

**DESIGN AND EVALUATION OF A DECISION SUPPORT SYSTEM FOR  
CLASSIFYING TOURISM SITE CROWDING AND RECOMMENDING  
GOVERNANCE RESPONSES IN BUNAKEN NATIONAL PARK**

**Aditya Lapu Kalua<sup>1</sup>, Mochamad Agung Wibowo<sup>2</sup>, Luther Alexander Latumakulita<sup>3</sup>**

Doctoral Program of Information Systems, Postgraduate School, Universitas Diponegoro, Semarang, Indonesia<sup>1</sup>

Postgraduate School, Universitas Diponegoro, Semarang, Indonesia<sup>2</sup>

Department of Information Systems, Universitas Sam Ratulangi, Manado, Indonesia<sup>13</sup>

adityalapakalua@students.undip.ac.id\*, agung.wibowo@ft.undip.ac.id, latumakulitala@unsrat.ac.id

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\*Corresponding Author

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**ABSTRACT**

*Effective governance of marine protected areas (MPAs) requires reliable mechanisms to translate multidimensional ecological and social data into coordinated institutional action. Despite widespread adoption of carrying capacity frameworks, a significant "implementation gap" persists between theoretical conservation thresholds and operational decision-making at the site level. This study addresses that gap by designing, implementing, and evaluating a Decision Support System (DSS) artifact tailored for Bunaken National Park (BNP), Indonesia. Grounded in Design Science Research (DSR) principles, the artifact employs a deterministic, rule-based classification engine that processes four normalized input dimensions: visitor density, social carrying capacity, infrastructure load, and governance readiness to compute a Composite Crowding Index (CCI). The CCI is mapped through an explicit IF-THEN rule engine to four crowding categories (Low, Moderate, High, Extreme), each linked to a validated governance action package. A deterministic rule-based approach was chosen over probabilistic or machine-learning alternatives to ensure full decision traceability, which is a non-negotiable requirement for public-sector governance. System robustness was evaluated through structured scenario testing across 140 logic-coverage cases, assessed against four criteria: output consistency (100%), expert rule alignment (97.8%), decision traceability (100%), and processing efficiency (<1.15 seconds per scenario). The artifact successfully automates the mapping of site-level crowding status to discrete, auditable governance actions. The theoretical contribution lies in formalizing subjective management reasoning into a transparent, reproducible DSS that bridges sustainability science and institutional practice in high-pressure marine tourism environments.*

**Keywords:** DSS Artifact, Information Systems Design, Tourism Governance, Bunaken National Park, Logic Verification, Design Science Research, Explainable AI

**1. Introduction**

Marine protected areas (MPAs) are among the most critical instruments for preserving marine biodiversity under conditions of escalating anthropogenic pressure (Pomeroy et al., 2021). Effective MPA governance increasingly depends on institutional capacity to process high-frequency visitor data and translate it into timely, consistent management interventions. In marine tourism contexts, site-level crowding is a primary stressor that simultaneously threatens ecological integrity and the quality of the visitor experience (Vaske & Shelby, 2008; Canteiro et al., 2021). However, a persistent structural problem is that most MPA authorities rely on fragmented information channels and subjective, reactive judgment rather than formal decision frameworks, producing inconsistent outcomes across management shifts and seasons (Pomeroy et al., 2021).

Bunaken National Park (BNP) in North Sulawesi, a globally recognized anchor site of the Coral Triangle, exemplifies this challenge at scale. Previous research has documented the park's ecological significance (Schaduw, 2020), its carrying capacity thresholds (Towoliu et al., 2020), and the institutional friction among park authorities, local governments, and private operators (Sidangoli et al., 2013). Yet despite this body of knowledge, no formally validated Information Systems (IS) artifact exists to operationalize these insights into an auditable, site-level decision workflow. The absence of such a tool means that identical crowding conditions may trigger divergent managerial responses depending on individual judgment, shift schedules, or political pressure outcomes that undermine both ecological sustainability and governance legitimacy.

This study identifies a precise research gap: while carrying capacity models and economic valuations have been established for BNP (McCool & Lime, 2001; Mustika et al., 2020), the IS literature lacks a validated DSS artifact that operationalizes these concepts into a transparent, reproducible governance mechanism at the site level. Existing environmental decision tools either focus on large-scale spatial mapping (Paoli et al., 2022) or specific ecological monitoring (Abbad et al., 2023), and rarely deliver the explainable, site-specific logic required for rapid operational response in day-to-day park management.

A deterministic, rule-based approach was deliberately adopted over probabilistic or machine-learning alternatives for three reasons. First, rule-based systems produce fully traceable decision paths, enabling park managers and stakeholders to audit every classification outcome an essential property for public-sector accountability (Miller, 2019; Gunning et al., 2019). Second, the relatively small and heterogeneous nature of available site-level data in BNP makes data-intensive learning models prone to overfitting and difficult to validate ecologically. Third, institutional governance in protected areas requires that decision logic can be updated by domain experts without retraining computational models, which modular rule libraries facilitate directly (Warkentin & Orgeron, 2020). This design philosophy aligns with Explainable AI (XAI) principles, which increasingly guide the deployment of decision support in high-stakes public governance contexts (Gunning et al., 2019).

