Trail Triage: Identifying Collaborative Workflows in Trail Management Assisted by Crowdsourced Reports

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Trail management is a complex, distributed endeavor that requires coordination among conservancies, government agencies, and local trail clubs to ensure visitor safety, environmental stewardship, and the protection of historical resources. Despite its importance, there has been limited systematic research on understanding or supporting the collaborative workflows that sustain this work. To help bridge this gap, we conducted interviews with 10 trail managers involved in or familiar with field operations across five major U.S. long-distance trails. A thematic analysis of the transcripts reveals that trail management spans a wide array of responsibilities, including volunteer coordination, resource allocation, hazard sense-making, and on-the-ground fieldwork. We identify institutional inefficiencies that surface during four distinct stages of the temporal collaborative sense-making process as managers interpret and act upon hiker-submitted reports of trail hazards. We conclude by outlining design implications for field reporting and decision-support systems that better align with the realities of volunteer-based, resource-constrained trail organizations, supporting more timely and coordinated action across distributed stakeholders.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; **Empirical studies in collaborative and social computing**.

Additional Key Words and Phrases: Trail management, Crowdsourced reporting, Volunteer coordination, Temporal Sense-making

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1 Introduction

Hiking is one of the most popular outdoor pursuits in the United States, with an estimated 59.6–63.4 million Americans set foot on a trail each year, demonstrating sustained public demand and enthusiasm for nature-based recreation [17, 86]. However, poorly maintained trails raise the likelihood of hiker injury [60, 94] and accelerate ecological damage [72, 95]. To keep routes both safe and sustainable, land stewards must continually monitor conditions and carry out labor-intensive tasks such as drainage repair, blow-down removal, rerouting, and visitor education [94]. Although

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demanding on any trail, this work becomes exponentially more complex on marquee long-distance corridors like the Appalachian Trail (2,190 mi) and the Pacific Crest Trail (2,653 mi), which span multiple ecosystems, jurisdictions, and terrain types—making coordinated management a formidable logistical and organizational challenge.

Addressing these challenges requires a decentralized but highly collaborative approach. Long-distance trails in the U.S. are generally managed through a collaboration between volunteer groups and government authorities [3, 4, 71]. This collaboration ensures that trails are not only maintained but also preserved as cultural, ecological, and recreational assets [3, 4, 71]. Together, these stakeholders play a critical role in minimizing hiker risk [33, 34, 62], protecting fragile ecosystems [61], and safeguarding the cultural and historic resources embedded within the trail landscape [19, 23].

Effective trail management begins with reliable, up-to-date situational awareness. Traditionally, this has relied on manual field monitoring: volunteers or rangers walking the corridor to document hazards and assess trail conditions, which remains the foundation of stewardship because it is accurate, context-aware, and embedded in routine workflows [40, 52, 70]. In the past decade, researchers have experimented with in-situ sensors (e.g., vibration counters, camera traps, soil-moisture loggers) [21, 43, 59], and remote-sensing pipelines [2, 11, 48] in assisting tail monitoring to replace the manual labor. However, studies in CSCW and HCI consistently find that fixed-sensor infrastructures are rarely sustainable for low-resource projects; their long-term operational costs: including battery replacement, truck rolls, data-plan fees, and maintenance, often exceed organizational capacity [91].

Consequently, recent research has advocated for citizen-powered sensing and bring-your-own-device (BYOD) strategies as low-cost, scalable alternatives to sensor-based monitoring [24, 91]. "Human sensors" have shown promise; crowdsourced images, for example, have been found to match the effectiveness of bike-mounted cameras in tracking urban hazards [24]. Despite growing interest, only a modest corpus of CSCW and HCI research has tested whether crowed sourced information like hiker sourced reports, smartphone traces, or social media posts can serve as a low-cost "citizen science" layer for crowed-soruced trail monitoring. Preliminary evidence is encouraging [22, 31], but interviews with Appalachian Trail staff reveal that, when processing crowd sourced input for integration into daily workflows, managers often face data overload, fragmented reporting channels, and limited organizational capacity. Which underscoring a persistent sociotechnical gap between digital possibilities and organizational realities [68]. Moreover, while these findings are well-documented in the context of the Appalachian Trail's governance model [68], it remains unclear whether, and how, similar challenges manifest across other U.S. trail systems operating under different land-management regimes, geographic conditions, and volunteer capacities. It also remains to be seen which specific workflows crowd-sourced reports support or hinder in practice.

