

Digital risk matrix and safety management workflow for airport infrastructure in developing countries: a data-driven prioritization approach

Rita Salmorbekova¹, Miraziz Talipov²

¹Department of Natural Sciences, Kyrgyz Aviation Institute Named After I. Abdraimov, Bishkek, 720016, Kyrgyzstan

²Tashkent State Transport University, 1 Temiryulchilar St., Tashkent, 100167, Uzbekistan

²Corresponding author

E-mail: ¹aviatorykai@gmail.com, ²talipov_m@tstu.uz

Received 13 February 2026; accepted 12 March 2026; published online 8 June 2026

DOI <https://doi.org/10.21595/vp.2026.26121>



76th International Conference on Vibroengineering in Tashkent, Uzbekistan, April 28-29, 2026

Copyright © 2026 Rita Salmorbekova, et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract. This paper presents a digital risk assessment and safety management workflow for airport infrastructure in developing countries, designed to operate under limited and heterogeneous safety data. The proposed approach combines hazard identification, exposure-normalized probability estimation, severity scoring, and automated prioritization using a numerical risk index $R_i = P_i \times S_i$. Probability is derived from event frequency normalized by an exposure metric (flight hours or aircraft movements), while severity is assigned using a predefined five-level consequence scale aligned with SMS practice. The workflow is implemented as a lightweight digital tool that standardizes event records, applies scoring rules, generates risk matrices/heatmaps, and automatically produces a risk register with mitigation actions for key airport asset classes. A case study illustrates how national safety records can be transformed into ranked risk priorities under data scarcity. The contribution is a reproducible scoring framework with transparent thresholds and a practical digital reporting format that improves traceability and decision-making in Safety Management Systems.

Keywords: airport infrastructure, safety management system, risk prioritization, digital workflow, risk matrix, risk register, data-driven assessment.

1. Introduction

Aviation infrastructure safety is a key component of sustainable air transport development, particularly in developing countries where growth in air traffic often outpaces the modernization of physical assets and management systems. According to the International Civil Aviation Organization (ICAO), infrastructure-related factors – such as runway conditions, airport ground operations, and air navigation services – remain significant contributors to aviation safety risks, especially in resource-constrained environments [1], [2].

In recent years, developing countries have demonstrated steady growth in flight operations, increasing the operational load on existing aviation infrastructure. For example, in the Kyrgyz Republic, total flight hours in civil aviation increased by 13.5 % in the first half of 2025 compared to 2024, reaching 17,704 flight hours, primarily in commercial aviation [14, 15]. While this growth reflects positive economic and connectivity trends, it simultaneously intensifies exposure to infrastructure-related safety risks.

Safety statistics indicate that the absence of fatal accidents in a given period does not eliminate systemic vulnerabilities. Between 2017 and mid-2025, five aviation accidents, including three with fatalities, were recorded in the civil aviation sector of the Kyrgyz Republic, highlighting the long-term impact of latent operational and infrastructural risks [3]. Moreover, 40 aviation incidents were reported in the first half of 2025 alone, many of which were associated with technical system failures, wildlife strikes, meteorological conditions, and air traffic management

issues – factors closely linked to infrastructure performance.

Traditional safety management approaches in developing countries remain largely reactive and compliance-oriented, relying on retrospective analysis of incidents. Although Safety Management Systems (SMS) have been introduced in accordance with ICAO Annex 19 and Doc 9859, their effectiveness is often limited by fragmented data, delayed risk identification, and insufficient analytical tools [4], [5]. Under conditions of increasing traffic and environmental uncertainty, such approaches are no longer sufficient to ensure proactive safety management.

Digital risk assessment provides an opportunity to overcome these limitations by enabling continuous monitoring, integration of safety and infrastructure data, and early identification of emerging risks. The use of digital reporting systems, standardized risk taxonomies, and data-driven decision-support tools allows aviation authorities to move from reactive to predictive safety management [6], [7]. For developing countries, these approaches are particularly relevant, as they support more efficient use of limited resources while enhancing transparency and regulatory effectiveness.

Against this background, the present study addresses the growing need for digital risk assessment in aviation infrastructure safety management in developing countries. By focusing on the integration of digital tools into existing safety management frameworks, the paper highlights pathways for improving infrastructure safety, operational resilience, and sustainable aviation development.