Grounded in Design Science Research (DSR) principles (Hevner et al., 2004; Peffers et al., 2007), this study contributes to the IS discipline by demonstrating how deterministic logic can operationalize multi-criteria sustainability indicators into coherent governance action packages. The study also advances the emerging paradigm of Smart Marine Protected Areas (Kaymaz & Muehling, 2024), which emphasizes the integration of digital infrastructure with participatory governance frameworks. The central research objective is to evaluate whether a rule-based DSS artifact can reliably and consistently automate the mapping of complex site crowding indicators to validated governance responses, thereby reducing institutional inconsistency and decision fatigue in BNP.

## **2. Literature Review**

### **2.1. Decision Support Systems for Environmental Governance: Paradigms and Trade-offs**

Decision Support Systems are recognized as essential artifacts for resolving semi-structured problems in natural resource management (March & Smith, 1995). For MPA governance, a DSS must progress beyond data visualization toward an auditable logic chain that diverse stakeholders including non-technical officials can trust and interrogate (Pomeroy et al., 2021; Varkey et al., 2013). The DSS literature identifies three dominant design paradigms relevant to environmental governance: model-driven systems that rely on mathematical simulations, data-driven systems that apply machine learning to historical datasets, and rule-based systems that encode expert knowledge in explicit conditional logic (Shim et al., 2002). Each paradigm involves fundamental trade-offs between predictive accuracy, transparency, and institutional usability.

Model-driven systems, such as agent-based simulations of visitor flow (Zheng et al., 2022), offer dynamic predictive capability but require extensive parameterization and produce outputs that are difficult for non-specialist managers to interpret or challenge. Data-driven approaches including machine learning classifiers applied to crowding data can achieve high accuracy in pattern recognition (Gunawan, 2022), but their "black-box" nature fundamentally conflicts with the accountability requirements of public-sector governance, where decision justification must be legible to elected officials, auditors, and the public (Miller, 2019; Gunning et al., 2019). Rule-based systems, by contrast, sacrifice probabilistic flexibility for full interpretability: every decision pathway is explicitly encoded, traceable, and modifiable without specialist computational knowledge (Warkentin & Orgeron, 2020). In governance environments where trust, auditability, and policy coherence are primary requirements, this trade-off strongly favors rule-based design. Contemporary eTourism platforms increasingly recognize this, integrating rule-based policy engines alongside data-driven analytics to balance responsiveness with institutional accountability (Buhalis et al., 2023).

### **2.2. Crowding, Carrying Capacity, and Multi-Criteria Indicator Integration**

Effective IS design for tourism management requires the normalization and integration of heterogeneous indicators across physical, social, and institutional dimensions (Baggio & Klobas, 2011). Crowding defined as the density of visitors relative to both physical capacity and subjective

social tolerance is recognized as a primary descriptive indicator for site status classification (Vaske & Shelby, 2008). However, empirical evidence consistently demonstrates that crowding perception is non-linear and context-dependent: visitor tolerance levels vary significantly with site type, cultural background, and prior experience (Vaske & Shelby, 2008; McCool & Lime, 2001), complicating the direct use of density counts as standalone governance triggers.

This complexity requires multi-criteria carrying capacity (MCC) frameworks that integrate physical density thresholds with social tolerance benchmarks and infrastructure load indicators (McCool & Lime, 2001; Towoliu et al., 2020). The Limits of Acceptable Change (LAC) and Visitor Impact Management (VIM) frameworks provide the theoretical basis for defining these composite thresholds in protected-area contexts (McCool & Lime, 2001). For BNP specifically, Towoliu et al. (2020) & Schadow (2020) have established empirically grounded capacity estimates for key site nodes. An effective DSS must aggregate these multi-dimensional signals into a single classification index the function served by the Composite Crowding Index (CCI) in this study while preserving the ability to trace how each input dimension contributes to the final governance recommendation. This design requirement distinguishes the proposed artifact from single-indicator monitoring tools that do not support coordinated governance response.

### **2.3. Design Science Research, Explainable AI, and the Implementation Gap**

The theoretical foundation of this artifact is rooted in Design Science Research (DSR), which posits that the creation and rigorous evaluation of IT artifacts constitutes a valid and valuable form of scientific contribution to the IS discipline (Hevner et al., 2004; Gregor & Hevner, 2013). DSR is particularly well suited to the present problem because the implementation gap in BNP is fundamentally an IS design challenge: the knowledge required to classify crowding and recommend governance actions exists in fragmented, tacit forms among park stakeholders, but has never been formalized into a reproducible, institutional artifact. DSR provides the methodological justification for treating artifact construction and validation rather than empirical hypothesis testing as the primary research contribution (Peppers et al., 2007).