As a continuation of the GROUP workshop "Technology on the Trail" [64], we extend this line of inquiry to the domain of outdoor infrastructure maintenance, where collaboration unfolds across both digital and physical terrains. This setting introduces distinctive coordination challenges shaped by geographic dispersion, intermittent connectivity, and reliance on volunteer labor. Our work builds on recent CSCW frameworks of temporal sensemaking [69] and collaborative rhythms [39], as well as prior GROUP research on crowdsourced collaboration, participatory sensemaking, and automated information workflows [36, 58, 75, 104]. By examining how decentralized trail organizations ingest, evaluate, and act on hiker-submitted reports, we uncover unique sociotechnical frictions and adaptive workarounds that emerge when fragmented, user-generated data must be reconciled with the temporal rhythms and operational constraints of field-based maintenance.

Specifically, we ask:

- **RQ1**: What work roles and tasks define the day-to-day operations of trail management organizations?
- **RQ2**: In what ways can community-sourced reports support the operational workflows of volunteer-driven trail organizations?
- **RQ3**: What sociotechnical design opportunities can enhance the capture, verification, and integration of crowd-sourced data within trail-management workflows?

Through interviews, field observations, and artifact walkthroughs with trail administrators and club volunteers across diverse U.S. regions, we document existing practices, identify key information gaps and coordination challenges, and surface design directions for collaborative communication and decision-support systems. Our goal is to support more resilient, data-informed trail stewardship that empowers both institutional stakeholders and the public to contribute meaningfully to trail safety and sustainability.

The rest of this paper is organized as follows. Section 2 presents our analysis of related work. Section 3 describes our study design, data collection, and data analysis methods. Section 4 outlines key findings about trail management work roles and collaborative workflows. Section 5 discusses these findings in the context of prior CSCW work, and outlines implications for the design of decision support systems for trail management. Section 6 outlines key limitations and associated future work vectors, and Section 7 concludes the study.

2 Related Work

In this section we review previous research on trail management. We review studies from two primary research areas: (1) organizational barriers to collaborative work, especially in resource-constrained settings, and (2) crowdsourcing and collaborative sensemaking in environmental monitoring applications. These studies provide a foundational view of collaborative work opportunities and barriers in volunteer-run organizations, and highlight the need for thorough, fine-grained models of trail management work processes.

2.1 Trail Management: Resource Management and Temporal Coordination

Volunteer-run trail organizations manage the trail by juggling urgent hazards, balancing seasonal windows, and working under chronic resource scarcity [3, 4, 71]. Like many nonprofit organizations, they operate on limited resources, characterized by limited budgets, dispersed teams, and a largely volunteer workforce [98]. These constraints shape every aspect of their collaborative work, from recruiting and scheduling volunteers to sharing information and coordinating with external partners. [4, 71].

Prior CSCW research identifies several persistent barriers that complicate internal collaboration in volunteer-run nonprofits. Data fragmentation is a core challenge: coordinators often juggle parallel spreadsheets, paper files, and custom databases because “no single system met all needs” [96]. Communication workflows are similarly siloed, with key tasks funneled through a designated point person, which often results in delays to real-time engagement [97]. Digital skill gaps further strain operations; without dedicated IT support, staff must learn and maintain tools on the fly [65]. Even when data are collected for daily operation, many organizations lack the analytic capacity to translate them into decisions. This leaves behind ’piles of unused numbers’ that still require time and upkeep. [9]. Recruiting and retaining volunteers adds additional friction, as listings often fail to communicate the complexity of tasks, leading to mismatched expectations and eventual disengagement. [90], while maintaining morale requires time-intensive recognition practices like newsletters and thank-you events [98]. Together, these barriers force nonprofit coordinators to act as de facto tech support, analysts, and community managers—roles that generate structural overhead and limit their ability to streamline collaboration [98].