Despite the growing adoption of Safety Management Systems, airport infrastructure risk assessment in developing countries still suffers from three persistent limitations: fragmented safety records, insufficient exposure-normalized prioritization, and weak digital support for translating safety data into operational decisions. Existing studies mainly discuss aviation risk conceptually or at the system level, whereas limited attention has been given to lightweight digital workflows that can operate under data scarcity and support infrastructure-oriented mitigation planning.

Therefore, the objective of this study is to develop and demonstrate a data-driven digital prioritization workflow for airport infrastructure safety management in a developing-country context using national aviation safety records from the Kyrgyz Republic. The novelty of the study lies in three aspects. First, it transforms heterogeneous safety records into an exposure-normalized numerical prioritization framework for airport infrastructure hazards. Second, it combines ICAO-aligned severity scoring with automated generation of a risk matrix and mitigation-oriented risk register. Third, it adapts this workflow to data-constrained aviation systems, where full-scale predictive models are often impractical. In this way, the study contributes a reproducible and operationally feasible tool for improving the traceability, transparency, and timeliness of infrastructure safety decisions.

2. Methods

2.1. Research design and conceptual framework

This study adopts a risk-based and data-driven methodological approach to assess safety risks associated with aviation infrastructure in developing countries. The research design integrates principles of Safety Management Systems (SMS) with digital risk assessment tools, enabling a transition from reactive to proactive and predictive safety management. The methodological framework is grounded in ICAO risk management guidance and contemporary risk assessment theory, which conceptualizes risk as a function of probability and consequences [7].

The proposed framework consists of four sequential stages: (1) identification of infrastructure-related hazards, (2) estimation of risk probability, (3) assessment of potential consequences, and (4) risk prioritization and decision support using digital tools.

2.2. Hazard Identification

Hazard identification focuses on aviation infrastructure subsystems, including runways, taxiways, lighting and navigation aids, air traffic management interfaces, and ground handling facilities. Hazards are identified using safety reports, incident databases, and regulatory oversight data, structured according to the ICAO ADREP taxonomy [3]. This taxonomy enables standardized classification of safety events and supports comparability across datasets.

In line with established risk theory, hazards are defined as system states or conditions with the potential to lead to an aviation incident or accident if not adequately controlled [5]. Digital reporting systems and centralized databases are used to reduce underreporting and improve the reliability of hazard identification [6].

2.3. Risk probability assessment

The probability of occurrence for each identified hazard is estimated using historical safety data and normalized exposure indicators. Following the classical probabilistic approach, the probability P_i of hazard is calculated as:

$$P_i = \frac{N_i}{E}, \quad (1)$$

where N_i – number of recorded events related to hazard i within a defined period, E – exposure measure (e.g., total flight hours or number of aircraft movements).

This approach is widely applied in aviation risk studies and allows comparison across different operational contexts [10]. To improve robustness, probability values are categorized into ordinal scales (e.g., very low to very high), consistent with SMS practice.

2.4. Consequence severity assessment

The severity of consequences S_i associated with each hazard is assessed using a semi-quantitative scale based on potential outcomes, including infrastructure damage, operational disruption, injuries, fatalities, and economic losses. Severity levels are defined in accordance with ICAO safety risk matrices and previous aviation safety research [9].

Severity scoring follows the general form: $S_i \in \{1, 2, 3, 4, 5\}$.

where higher values represent more severe consequences. This approach balances analytical rigor with practical applicability in data-limited environments [9].

2.5. Risk estimation model

Overall safety risk R_i for each hazard is calculated as the product of probability and consequence severity: $R_i = P_i \times S_i$.

This multiplicative risk model is widely used in aviation safety management due to its transparency and compatibility with decision-making processes [7]. Risks are subsequently mapped into predefined risk categories (acceptable, tolerable, unacceptable), enabling prioritization of safety interventions.

To enhance analytical depth, digital tools are employed to automate risk calculations, visualize trends, and identify emerging risk patterns over time. Such digitalization supports continuous monitoring and dynamic updating of risk profiles [9].

Probability classes were assigned using fixed normalized-frequency thresholds based on recorded events per 10,000 flight hours (or per 10,000 aircraft movements), ensuring consistency of classification across reporting periods.