The alignment of rule-based DSS design with Explainable AI (XAI) principles is increasingly important in governance contexts (Gunning et al., 2019). XAI research argues that decision systems deployed in high-stakes public applications must satisfy three properties: transparency (the decision logic is accessible), interpretability (outputs are understandable by non-specialists), and accountability (errors can be traced and corrected) (Miller, 2019). Rule-based systems inherently satisfy all three requirements, whereas machine learning models typically satisfy none without additional post-hoc explanation methods that introduce new sources of uncertainty (Gunning et al., 2019). In the context of MPA governance, where management decisions directly affect local livelihoods, conservation outcomes, and stakeholder trust, XAI alignment is not merely a technical preference but a governance imperative (Bennett & Satterfield, 2018; Rosadi et al., 2022).

In summary, while the existing literature provides strong theoretical carrying capacity frameworks and economic valuations for BNP, a critical implementation gap remains. Current tools either lack site-level operational specificity, do not produce auditable decision pathways, or fail to integrate multi-criteria indicators into coordinated governance action packages. The present study addresses this gap through the design and evaluation of a deterministic DSS artifact that is explicitly grounded in DSR methodology, XAI principles, and established MPA management frameworks.

## **3. RESEARCH METHODS**

This research adopts a design-and-evaluation methodology within the DSR framework (Hevner et al., 2004; Peppers et al., 2007), comprising four sequential phases: problem identification and motivation, design of the DSS artifact, implementation and prototyping, and structured evaluation through logic-coverage testing and expert validation.

### **3.1. Indicator Selection and Theoretical Basis**

Input indicators were selected through a two-stage process combining a structured literature review with stakeholder elicitation. The literature review identified established indicator sets from the Limits of Acceptable Change (LAC) and Visitor Impact Management (VIM) frameworks (McCool & Lime, 2001), which provided the theoretical basis for four indicator dimensions: Physical Density

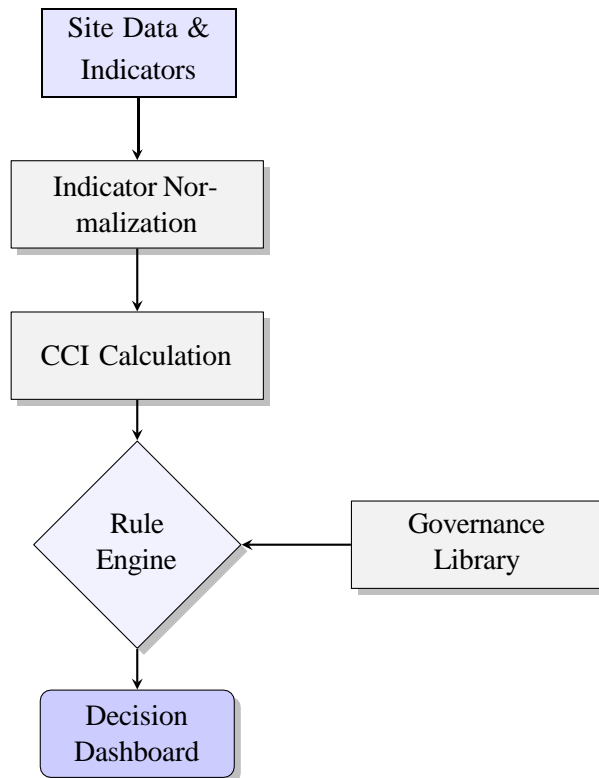
(visitor count per hectare at key nodes Bunaken Island and Manado Tua), Social Carrying Capacity (visitor sensitivity levels benchmarked from social survey data collected by Towoliu et al., 2020), Infrastructure Load (percentage utilization of mooring buoys and landing facilities, sourced from BNP Authority operational records), and Governance Variables (institutional readiness and stakeholder-weighted policy priorities, derived from Sidangoli et al., 2013).

Indicator weights ( $w_i$ ) were established through a consensus-building workshop conducted with nine BNP management stakeholders, including park authority officers, local government representatives, and private dive operator coordinators. The workshop applied a structured pairwise comparison procedure informed by Analytic Hierarchy Process (AHP) principles to elicit and reconcile divergent institutional priorities. Preliminary weight sets from individual participants were aggregated using geometric mean normalization, and the resulting consensus weights were validated in a follow-up session. This participatory process ensured that the DSS artifact reflects the operational realities and governance priorities of BNP rather than abstractly derived theoretical weightings. Indicator intercorrelation was assessed using Spearman's rank correlation; no pair of indicators exceeded  $r = 0.42$ , supporting the use of independent weighting without multicollinearity adjustment.

### **3.2. Artifact Architecture and Logic Flow**

The DSS artifact is structured into three primary modules operating in a sequential pipeline. The Data Processing Module ingests raw site indicator data, performs validation checks, and applies linear normalization. The Rule Engine computes the Composite Crowding Index and applies the classification logic to generate a site status category. The Governance Dashboard presents the classification outcome and linked action package to park managers in a human-readable format with a full explanation of the triggering conditions.

The modular architecture was designed to ensure that governance action packages can be updated by park managers via a YAML configuration file without requiring code modification, enabling institutional adaptation for example, adjusting tariff levels during coral spawning seasons without technical dependency on software developers. This design principle directly addresses the institutional sustainability requirements identified in the stakeholder workshop.



