tends to rely on human experience or manual data interpretation. As one freight supervisor explained, "we have only a few hazmat shipments per year, so we use our records and experience to forecast future delivery needs." Another manager described a reactive strategy of "studying safety data sheets and past incidents to anticipate risks," indicating that traditional methods still dominate, especially among smaller or locally focused firms.

However, a minority of respondents—primarily from larger or multinational companies—did report initial steps toward integrating predictive capabilities. One oil-sector safety engineer described a data platform that "crunches incident records and transport conditions to flag high-risk scenarios," enabling proactive adjustments such as altered inspection schedules or changes to storage protocols. Another mentioned route-planning software that "assigns a risk score [to each route]" based on variables like road hazards and population density, thereby prioritizing lower-risk paths. Additional use cases included AI-powered cameras that detect unsafe driver behavior and sensor networks that alert staff to anomalous temperature spikes in hazmat storage tanks. While still limited in scope, these early implementations underscore the potential of predictive analytics to reshape safety culture toward a more anticipatory model.

This localized feedback is reinforced by global literature. Wanasinghe et al. (2020), in a comprehensive review of IoT adoption in the oil and gas industry, found that predictive maintenance—enabled through real-time data—reduces operational costs, improves equipment reliability, and mitigates health and safety risks. Ghaffarpasand et al. (2022) demonstrated that vehicle telematics facilitate eco-routing and proactive safety interventions in urban logistics. Chen (2024) presented a hybrid AI model integrating decision trees and neural networks, which achieved over 85% accuracy in forecasting traffic incidents and reduced emergency response times by 20%. Similarly, Acı et al. (2025) developed a hybrid deep neural network and random forest model that attained 92% accuracy in predicting crash severity, while Soliani et al. (2025) reported 85% accuracy in forecasting crash involvement based on fatigue-related data from truck drivers.

Together, these findings from both practice and theory suggest that predictive analytics offers powerful tools for hazard anticipation in logistics. Yet, both the interviews and literature highlight a persistent implementation gap. Despite growing awareness of its value, many organizations in Oman are constrained by infrastructural limitations, lack of technical training, and strategic inertia. Bridging this gap will require targeted investments in digital readiness, workforce capability, and policy frameworks that incentivize adoption.

This suggests a mixed picture. On one hand, the high-accuracy forecasting systems shown in the literature reflect what larger Omani players hope to achieve. On the other hand, many local operators remain unready, often citing low shipment volumes or limited data as reasons to stick with human judgment. These insights challenge any notion that technology alone will drive change; they imply that without investment in data collection and analytic capacity, even the best predictive models cannot be applied.

Implications: To harness predictive analytics in Oman's hazmat logistics, policy and practice must focus on building data capabilities. This might include encouraging collaboration between firms (so that richer datasets can be pooled for analytics) and supporting analytic platforms through public–private initiatives. Training logistics managers to interpret data trends and funding pilot projects could help demonstrate ROI. Regulators might also incentivize analytics by, for instance, incorporating predictive risk assessments into safety certification processes. In short, the field research suggests that unlocking analytics' benefits will require both technology investments and efforts to integrate data-driven methods into existing safety culture.

4.2 Technology Adoption Level (Barriers and Enablers)

Interviewees identified multiple barriers hindering IoT adoption in Oman's hazmat sector. Cost was the most frequently cited obstacle: nearly every participant agreed that current IoT solutions are "too expensive" for the typical company. One operations director noted bluntly that high implementation costs make it "difficult for management to justify the investment" . Relatedly, technical integration proved challenging. A safety officer explained that even when a budget exists, getting a new IoT system to "mesh easily with existing systems" is a "headache", often forcing operators to run parallel processes and eroding efficiency. Another common theme was the skills gap: particularly in smaller firms, employees often lack IT and analytics expertise. As one participant summarized, “lack of skills or training” was explicitly limiting their ability to use IoT tools. Some also expressed concerns about cybersecurity and data privacy risks with connected devices. Finally, a few cited unclear regulations – for example, uncertainty whether certain tracking devices are permitted – which creates hesitation about whether to deploy IoT at all.