Probability classes were defined using fixed thresholds per 10,000 flight hours: Level 1: < 0.5 ; Level 2: $0.5-1.0$; Level 3: $1.0-2.0$; Level 4: $2.0-4.0$; Level 5: > 4.0 .

Table 1. Probability, severity, and risk-category thresholds used in the digital prioritization workflow

Component	Level	Criteria	Interpretation
Probability (P_i)	1	Very low normalized frequency	Rare occurrence
Probability (P_i)	2	Low normalized frequency	Occasional occurrence
Probability (P_i)	3	Medium normalized frequency	Recurrent but manageable
Probability (P_i)	4	High normalized frequency	Frequent operational concern
Probability (P_i)	5	Very high normalized frequency	Persistent and systemic occurrence
Severity (S_i)	1	Negligible operational effect	No meaningful disruption
Severity (S_i)	2	Minor consequence	Limited operational disturbance
Severity (S_i)	3	Moderate consequence	Noticeable disruption and/or repair need
Severity (S_i)	4	Major consequence	Serious operational impact, injury or major damage potential
Severity (S_i)	5	Catastrophic consequence	Fatality and/or severe system loss potential
Risk category	1-4	Acceptable	Routine monitoring
Risk category	5-12	Tolerable with mitigation	Corrective measures required
Risk category	13-25	Unacceptable	Immediate intervention required

2.6. Validation and evidence base

The methodological approach is validated through triangulation of multiple data sources, including safety reports, regulatory inspection results, and infrastructure performance indicators. Consistency with ICAO Annex 19 and Doc 9859 ensures regulatory validity, while alignment with peer-reviewed risk assessment literature provides theoretical robustness [1].

The use of digital data integration and standardized taxonomies strengthens the evidence base and reduces subjectivity inherent in purely expert-based assessments. This is particularly important for developing countries, where data limitations necessitate methods that are both analytically sound and operationally feasible [12].

2.7. Methodological contribution

The proposed methodology contributes to aviation safety research by combining established risk assessment models with digital data integration tailored to developing-country contexts. By linking infrastructure-specific hazards with probabilistic and consequence-based analysis, the framework supports evidence-based decision-making and enhances the resilience of aviation infrastructure safety management systems.

For reproducibility, the digital workflow applies predefined scoring rules for both probability and severity. Probability classes are assigned from normalized event frequency using fixed exposure-based thresholds, while severity classes are mapped to standardized operational consequences, including disruption, infrastructure damage, injury potential, and fatality potential. The resulting risk index is then translated into decision categories (acceptable, tolerable with mitigation, and unacceptable) using predefined threshold intervals. These explicit rules reduce assessor subjectivity and improve consistency across reporting periods.

2.8. Practical digital implementation

The proposed digital workflow is designed as a lightweight and operationally feasible decision-support tool for airport authorities and regulators working under data scarcity. At the input stage, the system receives standardized event records containing hazard type, occurrence date, infrastructure context, exposure indicator, and consequence description. The processing

stage performs four automated functions: (1) hazard classification using a predefined taxonomy, (2) probability scoring from normalized event frequency, (3) severity scoring from consequence descriptors, and (4) risk calculation using the multiplicative model $R_i = P_i \times S_i$.

At the output stage, the tool generates a ranked hazard list, a risk matrix/heatmap, and a mitigation-oriented risk register. Each risk entry is linked to an infrastructure context and recommended control action, enabling traceable prioritization within the Safety Management System. The workflow can be implemented in a spreadsheet-based environment or simple database interface, which makes it suitable for developing aviation systems that do not yet possess advanced predictive analytics platforms.

3. Results and discussion

Table 2 presents an integrated safety risk matrix constructed on the basis of probability and consequence severity assessments for major hazard categories identified in the aviation infrastructure system of the Kyrgyz Republic. The matrix synthesizes empirical safety data, normalized exposure indicators, and ICAO-aligned severity scales, providing a structured overview of relative risk levels across infrastructure-related, operational, and human-factor-driven hazards.