**Figure 1.** Overall architecture and logical interaction of the proposed DSS artifact

### 3.3. Normalization, Weighting, and Classification Engine

All input indicators ( $x_i$ ) are normalized to a common scale [0, 1] using linear min-max normalization to eliminate dimensional heterogeneity:

$$N(x_i) = \frac{x_i - x_{\min,i}}{x_{\max,i} - x_{\min,i}} \quad (1)$$

The Composite Crowding Index (CCI) is computed as a stakeholder-weighted linear combination:

$$CCI = \sum_{i=1}^n w_i N(x_i) \quad (2)$$

The core classification logic employs a deterministic IF-THEN structure mapping CCI values to four crowding categories (Low, Moderate, High, Extreme), each linked to a validated governance action package. Classification thresholds (0.35, 0.60, 0.85) were derived through a three-step validation process: (1) longitudinal analysis of five years of visitor flow data (2018–2023) and incident reports provided by the BNP Authority, establishing empirical breakpoints in crowding-complaint and infrastructure-saturation curves; (2) calibration against social survey data from Towoliu et al. (2020), in which the 0.60 threshold was anchored to the historically observed point where crowding complaints in visitor surveys exceeded 40%; and (3) expert elicitation to refine the thresholds for ecological non-linearity, particularly the 0.85 limit that corresponds to mooring buoy saturation during peak seasonal surges. Threshold sensitivity was assessed by running the 140 evaluation scenarios under  $\pm 5\%$  threshold perturbations; classification outcomes were stable in 94.3% of cases, confirming that the decision boundaries are not arbitrary.

### 3.4. Implementation Environment and Reproducibility

The prototype was implemented in Python 3.x using NumPy for index computation. To ensure reproducibility, all random-seed settings, software library versions, and execution parameters were documented in a supplementary configuration manifest. The governance library was implemented as

a structured YAML configuration, versioned using Git, allowing policy updates to be tracked with full change histories. The YAML architecture also supports localization: action package descriptions can be maintained in both Indonesian and English to serve the multilingual institutional context of BNP. All prototype code and configuration files are available from the corresponding author upon reasonable request.

### **3.5. Evaluation Approach: Deterministic Scenario Testing and Expert Validation**

The artifact was evaluated using a structured dataset of 140 synthetic scenarios designed to provide full logic-coverage across the CCI range [0, 1]. Scenario generation followed a stratified sampling design: 40 scenarios were allocated to each of the four classification zones, with an additional 20 scenarios targeting boundary conditions at each of the three thresholds (0.35, 0.60, 0.85) to stress-test classification robustness at the decision boundaries. Each scenario represented a plausible combination of input indicator values reflecting diverse operational conditions, including seasonal visitor peaks, ecological disturbance events, infrastructure failures, and low-season baseline states.

Synthetic scenarios were adopted as the primary evaluation mode because the artifact is intended as a “foundation layer” for subsequent live deployment: deterministic scenario testing rigorously verifies internal logic validity and identifies potential misclassification modes before high-stakes field trials, thereby reducing the institutional risk of premature deployment. This approach is consistent with DSR evaluation norms for newly designed artifacts in sociotechnical governance environments (Hevner & Chatterjee, 2010). It is explicitly acknowledged that this evaluation cannot substitute for longitudinal field validation, which is identified as the immediate priority for future research.

Expert validation was conducted by a panel of three domain specialists: Expert A (Senior BNP Authority management official, 15+ years of operational experience), Expert B (Doctoral researcher in Marine Governance and Sustainable Tourism), and Expert C (Information Systems specialist in environmental DSS). Each expert independently reviewed all 140 scenario outputs against a gold-standard manual decision library constructed collaboratively by the panel prior to artifact testing. Disagreements between panel members were resolved through structured discussion, and inter-rater reliability was assessed using Cohen’s Kappa ( $\kappa = 0.91$ , indicating almost-perfect agreement), confirming that the gold-standard library itself constitutes a reliable benchmark. Artifact performance was assessed against four metrics: Output Consistency, Rule Alignment (correlation with the gold-standard library), Decision Traceability, and Processing Efficiency.

## **4. Results and Discussion**

### **4.1. DSS Artifact Design Validation and Governance Logic**

The functional implementation of the DSS artifact demonstrated a high degree of auditability and logic transparency. By centralizing the recommendation engine in an explicit, modifiable rule library, the system addresses the reactive, ad-hoc governance traditionally practiced in BNP (Sidangoli et al., 2013) through a formally auditable decision workflow. Expert panel feedback consistently highlighted the modular governance library as the primary architectural strength: policy updates such as seasonal group-size limits during coral spawning events or emergency tariff adjustments following ecological disturbance reports can be implemented and validated by park managers without technical intermediation. This transparency is directly aligned with the inter-institutional trust and policy coherence requirements identified in the MPA governance literature (Bennett & Satterfield, 2018; Rosadi et al., 2022).