While these studies surface concrete examples of structural barriers in volunteer settings, theoretical scaffolding is needed to make sense of why these frictions persist—and how they manifest across different temporal and collaborative scales. Trail stewardship, in particular, demands fine-grained coordination across organizational, seasonal, and biographical rhythms. To interpret this complexity, we draw on two frameworks from related CSCW work that help illuminate not just what breaks down in thin infrastructures, but when and why.

First, Norris et al.'s temporal sensemaking framework—developed in the context of collaborative disaster response—maps cleanly onto backcountry maintenance workflows. Their four-phase cycle of triage, evaluation, negotiation, and synchronization provides a useful lens for pinpointing where coordination overhead spikes, especially when hazard reports, weather windows, and permit timelines collide [69]. These stages parallel how trail crews assess incident reports, verify on-the-ground conditions, deliberate next steps with partner agencies, and ultimately deploy resources.

Second, Jackson's notion of pluritemporality captures the entanglement of organizational, biographical, and infrastructural timescales in scientific collaboration—a concept we extend to trail work. In our context, urgency driven by storm damage or safety hazards ("phenomenal rhythms") often clashes with slower institutional processes like grant cycles, equipment procurement, or volunteer availability ("organizational" and "biographical" rhythms) [39]. These temporal mismatches can stall decision-making or force redundant efforts, especially when key information is delayed or siloed.

Together, these frameworks allow us to conceptualize trail management not just as a series of isolated breakdowns but as a recurring coordination challenge shaped by competing rhythms, limited capacity, and fragmented infrastructures. In the section that follows, we show how this temporal lens helps interpret the friction points observed across multiple clubs and trail systems—surfacing design opportunities for tools that support timely, collaborative action under constrained conditions.

2.2 Trail Communities: Hiker Reports for Environmental Monitoring

In environmental monitoring, crowdsourcing and collaborative sensemaking offer a cost-effective means to gather high-resolution, locally relevant data. Their efficiency stems from three factors: the breadth of distributed participation, which expands spatial and temporal coverage beyond what professional teams can achieve [63, 82]; the use of existing community networks and low-cost tools, which reduce infrastructure and labor demands [18, 35]; and the reciprocal nature of engagement, where volunteers' local knowledge and stewardship motivations improve contextual accuracy [41, 100, 102]. Together, these mechanisms make crowdsourced monitoring both scalable and economically sustainable while fostering public involvement in environmental decision-making.

However, the success of such systems relies heavily on robust quality assurance processes, including participant training, sensor calibration, consensus modeling, and expert validation [18, 47, 81, 82]. In contrast, citizen-science research foregrounds the challenges of validation and trust. Community review enhances data reliability [99]; structured feedback supports peer consensus and learning [84]; and ability-weighted modeling improves result credibility [81]. Yet even mature systems face expertise gaps and spatial inconsistencies, requiring sustained investment in training and quality control [12, 15, 47].