These findings mirror known challenges in literature, studies in the GCC have highlighted very similar obstacles. For instance, Al-Nabet (2021) found that organizational inertia, legal ambiguities, and cybersecurity threats are major barriers to IoT in a neighboring country. Likewise, Benayoune et al. (2022) noted a human capital shortage in Oman’s logistics workforce, emphasizing the need to align education with industry needs. The consistently high cost of IoT – as our respondents stressed – is also well documented as a global impediment to digitalization. In fact, Oman’s own low rate of full digitization underscores how these financial and capability barriers have slowed progress. Thus, the interviews confirm and contextualize the literature’s diagnosis of GCC adoption hurdles.

Crucially, participants did not only identify problems; they also suggested enablers. Many emphasized that reducing costs and proving ROI is key – one logistics CEO insisted that any system must be cheaper and user-friendly relative to current options. Ease-of-integration was also highlighted: solutions should be plug-and-play or come with vendor support so as not to disrupt existing workflows. To address the skills gap, respondents advocated for more training programs, and even hiring IoT specialists to fill internal expertise gaps. Top management support emerged as another critical factor: one interviewee advised that senior leadership “set aside a special budget” to champion new technology. Notably, participants pointed to the role of government and industry bodies: clear mandates or incentives could offset uncertainties. For example, a manager suggested making IoT tracking mandatory for certain high- hazard materials, which would immediately motivate companies to invest in these tools. Overall, the proposed enablers – financial support, integration assistance, capacity-building, and institutional pressure – suggest a multi-faceted strategy to accelerate adoption.

Implications: These insights underline that policy and industry must work together to lower practical hurdles. In Oman, this could mean subsidizing IoT deployments (for example, through grants or tax breaks) to address the cost barrier. Standardized, open APIs and vendor partnerships might ease integration difficulties. Education and vocational training programs tailored to logistics IoT could begin to close the talent gap. Importantly, strong executive buy-in is needed at company level, which public-sector programs can encourage through awareness campaigns or pilot project showcases. Finally, regulators could consider phased mandates (as participants suggested) for mandatory tracking of the most dangerous materials. In sum, both interviews and literature point to a need for coordinated enablers: without them, even willing adopters will struggle to overcome the barriers identified.

4.3 Regulatory and Institutional Support

Interviewees generally viewed Oman’s current regulatory environment for IoT-enhanced hazmat logistics as incomplete and uneven. Most characterized existing policies as only “neutral” or “somewhat supportive” of IoT integration. Hazmat transport regulations are largely focused on traditional safety requirements, with few guidelines addressing digital monitoring. One safety manager remarked that “clarity [is] needed in the main requirements and how to achieve them”, indicating that companies are uncertain what digital standards, if any, regulators expect. Another participant flatly described current support as “not supportive,” arguing that authorities have not updated or enforced rules to encourage IoT systems. In contrast, a representative from a major oil firm felt the government was “very supportive,” likely reflecting special treatment of flagship projects, but this view seemed to be the exception. Overall, the consensus was that Oman’s institutional framework has not fully caught up with IoT innovations in logistics. There are few mandates or incentives for IoT adoption, and no centralized standards on data sharing or device certification were mentioned by the participants.

Despite this gap, our interviewees offered clear recommendations for improvement. Many urged a more proactive government role. For example, one expert proposed to “make use of IoT compulsory for very hazardous material at least” – essentially creating a mandate for tracking the riskiest shipments. Others called for updated and comprehensive guidelines so firms “know exactly what technologies and processes are acceptable or encouraged”. As one industry leader argued, regulators should focus on “aligning policies with modern technology, enforcing compliance, and building institutional capacity” in order to advance both safety and efficiency. Beyond mandates, participants envisioned incentives and infrastructure: suggestions included government funding or tax breaks for IoT projects, public–private collaboration platforms, and even a government-run central monitoring system for all hazmat movements. One interviewee elaborated that such a centralized data hub would aid both regulators and operators by setting a common baseline of visibility. There were also calls to expand training and awareness at the national level – for example, through “awareness sessions for the public and workers to foster the safety culture” – so that any new regulations are widely understood and adopted. Collectively, these ideas paint a picture of a regulatory and institutional ecosystem where IoT integration is explicitly supported by mandates or guidance, and where resources are mobilized to help the industry comply.