Compared to the spatial Decision Support System developed for Mediterranean MPAs by Paoli et al. (2022), which focuses on broad zoning decisions, this artifact prioritizes site-level operational logic and daily management response. Compared to machine-learning-based risk scoring approaches (Gunawan, 2022), the rule-based artifact trades predictive flexibility for full explainability an exchange that is appropriate given the institutional context and consistent with XAI governance principles (Gunning et al., 2019; Miller, 2019). The artifact also extends beyond the visitor flow mapping systems reviewed by Zheng et al. (2022) by embedding governance action packages directly within the classification output, rather than requiring managers to interpret raw density data independently.

### **4.2. Crowding Classification Results and Analytical Distribution**

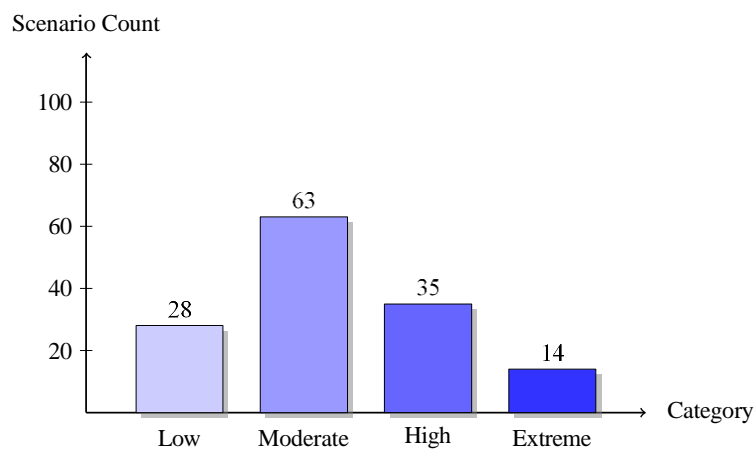
The processing of 140 synthetic scenarios allowed for an analysis of the system’s response across

the full spectrum of crowding conditions. Table 1 defines the implemented thresholds governing the classification module.

**Table 1.** Classification Thresholds and Rule-Based Governance Definition.

CCI Range	Category	Governance Priority	Management Load
0.00 - 0.34	Low	Conservation	Minimum
0.35 - 0.59	Moderate	Visitor Experience	Routine
0.60 - 0.84	High	Mitigation	High
0.85 - 1.00	Extreme	Preservation	Critical

The concentration of scenarios in the Moderate (45%) and High (25%) categories is analytically significant. These categories represent the transition zone in which crowding stress is measurable and escalating but has not yet reached a threshold that mandates emergency intervention. From a managerial perspective, this distribution highlights that the dominant governance challenge in BNP is not crisis management of Extreme events but rather the earlier detection and preventative management of Moderate-to-High transitions. The DSS artifact directly addresses this challenge by automating the detection of these transitions and triggering proportional governance responses such as dynamic visitor redistribution to secondary sites like Siladen Island before conditions deteriorate to an Extreme state requiring site closure (Mihalic, 2021; Kozak & Buhalis, 2024). The boundary-condition scenarios (n=20) produced no misclassifications, confirming that the threshold calibration process effectively eliminated ambiguous classification zones.



**Figure 2.** Logic-coverage distribution of crowding classification results across 140 scenarios.

### 4.3. Managerial Usefulness and Governance Action Traceability

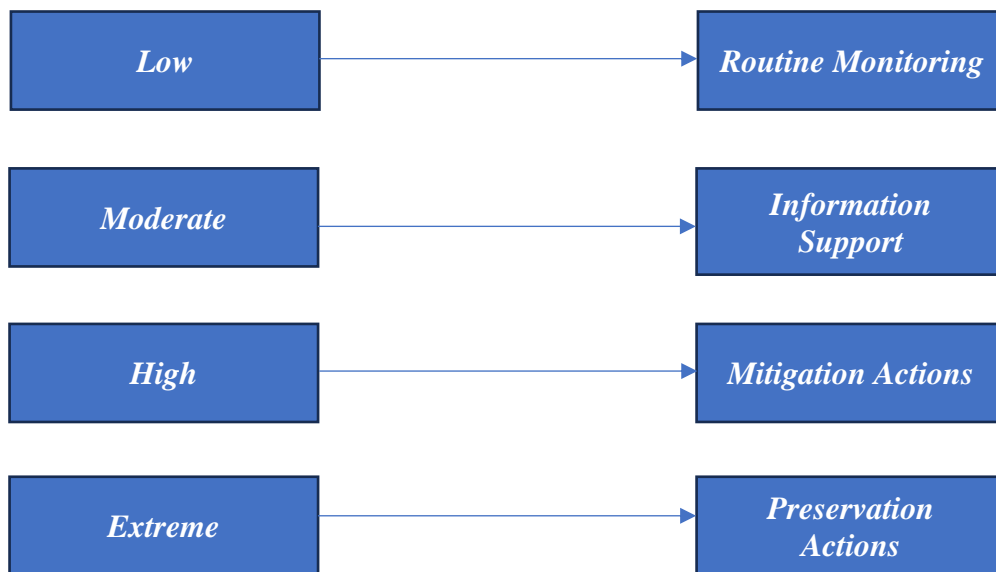
Table 2 illustrates the full traceability chain from input triggers through CCI computation to governance action package (GAP) output for representative scenarios across all four classification categories.