In the context of trail management, crowdsourced observations submitted by hikers may offer a valuable opportunity to enhance monitoring through distributed, real-time reporting. However, persistent challenges arise in integrating these submissions into existing workflows. Studies in other domain have shown that, although large-scale volunteer reporting is feasible—especially when supported by clear guidance and real-time upload capabilities [51, 89], many land management

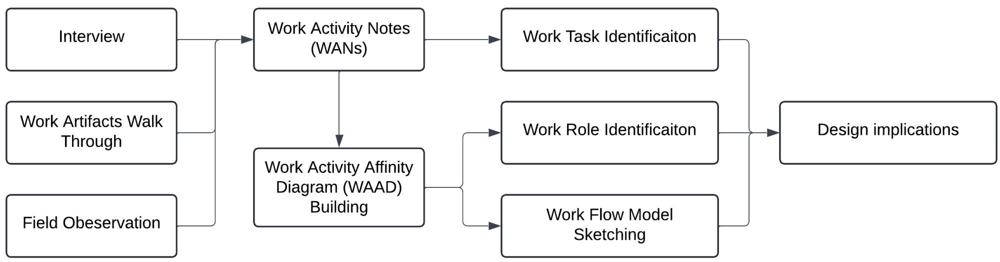

Fig. 1. This diagram illustrates our study methodology grounded in Hartson and Pyla's UX research process [28, 29]. We began with a contextual inquiry into the work practice of trail management. We conducted interviews, work artifact walkthroughs, and field observations to generate work activity notes (WANs). These notes were organized through affinity diagramming (WAAD) to surface frequent themes. We then identified work tasks and roles, sketched workflow models, and derived design requirements for community-sourced decision support in trail management.

organizations struggle to incorporate heterogeneous, location-dependent data into formal processes. These difficulties stem from issues in data quality, redundancy, and alignment with legacy systems, which often lack the flexibility to process unstructured and variable citizen inputs [20, 44, 78].

Moreover, similar issues identified in prior citizen-science projects persist in trail management domain. Concerns around trust, verification, and data overload remain central barriers to the formal adoption of crowd-sourced inputs in decision-making workflows [51, 56, 68, 103][81, 84, 99] Simply collecting observations is not enough. As Patel argues, the full potential of these systems lies not just in information capture but in fostering structured, two-way communication between hikers and trail managers [73]. Extending this idea, trail information platforms can promote mutual understanding, strengthen transparency, and build shared responsibility for trail conditions, resource stewardship, and environmental resilience[73].

Taken together, these studies highlight that while crowdsourced risk reporting holds significant potential for enhancing environmental monitoring and supporting collaborative stewardship among multiple parties, effective system design must address motivational, technical, organizational, and data validation challenges to fully integrate community-contributed data into actionable decision-making workflows in trail management and environmental governance.

3 Methodology

To explore our research questions, we conducted a qualitative study grounded in contextual inquiry and thematic analysis (Figure 1), as outlined in Hartson & Pyla's UX research methodology [28, 29]. This approach enabled us to identify recurring patterns in tasks, roles, workflows, and coordination challenges. Below, we describe our study setting, participant recruitment, data-collection procedures, and analytic workflow.

3.1 Study Setting and Participants

The study focused on long-distance hiking trails in the United States—continuous, primarily non-motorized corridors extending at least 100 miles (161 km), as defined by the National Trails System Act [16]. We deliberately centered our inquiry on trail-management groups with on-the-ground jurisdiction, including local trail clubs, conservancy or trail association staff, and government field staff who handle the day-to-day realities of maintenance/repair, hazard triage, and volunteer

NPS region	**Trail(s)**	**Participant Affiliation**	**Participant IDs and Role(s)**
Pacific West Region	Pacific Crest Trail (PCT)	USDA Forest Service PCT Program	(**U1**) Trail Operations Specialist
Intermountain Region	Colorado Trail	Colorado Trail Foundation	(**U2**) Field Operations Supervisor
Midwest Region	North Country Trail	North Country Trail Association	(**U3**) Regional Supervisor
Northeast Region	Appalachian Trail (AT) North	Green Mountain Club	(**U4**) Director of Field Programs
		Appalachian Trail Conservancy (ATC)	(**U5**) Regional Manager
Southeast Region	Appalachian Trail (AT) South	Georgia Appalachian Trail Club	(**U6**) Trail Supervisor
		Natural Bridge Appalachian Trail Club	(**U7**) Trail Supervisor
			(**U8**) President (Retired)
		Roanoke Appalachian Trail Club	(**U9**) Trail Supervisor and Volunteer Manager
	Florida Trail	USDA Forest Service Florida National Scenic Trail	(**U10**) Deputy Manager