Table 2. Integrated safety risk matrix for aviation infrastructure in the Kyrgyz Republic (2024)

Hazard category	Typical infrastructure context	Probability level (P_i)	Severity level (S_i)	Risk index ($R_i = P_i \times S_i$)	Risk category
Human factor-related deviations	Runway operations, ground handling, ATC coordination	Medium	High (4)	Medium-High	Tolerable with mitigation
Runway incursions / obstacles	Airports Manas, Osh	Low-Medium	High (4)	Medium	Tolerable with mitigation
Bird strikes (wildlife hazard)	Airport perimeter and approach zones	Medium	Medium-High (3-4)	Medium	Tolerable with mitigation
SCF-NP (non-powerplant system failures)	Landing gear, hydraulics, navigation systems	Medium	Medium (3)	Medium	Tolerable
SCF-PP (powerplant-related failures)	Engine and propulsion systems	Low	High (4)	Medium	Tolerable
Meteorological limitations	Mountainous terrain, low-visibility approaches	Low	Medium (3)	Low-Medium	Acceptable with monitoring

Probability levels are derived from normalized event frequency per flight hour, while severity levels follow ICAO five-point safety risk scales. Classification reflects national safety data for 2024 [14] and ICAO SMS guidance [1; 2].
 Human factor-related deviations: $P_i = 4, S_i = 4, R_i = 16$
 Runway incursions / obstacles: $P_i = 3, S_i = 4, R_i = 12$
 Bird strikes: $P_i = 3, S_i = 3, R_i = 9$

The constructed risk matrix demonstrates that the dominant safety risks in the Kyrgyz Republic are not catastrophic in nature but systemic and recurrent, arising from sustained interactions between infrastructure limitations, human performance, and environmental conditions. In addition, human-factor risk controls should consider occupational health and hygienic conditions of operational personnel, as these factors influence performance reliability and safety margins [17]. Such a risk profile is characteristic of developing aviation systems undergoing traffic growth while operating with aging infrastructure, constrained maintenance capacity, and limited

operational redundancy [13]. Although accident and fatality rates remain relatively low, the prevalence of medium-to-high risk categories indicates the accumulation of latent safety threats that may escalate if left unaddressed.

The distribution of risks across predominantly “tolerable with mitigation” categories underscores the necessity of proactive safety management, where priority is given to early intervention, trend monitoring, and targeted risk controls rather than post-event corrective actions. In this context, digitally supported risk prioritization enables continuous updating of risk profiles and more efficient allocation of safety resources, reinforcing the transition from reactive, accident-driven oversight to predictive and preventive safety governance.

3.1. Implications for aviation infrastructure management

The risk matrix highlights that safety challenges in the Kyrgyz aviation system are concentrated not in isolated high-impact events, but in persistent medium-level risks embedded in everyday infrastructure operations. From an infrastructure management perspective, this finding implies that safety improvements should prioritize systemic interventions, including ground condition monitoring, wildlife management around airport perimeters, modernization of ground handling procedures, and reinforcement of human–system interfaces. Given the observed growth in flight activity, reliance on reactive measures following incidents is insufficient. Instead, integrating digital risk assessment tools into routine infrastructure oversight enables earlier detection of risk escalation and supports more cost-effective allocation of limited safety and maintenance resources [7], [16]. For developing aviation systems, such an approach strengthens resilience by addressing risk accumulation before it manifests in severe safety outcomes.

3.2. Case-based demonstration of prioritization benefits

To demonstrate the practical value of the proposed approach, the 2024 safety dataset was processed not only as a descriptive record, but also as a decision-support sequence for airport infrastructure management. Under conventional reactive oversight, recurrent hazards such as wildlife strikes, runway incursions, and human-factor-related deviations may be reviewed separately after occurrence, without a consistent mechanism for ranking intervention urgency. In contrast, the proposed digital workflow converts these events into a comparable priority structure by combining normalized probability and consequence severity within a single risk index.

The case application shows that human factor-related deviations constitute the highest-priority group because they combine recurrent occurrence in runway operations, ground handling, and ATC coordination with comparatively high potential consequences. Runway incursions/obstacles and wildlife hazards form the second intervention tier, since both are operationally frequent and infrastructure-dependent, particularly in airport movement areas and perimeter zones. By comparison, meteorological limitations remain important but are classified as acceptable with monitoring, indicating that scarce safety resources should not be allocated to them at the same level as recurrent infrastructure-linked hazards.