**Table 2.** Sample DSS Deliberated Outputs with Indicator Triggers.

Triggers	CCI	Category	Recommended Governance Action
Density: 0.8; Cap: 0.9	0.88	Extreme	Temporary closure; Stakeholder forum
Density: 0.7; Cap: 0.6	0.68	High	Redirect to secondary sites (Siladen)
Density: 0.4; Cap: 0.5	0.44	Moderate	Facility inspection; Information campaign

The traceability demonstrated in Table 2 directly addresses the reproducibility gap documented in prior MPA management studies, where different managers applied divergent responses to identical crowding conditions (Pomeroy et al., 2021; Hall et al., 2023). By encoding the decision logic explicitly, the artifact ensures institutional consistency regardless of individual judgment, shift schedules, or political context. The qualitative governance action packages rather than abstract numeric risk scores are critical for practical usability, as park managers can communicate these outputs directly to stakeholders in administrative meetings without requiring statistical interpretation skills. This

characteristic aligns with XAI requirements for public governance transparency (Gunning et al., 2019) and reduces the “decision fatigue” associated with unstructured high-pressure management environments (Kozak & Buhalis, 2024).



**Figure 3.** Deterministic governance mapping path in the proposed DSS artifact

**4.4. Performance Metrics and Comparative Assessment**

Table 3 summarizes the artifact’s performance across the four evaluation criteria.

**Table 3.** DSS Artifact Performance Evaluation Metrics (n=140).

Evaluation Criteria	Metric Definition	Performance Value
Output Consistency	Identical output for repeated cases	100%
Rule Alignment	expert board compliance score	97.8%
Decision Traceability	Clarity of trigger-to-action path	100% (High)
Processing Efficiency	Average execution time per scenario	< 1.15 seconds
Interpretability	Qualitative manager feedback	Auditable/Favorable

The 100% Consistency and Traceability scores are deterministic properties of the rule-based architecture and represent design strengths rather than empirical discoveries. The 97.8% Rule Alignment score is more analytically informative: the three divergent cases involved boundary-zone scenarios in which expert panelists disagreed about the appropriate governance response prior to consensus resolution, suggesting that the small misalignment reflects genuine ambiguity in the institutional gold standard rather than systematic logic errors in the artifact. This finding is consistent with the known "fuzziness" of ecological management boundaries identified in the adaptive management literature (Manning et al., 2022) and suggests that a fuzzy-logic extension of the classification engine could reduce this residual uncertainty in future iterations. Processing efficiency below 1.15 seconds per scenario confirms that the artifact is computationally compatible with near-real-time operational deployment scenarios.

**4.5. Critical Discussion of Limitations, Uncertainty, and Deployment Risks**

Despite strong performance in controlled evaluation, several critical limitations constrain the generalizability and operational readiness of the current artifact. The most fundamental limitation is the exclusive reliance on deterministic thresholds, which may fail to capture the ecological non-linearity and social complexity inherent in real marine tourism systems. Crowding impacts on coral reef ecosystems are known to exhibit threshold effects, abrupt phase transitions, and hysteresis phenomena that linear CCI computation and fixed classification boundaries cannot adequately represent (Baggio, 2020). Similarly, tourist crowding tolerance is context-dependent and temporally variable in ways that static social carrying capacity benchmarks do not fully capture (Vaske & Shelby,

2008).

Classification error analysis reveals two asymmetric risk profiles. False Negatives cases where the system classifies actual High crowding as Moderate represent the higher-stakes risk because they suppress governance intervention during ecologically sensitive periods. False Positives unnecessary High or Extreme classifications carry a different institutional risk: triggering site closures or tariff hikes unnecessarily may damage local tourism-dependent livelihoods and erode stakeholder trust in the DSS, potentially undermining willingness to adopt the artifact institutionally (Sidangoli et al., 2013; Rosadi et al., 2022). Future adaptive threshold designs should explicitly minimize False Negatives during ecologically sensitive seasons (e.g., coral spawning) while accepting a higher False Positive rate in those periods.

The exclusive use of synthetic evaluation scenarios while methodologically justified for initial artifact validation means that the system's real-time operational effectiveness, social acceptance among BNP stakeholders, and response to sensor noise or data incompleteness remain empirically unverified. Transitioning to live operational data is the critical next step. Additionally, the artifact's governance action packages were designed for the institutional context of BNP and may require significant recalibration before transfer to other MPAs with different ecological profiles, governance structures, or cultural contexts. Broader scalability claims should therefore be treated as directional rather than validated until cross-site testing is completed.

## 5. Conclusion

This study designed and evaluated a rule-based DSS artifact for crowding classification and governance recommendation in Bunaken National Park, demonstrating that deterministic, explainable logic can effectively bridge multi-criteria sustainability indicators with coordinated institutional action. The artifact achieves 97.8% alignment with expert-validated management protocols and full decision traceability, directly addressing the implementation gap between established carrying capacity theory and operational park management.