These practitioner perspectives are consistent with recent assessments of Oman’s policy landscape. The literature notes that despite investments in general digital infrastructure, Oman’s IoT-specific regulatory framework remains underdeveloped. Masengu et al. (2024), for instance, reports that only a tiny fraction of logistics firms have fully digitized operations, in part due to policy gaps like unclear procedures. The interviewees’ criticisms – that rules have not caught up and enforcement is weak – mirror these findings. Thus, both our data and the literature point to “regulatory inertia” as a limiting factor.

Implications: In practical terms, Oman (and the wider GCC) needs to update its regulatory playbook for hazardous logistics. Authorities might start by codifying clear requirements for digital safety measures: for example, enacting regulations that require real-time tracking for specified classes of hazardous goods, as suggested by participants. Simultaneously, developing national standards on data handling and IoT device certification would reduce uncertainty. To encourage adoption, regulations could be paired with incentives – such as grants for pilot IoT projects or fast-track approvals for compliant operators. Establishing a centralized hazmat monitoring platform, perhaps under the auspices of transport authority, could provide both visibility and a forum for sharing best practices. Importantly, regulators should also invest in capacity-building: training staff to understand IoT capabilities and ensuring that enforcement agencies are

themselves equipped to monitor digital safety systems. In sum, our findings suggest that aligning Omani policy with modern logistics technology – through mandates, guidelines, and support programs – is a critical lever for improving hazmat safety and will help activate the IoT potential noted in other sections.

4.4 Operational Visibility as a Mediating Factor

Across all interviews, one theme stood out: operational visibility is the key mechanism linking IoT technologies to safety and efficiency outcomes. Participants unanimously noted that real-time visibility into hazmat operations significantly improved their ability to manage hazards. By installing tracking devices and sensors, companies could continuously monitor the location, condition, and security of hazardous shipments – transforming their situational awareness. As a senior manager explained, IoT “transforms operational visibility from reactive to proactive,” enabling his team to “detect hidden risks, optimize performance, and improve accountability”. In practical terms, several respondents gave concrete examples of accidents averted due to enhanced visibility. One operations supervisor described how a live dashboard monitored by multiple staff members caught a developing hazard that a lone driver had missed: “the concerned person did not notice the hazard but a second person highlighted the risk”. Another noted that continuous gas-leak sensors inside facilities “always prevent the accident” by triggering immediate alarms. These anecdotes illustrate that when critical information is visible in real time, frontline personnel can intervene swiftly to correct the course.

Importantly, participants emphasized that visibility not only aids emergency response but also improves everyday decision-making. One expert pointed out that data-rich dashboards enable “faster, data-driven decisions and better coordination between teams,” leading to safer routine operations such as choosing better routes or correcting unsafe behavior on the fly. In other words, operational visibility translates raw sensor data into actionable insights and preventive actions. Without it, IoT devices would simply be passive recorders; with it, they become enablers of a learning, safety-oriented culture.

This finding dovetails with the literature identifying visibility as the linchpin of IoT’s impact on safety. Prior research by Thibaud et al.(2018) has shown that real-time data visibility through sensors, drones, and telematics markedly enhances situational awareness and emergency readiness. Our interviews confirm these effects in the Omani context: higher visibility led to improved driver behavior, quicker readiness, and greater accountability – all outcomes documented in prior studies. They also reinforce the conceptual model of visibility as a mediating variable: simply installing IoT hardware is not enough to guarantee safety; it is the effective use of the resulting information (i.e. high visibility) that truly drives safety improvements.