Table 1. Overview of study participants (N=10) by National Park Service region, trail organization affiliation, and general role title. Specific names and detailed titles have been withheld for confidentiality reasons.

coordination in the field. In contrast, higher-level trail administrators—such as federal policy officers—were outside the scope of this study, as their work focuses on funding, legislation, and long-term planning rather than the hands-on stewardship that shapes trail conditions week by week [93].

To ensure that our study spanned diverse terrains and jurisdictions, we used National Park Service (NPS) regional divisions to select long-distance trails across the mainland United States [92]. This approach allowed us to capture variability in trail environments, climate conditions, and management structures across regions. Specifically, we focused on the following trails within each NPS region, along with their primary conservancy or regional management organization. And after several rounds of outreach, connection, and participant referrals, we identified and recruited the following interview candidates, each directly responsible for or familiar with on-the-ground trail management within their respective regions (table 1).

3.2 Data Collection and preparation

Following Hartson and Pyla's guidelines [28], we conducted ten semi-structured interviews (45–60 minutes each) with trail managers, guided by open-ended questions about their problem solving workflows, information sources, coordination methodology, and digital tools usage. The format allowed for flexible follow-up questions to probe unanticipated practices or examples raised by participants. In addition, we carried out one on-site observation of a full workday that included report-triage meetings, work-trip scheduling, and field operations. The observation focused on how information moved across people, tools, and settings, with field notes documenting nonverbal interactions, workspace arrangements, and technology use. We also performed an artifact walkthrough of spreadsheets, email threads, and photo archives related to a major infrastructure repair—the Brown Mountain Creek bridge on the Virginia section of the Appalachian Trail—to contextualize references made during interviews. All procedures received ethical approval from the [University Name] Institutional Review Board. Participants volunteered without monetary compensation but were offered continued collaboration opportunities and access to published results. Each session was audio-recorded with consent, and field notes were used to triangulate findings and attribute insights to specific data sources (interview, observation, or artifact review).

Recordings of interviews and field observations were transcribed using an AI voice-to-text tool (https://otter.ai/), producing approximately 57,000 words of transcript. All authors collaboratively converted the raw transcripts into 170 Work-Activity Notes (WANs): each a concise, one-to-three-sentence, first-person statement capturing a single action, rationale, or breakdown encountered

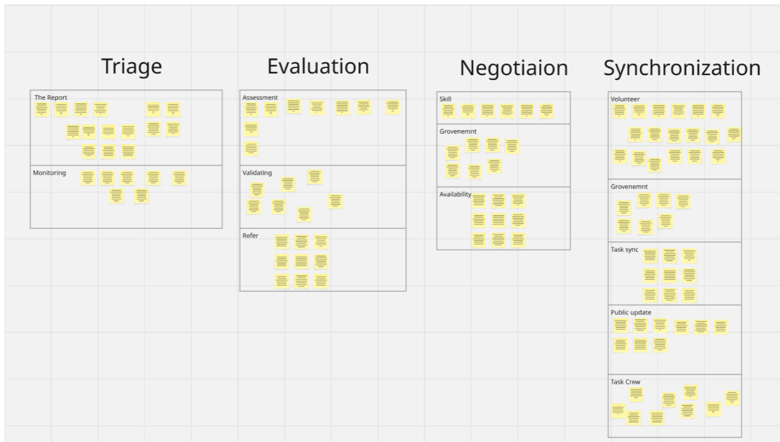

Fig. 2. An illustration of the coding and affinity diagramming process used for thematic analysis of interview data. We grouped WANs bottom-up and promoted them into super-groups aligned with key stages of temporal sensemaking (triage, evaluation, negotiaton, synchornization), capturing where coordination challenges and opportunities emerge across club, conservancy, and agency workflows.

during participants' trail management work [29]. Each WAN was tagged with participant ID and provisional topical codes to support systematic clustering and thematic analysis.