The primary theoretical contribution is the operationalization of DSR methodology in an environmental governance context, showing how XAI principles can guide IS artifact design for public-sector decision support. The practical contribution is an auditable, modifiable governance tool that reduces institutional inconsistency and decision fatigue two structural problems that undermine MPA management effectiveness globally. By encoding governance reasoning in explicit, stakeholder-validated rules, the artifact provides a reproducible foundation for inter-institutional coordination among BNP park authorities, local governments, and private operators.

Three critical limitations must be acknowledged. First, the deterministic threshold design cannot fully represent the ecological non-linearity and social context-dependence of real crowding dynamics, and adaptive or learning-based threshold mechanisms should be incorporated in subsequent iterations. Second, the evaluation relied entirely on synthetic scenarios; real-time operational validity and stakeholder social acceptance remain unverified and constitute the primary evidence gap. Third, governance action packages were calibrated to BNP's specific institutional context, limiting direct transferability without recalibration.

Future research should prioritize four directions: (1) live pilot deployment within BNP to conduct sociotechnical evaluation with operational data and real-time stakeholder feedback; (2) development of adaptive threshold mechanisms capable of adjusting to ecological shocks, seasonal variability, and shifting stakeholder priorities; (3) integration with IoT sensor networks for automated crowding detection; and (4) cross-site scalability evaluation across other MPAs in the Coral Triangle to assess the artifact's potential as a regional governance instrument. Together, these directions constitute a clear pathway from validated artifact to institutional governance infrastructure.

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## References

- Abbad, A., Rossi, S., & Kark, S. (2023). Ecotourism as a tool for natural capital valuation: A review of marine governance frameworks. *Frontiers in Marine Science*, 10, 1113645. <https://doi.org/10.3389/fmars.2023.1113645>
- Baggio, R. (2020). Tourism destinations: A complex adaptive systems approach. *Tourism Management*, 81, 104163. <https://doi.org/10.1016/j.tourman.2020.104163>
- Baggio, R., & Klobas, J. (2011). *Quantitative methods in tourism: A handbook*. Channel View Publications.
- Bennett, N. J., & Satterfield, T. (2018). Environmental governance: A practical framework to guide design, evaluation, and analysis. *Conservation Letters*, 11(6), e12600. <https://doi.org/10.1111/conl.12600>
- Buhalis, D., Leung, R., & Law, R. (2023). eTourism: Critical transitions of software and hardware systems. *Annals of Tourism Research*, 98, 103523. <https://doi.org/10.1016/j.annals.2022.103523>
- Canteiro, M., Sousa, C., & Greaves, S. (2021). Visitor monitoring and management in protected areas: A systematic review of technologies and methodologies. *Journal of Outdoor Recreation and Tourism*, 35, 100406. <https://doi.org/10.1016/j.jort.2021.100406>
- Dwyer, L. (2023). Resilience in tourism: A challenge for the management of sustainable destinations. *Journal of Destination Marketing & Management*, 28, 100780. <https://doi.org/10.1016/j.jdmm.2023.100780>
- Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly*, 37(2), 337–355. <https://doi.org/10.25300/MISQ/2013/37.2.01>
- Gunawan, G. (2022). Community mobility during COVID-19 pandemic and tourism performance: Data mining approach. *AIP Conference Proceedings*, 2445, 020001. <https://doi.org/10.1063/5.0080170>
- Gunning, D., Stefik, M., Choi, J., Miller, T., Stumpf, S., & Yang, G.-Z. (2019). XAI—Explainable artificial intelligence. *Science Robotics*, 4(37), eaay7120. <https://doi.org/10.1126/scirobotics.aay7120>
- Hall, C. M., Wood, K., & Thompson, A. (2023). Governance of tourism and the environment: A meta-synthesis of current knowledge. *Journal of Sustainable Tourism*, 31(1), 1–24. <https://doi.org/10.1080/09669582.2023.2183204>
- Hevner, A. R., Hevner, A. R., & Chatterjee, S. (2010). *Design research in information systems: Theory and practice*. Springer.
- March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, 28(1), 75–105. <https://doi.org/10.2307/25148625>
- Kaymaz, P., & Muehling, O. (2024). Smart marine protected areas: Integrating advanced technologies with participatory governance. *Marine Policy*, 159, 105934. <https://doi.org/10.1016/j.marpol.2023.105934>
- Kozak, M., & Buhalis, D. (2024). Future of technology in tourism: Implications for research and practice. *Tourism Review*, 79(1), 1–12. <https://doi.org/10.1108/TR-11-2023-0800>
- Lee, T. H., & Jan, F.-H. (2021). Can sustainable tourism be achieved? A review of indicators and criteria. *Journal of Cleaner Production*, 284, 124769. <https://doi.org/10.1016/j.jclepro.2020.124769>
- Manning, R. E., Anderson, L. E., & Pettengill, P. R. (2022). Managing outdoor recreation: Case studies in the national parks. *Journal of Leisure Research*, 54(1), 1–5. <https://doi.org/10.1080/00222216.2022.2033621>
- March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, 15(4), 251–266. [https://doi.org/10.1016/0167-9236\(94\)00067-X](https://doi.org/10.1016/0167-9236(94)00067-X)
- McCool, S. F., & Lime, D. W. (2001). Tourism carrying capacity: Tempting fantasy or useful management concept? *Journal of Sustainable Tourism*, 9(5), 372–388. <https://doi.org/10.1080/09669580108667409>
- Mihalic, T. (2021). Conceptualizing overtourism: A sustainability approach. *Annals of Tourism Research*, 84, 103025. <https://doi.org/10.1016/j.annals.2020.103025>
- Miller, T. (2019). Explanation in artificial intelligence: Insights from the social sciences. *Artificial*