This prioritization improves airport infrastructure safety management in a practical sense: it directs management attention toward the hazards that require immediate mitigation, supports more rational allocation of inspection and maintenance resources, and makes the basis for intervention auditable within the Safety Management System. In operational terms, the resulting risk register supports targeted actions such as enhanced runway condition monitoring, digital logging of ground-operation deviations, strengthened wildlife control around airport perimeters, and tighter coordination procedures between airside personnel and ATC units. Thus, the proposed approach improves safety not by replacing existing SMS procedures, but by making hazard ranking explicit, reproducible, and digitally traceable.

In practical terms, the workflow shortens the path from event reporting to mitigation planning by converting heterogeneous safety records into ranked and auditable intervention priorities.

Table 3. Example of prioritized mitigation actions

Hazard	Priority rank	Risk category	Recommended action	Responsible unit	Time horizon
Human factor-related deviations	1	Tolerable with mitigation	Refresher training + digital deviation logging	Airport operations / ATC	Short-term
Runway incursions / obstacles	2	Tolerable with mitigation	Runway inspection + signage control	Airside safety unit	Short-term
Bird strikes	3	Tolerable with mitigation	Perimeter wildlife control	Airport safety service	Ongoing

3.3. Example of mitigation-oriented risk register

To further illustrate the operational value of the prioritization approach, the ranked hazards were translated into a mitigation-oriented risk register. Human factor-related deviations were assigned first-order priority and linked to actions such as digital logging of procedural deviations, targeted refresher training, and strengthened coordination between ground operations and ATC. Runway incursions and obstacle-related events were associated with enhanced runway inspection frequency, signage and marking checks, and procedural control of airside access. Wildlife hazards were linked to perimeter surveillance, habitat control, and scheduled bird-strike monitoring around approach and departure zones.

This transformation from risk scoring to action planning is an important practical outcome of the proposed workflow. It allows airport operators not only to identify which hazards are significant, but also to document why certain interventions are prioritized and how limited safety resources should be allocated.

For operational use, the mitigation-oriented risk register may also include the responsible organizational unit, implementation horizon, and verification indicator for each action. This makes the prioritization workflow compatible not only with hazard ranking, but also with routine safety performance monitoring and accountability within the airport Safety Management System.

3.4. Limitations and future research

The study has several limitations that should be acknowledged. First, the proposed model is semi-quantitative and is intended for transparent operational prioritization rather than full probabilistic forecasting. Second, the case application is limited to one national aviation system, and broader cross-country validation would improve generalizability. Third, while the digital workflow is operationally specified, the present study does not include a full software architecture, interface prototype, or algorithmic implementation details.

Future research should therefore extend the framework in three directions: (1) sensitivity analysis of probability and severity thresholds, (2) uncertainty-aware modeling using Bayesian or simulation-based methods, and (3) comparative validation across multiple developing-country airport systems. These extensions would increase methodological rigor while preserving the practical usability of the current workflow.

4. Conclusions

This study contributes not merely a descriptive discussion of airport safety risks, but a reproducible digital prioritization workflow tailored to developing-country aviation systems operating under data scarcity. Its key contribution is the integration of exposure-normalized probability estimation, ICAO-aligned severity scoring, and automated mitigation-oriented reporting into a single operational framework for airport infrastructure safety management. The Kyrgyz Republic case demonstrates that the proposed approach helps distinguish recurrent infrastructure-linked hazards from lower-priority monitored risks, thereby supporting more focused and transparent safety interventions.

The results indicate that, despite relatively stable accident and fatality indicators, the Kyrgyz aviation system exhibits a concentration of medium-level risks related to ground operations, wildlife hazards, technical system reliability, and human-infrastructure interaction. These risks, while individually manageable, accumulate over time and may significantly degrade safety margins if not addressed proactively. The constructed risk matrix confirms that most identified hazards fall within “tolerable with mitigation” categories, underscoring the importance of early intervention rather than post-incident response.

From a practical standpoint, the findings support a transition from reactive, accident-based oversight toward predictive and preventive safety governance, enabled by digital monitoring and continuous risk prioritization. Such an approach is particularly relevant for developing aviation systems facing traffic growth, infrastructure aging, and constrained financial and technical resources. Overall, the study contributes to aviation safety research by demonstrating how standardized risk models, when combined with national safety data and digital tools, can enhance evidence-based decision-making and infrastructure resilience.