3.3 Contextual Analysis

We constructed a Work-Activity Affinity Diagram (WAAD) to distill the hundreds of WANs gathered in our study into a coherent view of trail-management practice. First, using a bottom-up approach, the research team iteratively piled individual WANs by semantic affinity—adding, splitting, and merging notes until the structure stabilized [29]. Throughout these rounds we worked shoulder-to-shoulder with all co-authors, including three HCI specialists who have section-hiked the Appalachian Trail, so that coding decisions reflected both methodological rigor and lived experience.

During our field observations, we realized that trail management unfolds a similar temporal sense-making process as the related work suggested [69], as trail managers filter, validate, align, and act on reports and maintenance needs over time. Trail managers we interviewed confirmed that this framing resonated with how they coordinate and prioritize work under real-world conditions. Guided by this insight, once our affinity clusters stabilized, we promoted them into groups and super-groups aligned with the stages of temporal sensemaking, labeling each in participants' vernacular to preserve experiential nuance and accurately reflect the multi-stakeholder voice of trail management (Figure 2).

In parallel, we engaged in simultaneous flow-model sketching (following a similar approach as Koivunen et al. [49]) and work-role identification, using the Brown Mountain Creek bridge replacement case to trace how tasks, responsibilities, and information flow across clubs, conservancies, and government agencies over time. Anchoring these sketches in the detailed breakdowns of routine maintenance, intermediate projects, and capital projects, and the layered roles of volunteers, conservancy staff, and land management agencies, allowed us to pinpoint where community-sourced reports slot into workflows. And finally, generate design requirements for community-sourced decision support in trail management

Work Scope	Work Example	Responsible Actors	Shared Resources & Supports
Routine maintenance (club-led)	Local maintainer networks coordinate: blow-down removal, brushing, tread touch-ups, repainting blazes, minor sign replacement	Club Volunteer Club Field supervisor	Clubs draw on their own hand-tool caches, donated supplies, and volunteer labour; concervency provides safety trainings and liability coverage articulated in the VSA.
Intermediate projects (club + Concervency crews)	Joint club– concervency work trips tackle: tread reconstruction, water-bar or crib-step builds, short relocations, Bridge-deck swaps in-kind are also possible.	Project leads from the club; Conservancy field coordinator; Conservancy trail crews (when needed).	Concervency lends specialised tools, trail-crew labour, and mini-grants; clubs contribute local logistics and volunteer recruitment.
Capital projects (multi-agency)	Multi-party teams co-produce high-impact infrastructure new bridges or shelters, major relocations, privy construction.	Club crew and supervisor, Conservancy project staff, Conservancy trail crew Land-management agency staff (NPS, USFS, or state). External Contractor	Capital funds routed through FMSS; engineered drawings, NEPA studies, contractor bids, and shared reporting dashboards scaffold inter-organisational coordination.

Table 2. Three key work scopes in trail management revealed in our interviews: routine maintenance, intermediate projects, and capital projects. We describe the tasks, responsible actors, and shared resources within each scope.

4 Findings

Trail management on long-distance trails operates through a collaborative system shaped by local clubs, trail conservancies, and land-management agencies. In this section, we begin by describing the structure of trail management, outlining the work scopes, example tasks, and key roles that define maintenance practices across these organizations **(RQ1)**. We then provide additional context for the discussion section by illustrating how these dynamics unfold in practice through a recent bridge replacement project and by defining hiker-submitted, crowd-sourced reports within the trail management workflow. Finally, we summarize the factors that constrain internal collaboration within local trail clubs as a source of coordination overhead. Together, these findings provide the necessary foundation for answering **RQ2** and **RQ3** in the discussion section.