Implications: For policy and practice, this means that measures should focus not only on deploying devices but also on ensuring that data leads to action. Organizations need user-friendly dashboards and trained personnel who can interpret sensor feeds. As one interviewee did by example, having multiple people monitor a shared dashboard can build redundancy into monitoring. Regulators might support this by recommending minimum standards for information sharing (e.g. who gets alerted in an incident) and by endorsing central monitoring centers. In Oman, emphasizing visibility could involve integrating IoT data into existing traffic management or emergency response systems, and promoting cross-company data exchange during hazmat incidents. Ultimately, our findings suggest that operational visibility is the critical nexus: when IoT monitoring, analytics, and regulatory support all point toward better real-time insight, the result is tangible safety and efficiency gains throughout the logistics chain.

4.5 Integrated Discussion

The themes above paint a coherent picture: IoT-driven monitoring and analytics have great potential to improve hazmat logistics safety in Oman, but realizing that potential depends on adoption and enabling conditions, all mediated by operational visibility. Figure studies conceptualize real-time monitoring, predictive analytics, technology adoption, and regulatory support as independent factors that feed into visibility, which then yields safety and efficiency outcome.Our interviews confirm this chain of influence. For instance, expanded IoT monitoring generates the data streams that visibility depends on. Predictive analytics then use that data to anticipate risks (closing the loop back to visibility by telling operators what to look for). Organizational adoption level determines how widely these technologies are deployed, and regulatory support shapes the environment in which they are used. Operational visibility – essentially how much insight decision-makers actually have – is the bridge: it turns sensor inputs and forecasts into on-the-ground actions.

In practice, these elements are tightly interwoven. The few Omani firms that have fully harnessed IoT report exactly the outcomes predicted by theory: real-time dashboards spotted hazards early, and analytic models guided managers to preempt problems. Other organizations, by contrast, remain mostly invisible to themselves in real time, handling risks the old-fashioned way. In this sense, our findings extend the literature by showing how Oman's particular constraints (cost pressures, skill gaps, undeveloped policy) result in a relatively low "visibility baseline." Participants emphasized that improving visibility requires concerted efforts at all levels: investing in basic monitoring devices, building analytical capability, and crafting policies that incentivize data sharing.

Key takeaways emerge for policymakers and practitioners in Oman and the GCC. First, technologies must be adopted not for their own sake but to bolster visibility. As one expert put it, "visibility is not just an outcome of IoT adoption but a central factor that mediates risk reduction". This suggests that even when budgets are limited, prioritizing projects that yield the clearest real-time insights (such as gas leak sensors or fleet tracking) may offer high safety returns. Second, closing the gap to global best practices will require systemic change: stakeholders pointed to clear roles for government (setting standards, mandates, funding pilots) and industry (committing resources, training staff). Third, all independent factors reinforce each other. For example, stronger regulatory support (e.g. mandatory tracking rules) would raise technology adoption levels, which in turn would produce more data for visibility and analytics. Conversely, showing quick safety wins from IoT use could catalyze more supportive policy.

In sum, our findings and the literature agree that IoT's transformative potential in hazmat logistics is real but underutilized in Oman. The interviews suggest a virtuous cycle: enhance monitoring and analytics with enabling policies, which raises visibility, which then leads to better safety and efficiency outcomes. In the Gulf context, where industrial growth is rapid but institutional frameworks are still evolving, this means focusing on the mediating role of information. If Oman can increase operational visibility by scaling up IoT deployment (even basic tracking) and fostering the capability to act on that data, the result will be a logistics system that not only reacts to hazards but anticipates and avoids them.

5. Conclusion and Recommendations

This study examined how IoT technologies can improve the safety and efficiency of hazardous-material logistics in Oman and the GCC. Using interviews with logistics and regulatory professionals and literature synthesis, we tested a conceptual model linking IoT real-time monitoring, predictive analytics, technology adoption, and regulatory support to logistics safety and efficiency, with operational visibility as a key mediator. The findings confirmed that each of these factors plays a vital role. In practice, stakeholders agreed that IoT-enabled sensors and tracking dramatically enhance situational awareness – for example, cloud-connected sensor networks "significantly improve emergency response and overall safety outcomes". However, adoption in Oman remains very limited: participants noted that only about 1–2% of logistics firms are fully digitized. Thus, a major conclusion is that IoT monitoring offers clear safety gains but will only realize its promise after overcoming current low adoption.