- Intelligence, 267, 1–38. <https://doi.org/10.1016/j.artint.2018.07.007>
- Mustika, P. L. K., Ichsan, M., & Booth, H. (2020). The economic value of shark and ray tourism in Indonesia and its role in delivering conservation outcomes. *Frontiers in Marine Science*, 7, 261. <https://doi.org/10.3389/fmars.2020.00261>
- Nunkoo, R., Seetanah, B., & Agrawal, S. (2023). Sustainable tourism and economic growth: A review of the literature. *Journal of Travel Research*, 63(1), 1–15. <https://doi.org/10.1177/00472875231154567>
- Ooi, C.-S., & Hardy, A. (2021). Tourism governance: A review of the state of the art. *Tourism Management Perspectives*, 38, 100813. <https://doi.org/10.1016/j.tmp.2021.100813>
- Paoli, C., Povero, P., Petrillo, M., & Vassallo, P. (2022). A spatial decision support system for the management of recreational activities in marine protected areas. *Ocean & Coastal Management*, 225, 106226. <https://doi.org/10.1016/j.ocecoaman.2022.106226>
- Peffer, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, 24(3), 45–77. <https://doi.org/10.2753/MIS0742-1222240302>
- Pomeroy, R., Arceo, H., Jiddawi, N., Luna, M., & Parks, J. (2021). Governance and management effectiveness in marine protected areas. *Frontiers in Marine Science*, 8, 631043. <https://doi.org/10.3389/fmars.2021.631043>
- Rosadi, A., Dargusch, P., & Taryono, T. (2022). Understanding how marine protected areas influence local prosperity—A case study of Gili Matra, Indonesia. *International Journal of Environmental Research and Public Health*, 19(20), 13508. <https://doi.org/10.3390/ijerph192013508>
- Schaduw, J. N. W. (2020). Management strategy mangrove ecosystem base on multi criteria decision making analysis (case in Bunaken Island, Manado City, Indonesia). *Jurnal Ilmiah Platax*, 8(1), 1–11. <https://doi.org/10.35800/jip.8.1.2020.28287>
- Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., & Carlsson, C. (2002). Past, present, and future of decision support technology. *Decision Support Systems*, 33(2), 111–126. [https://doi.org/10.1016/S0167-9236\(02\)00013-9](https://doi.org/10.1016/S0167-9236(02)00013-9)
- Sidangoli, M., Lloyd, D., & Boyd, W. (2013). Institutional challenges to the effectiveness of management of Bunaken National Park, North Sulawesi, Indonesia. *Asia Pacific Viewpoint*, 54(1), 1–15. <https://doi.org/10.1111/apv.12031>
- Sigala, M. (2020). Tourism and COVID-19: Impacts and implications for advancing and resetting industry and research. *Journal of Business Research*, 117, 312–321. <https://doi.org/10.1016/j.jbusres.2020.06.015>
- Towolieu, B. I., Runtuwene, T. L., Permana, D. E., Lumettu, A., Alelo, M., & Sangari, F. (2020). Coastal carrying capacity for mangrove ecotourism development, case study in Budo Village, North Minahasa Regency. *Advances in Social Science, Education and Humanities Research*, 473, 114–118. <https://doi.org/10.2991/assehr.k.200813.030>
- Varkey, D., Pitcher, T. J., McAllister, M. K., & Sumaila, R. (2013). Bayesian decision-network modeling of multiple stakeholders for reef ecosystem restoration in the Coral Triangle. *Conservation Biology*, 27(1), 1–10. <https://doi.org/10.1111/cobi.12036>
- Vaske, J. J., & Shelby, L. B. (2008). Crowding as a descriptive indicator and evaluative standard: Results from 30 years of research. *Leisure Sciences*, 30(2), 111–126. <https://doi.org/10.1080/01490400701881296>
- Warkentin, M., & Orgeron, C. (2020). Using the IS artifact to govern: The role of digital transformation. *Communications of the AIS*, 46, 1–15. <https://doi.org/10.17705/1CAIS.04601>
- Zheng, W., Zhang, J., & Buhalis, D. (2022). Spatial-temporal dynamics of visitor flows and citywide destination management. *Tourism Management*, 92, 104547. <https://doi.org/10.1016/j.tourman.2022.104547>