In this sense, the proposed workflow should be understood as a practical bridge between regulatory SMS requirements and day-to-day airport infrastructure management. Its value lies not in replacing expert judgment, but in making hazard prioritization more explicit, auditable, and repeatable under real-world data constraints. For developing aviation systems, such transparency is essential for directing limited resources toward the most safety-critical infrastructure interventions.

Acknowledgements

The authors express their sincere gratitude to the State Agency of Civil Aviation under the Cabinet of Ministers of the Kyrgyz Republic for providing access to official aviation safety data and analytical materials used in this study. The support of the Agency made it possible to conduct an evidence-based analysis of aviation infrastructure safety. The authors also acknowledge the contribution of all specialists involved in data collection and reporting processes, whose work ensured the reliability of the empirical information. The views expressed in this paper are solely those of the authors and do not necessarily reflect the official position of the Agency.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that they have no conflict of interest.

References

- [1] “Safety management manual (SMM),” International Civil Aviation Organization, Montreal, Canada, Doc. 9859, 2013.
- [2] “Annex 19 to the convention on international civil aviation: safety management,” International Civil Aviation Organization, Montreal, Canada, 2018.
- [3] “Global aviation safety plan (GASP) 2023-2025,” International Civil Aviation Organization, Montreal, Canada, 2023.
- [4] “ICAO safety report 2024,” International Civil Aviation Organization, Montreal, Canada, 2024.
- [5] J. Reason, *Managing the Risks of Organizational Accidents*. Aldershot, U.K.: Routledge, 2016, <https://doi.org/10.4324/9781315543543>
- [6] A. J. Stolzer, C. D. Halford, and J. J. Goglia, *Safety Management Systems in Aviation*. London, U.K.: Routledge, 2017, <https://doi.org/10.4324/9781351149648>

- [7] T. Aven, "Risk assessment and risk management: review of recent advances on their foundation," *European Journal of Operational Research*, Vol. 253, No. 1, pp. 1–13, Aug. 2016, <https://doi.org/10.1016/j.ejor.2015.12.023>
- [8] T. Aven and E. Zio, "Foundational issues in risk assessment and risk management," *Risk Analysis*, Vol. 34, No. 7, pp. 1164–1172, Oct. 2013, <https://doi.org/10.1111/risa.12132>
- [9] E. Zio, "The future of risk assessment," *Reliability Engineering and System Safety*, Vol. 177, pp. 176–190, Sep. 2018, <https://doi.org/10.1016/j.res.2018.04.020>
- [10] F. Netjasov and M. Janic, "A review of research on risk and safety modelling in civil aviation," *Journal of Air Transport Management*, Vol. 14, No. 4, pp. 213–220, Jul. 2008, <https://doi.org/10.1016/j.jairtraman.2008.04.008>
- [11] T. Aven, *Foundations of Risk Analysis*. Wiley, 2012, <https://doi.org/10.1002/9781119945482>
- [12] World Bank, "Air transport safety and sustainability in developing countries," World Bank Group, Washington, DC, USA, 2020.
- [13] "Enhancing transport safety in developing countries," World Bank, Washington, DC, USA, 2020.
- [14] "Analysis of civil aviation flight safety in the Kyrgyz Republic for 2024," (in Russian), State Agency of Civil Aviation under the Cabinet of Ministers of the Kyrgyz Republic, Bishkek, Kyrgyz Republic, No. PI-CMA-03, 2025.
- [15] "Analysis of civil aviation flight safety in the Kyrgyz Republic for the first half of 2025," (in Russian), State Agency of Civil Aviation under the Cabinet of Ministers of the Kyrgyz Republic, Bishkek, Kyrgyz Republic, 2025.
- [16] M. Talipov, "Computational modeling and analysis of mechanical power consumption in train assemblers' work," in *International Conference on Applied Innovations in IT (ICAIIIT)*, Vol. 13, No. 2, pp. 419–426, Jun. 2025, <https://doi.org/10.25673/120513>
- [17] O. T. Aliev, M. M. Talipov, K. M. Kamilov, and O. R. Ilyasov, "Hygienic examination of employees of locomotive crews of UTY JSC companies," in *2nd International Conference and Exposition on Mechanical, Material, and Manufacturing Technology (ICE3MT 2022)*, Vol. 2943, No. 1, p. 040057, Jan. 2023, <https://doi.org/10.1063/5.0134056>