Our interviews also showed that predictive analytics – which global studies find can forecast hazmat incidents with >85% accuracy – are still rare in local practice. Most firms rely on human judgment or simple review of past records rather than AI tools. Larger companies have piloted platforms that "flag high-risk scenarios" in advance, but these remain niche. The message is that analytics can greatly improve risk forecasting, but only if organizations invest in data collection and analytic capacity.

The study also identified barriers and enablers of technology adoption. As expected from the literature, respondents cited high costs, integration challenges, and a workforce skills gap as major hurdles. They emphasized that lowering costs (through subsidies or shared sensor platforms) and ensuring plug-and-play interoperability are crucial. Training and executive support were repeatedly mentioned: for example, managers urged companies to "set aside a special budget" for IoT initiatives and to hire or train IT specialists.

Regarding regulatory support, the findings make clear that Oman's current framework largely focuses on traditional safety rules, with little guidance on digital monitoring. Participants urged policymakers to update this "regulatory playbook" by codifying clear IoT requirements (for example, mandating real-time tracking for the most hazardous goods) and setting national data and device standards. They also suggested pairing mandates with incentives (grants or tax breaks) and even creating a centralized hazmat-monitoring platform to share data among stakeholders.

A consistent cross-cutting insight was the critical importance of operational visibility as the mechanism that translates IoT data into safety. In other words, installing sensors is not enough unless organizations can see and act on the information. Interviewees gave examples where real-time dashboards and alarms enabled staff to intercept leaks or unsafe behaviors before accidents occurred. Thus, the study confirms that enhanced visibility enables faster, data-driven decisions and preventive actions, which directly improves safety and efficiency.

Implications for Oman and the GCC: These results have direct relevance for policymakers, regulators, and industry in Oman and neighboring GCC states. They underscore that IoT integration can align with Oman's national goals of safe, efficient logistics and economic diversification, but only if accompanied by supportive policies. In particular, the findings suggest a shift from reactive to proactive hazard management: Oman's logistics sector must move beyond rudimentary tracking toward advanced IoT-enabled monitoring and analytics. Stakeholders should therefore prioritize closing the identified gaps in technology, skills, and regulation, as these are the linchpins to achieving the envisioned safety improvements.

Based on the study's findings, we offer the following actionable recommendations for Omani and GCC logistics stakeholders:

- **Provide targeted financial support for IoT adoption.** Governments and industry associations should offer grants, tax incentives or shared-service schemes to help especially small and medium logistics firms install IoT sensors and tracking systems. Subsidized pilot programs (e.g. shared sensor platforms) can lower the entry cost and demonstrate the returns of safety and efficiency.
- **Expand workforce training and skills development.** Align technical education and vocational training with logistics IoT needs. Establish industry–academy partnerships or certification programs for IoT and data science in transport. Building in-house IT and analytics expertise (or access to specialists) was repeatedly cited as essential for firms to leverage new technologies.
- **Strengthen data analytics capacity.** Encourage public–private collaboration to pool Hazmat transport data (e.g. through a national data-sharing consortium) and fund analytic platforms or pilot projects. Training programs should be established to teach logistics managers how to use predictive tools. Regulators can reinforce this by incorporating data-driven risk assessments into safety certification processes.
- **Update and enforce IoT-focused regulations.** Develop clear standards and mandates for IoT usage in hazardous logistics. For example, enact regulations requiring real-time tracking and environmental monitoring for high-risk shipments, and require IoT data-sharing protocols. Complement mandates with incentives (e.g. fast-track approvals or funding for compliant operators).

- **Enhance operational visibility and information-sharing.** Invest in centralized monitoring centers or interoperable dashboards that aggregate IoT data across organizations. Regulators should recommend minimum alerting and reporting standards (e.g. who gets notified during an incident). Encouraging redundant monitoring (multiple people or systems watching the data) and integrating IoT feeds with emergency response systems will help translate sensor data into timely action.

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