4.1 Trail Management Relies on Cooperation Between Conservancies, Clubs, and Government Agencies

Trail management, or stewardship, on the major cross-state trail operates through a cooperative network of local trail clubs, the Trail Conservancy, and land-management agencies. Trail management operates as a cooperative tripod: volunteer trail-maintaining clubs conduct local fieldwork and routine upkeep, while a trail-wide coordinating nonprofit conservancy aligns these dispersed efforts through shared data systems, training, and logistics support. Federal and state land-management agencies contribute permits, compliance oversight, and capital resources, enabling clubs and the coordinating nonprofit to act within legal and ecological requirements.

From our interviews with club leaders, conservancy staff, and agency liaisons, three primary work scopes **(RQ1)** emerged: (1) routine maintenance, (2) intermediate projects, and (3) capital projects (Table 2). While the United States public "owns" federal public lands in principle, federal and state land-management agencies (e.g., the U.S. Forest Service and National Park Service) hold the legal title and manage these lands. On trails, this means that federal and state agencies retain ownership and management responsibilities while ensuring public access under legal frameworks that define and limit use.

Trail stewardship unfolds across a mosaic of ecosystems, budgets, and volunteer capacities, and those factors decide what gets done and when. Alpine segments in Colorado stay snowbound until midsummer, squeezing rock-step and bridge projects into a July–September sprint, whereas Florida's subtropical flats can disappear under palmetto days after a storm, driving an endless cycle of brush-cutting. Hazards vary—bear cables in the Smokies, poison ivy in the Mid-Atlantic—as do resources: a well-funded club can sling-load crushed granite by helicopter, while a rural club might wait years for a federal grant to replace one washed-out bridge. Volunteer depth widens the gap further. A small club, run by four managers and a lean crew, patrols 100 miles only three times a year, so blowdowns may linger for months; a large club can tap 2,000 volunteers and keep a rapid-response team on call, clearing hazards within hours.

Yet beneath those surface contrasts and differences, the organizational scaffold is remarkably consistent. Local hiking clubs often operate under agreements with government agencies that allow them to perform routine, low-capital maintenance without prior notification to the managing agency. Conservancies typically oversee the budgets for intermediate-sized repairs, providing additional funding and volunteer labor when minor capital expenses are involved. For projects requiring significant capital investment or involving property modifications, local land-management agencies are engaged for approval, and additional grants are sometimes pursued to support the work.

4.2 Trail Management Features a Broad Array of Tasks from Volunteer Management to Fieldwork, Outreach, and Leadership

Building on these three task scopes, our contextual analysis of interview transcripts (Section 3.3) identified 15 key work roles across three trail management entities: club members, conservancy staff, and land management agents. Table 3 describes these entities, work roles, and the individual responsibilities each assumes (**RQ1**. Local clubs are responsible for daily maintenance work, including routine inspections and minor repairs. Club staff collaborate with conservancies and government agencies on larger projects, providing local knowledge and on-the-ground assistance during planning and implementation. Conservancy staff coordinate stewardship efforts across club boundaries, providing information, training, and capital assistance to support projects beyond a club's routine capacity. Government agencies provide legal oversight, technical guidance, and regulatory approvals, ensuring that major projects comply with environmental and land-management policies. They may also offer grants and additional resources when projects require significant capital investment or involve property modifications.

Similar work roles appear across clubs, conservancies, and agencies, but each carries distinct tasks and responsibilities aligned with that organization's scope within trail management. Volunteers are the primary workforce for both clubs and conservancies, making volunteer management a significant part of their operations. However, while both recruit volunteers, local clubs typically seek repeat volunteers from nearby communities who can perform weekly maintenance on assigned trail sections, ensuring routine upkeep and rapid responsiveness. In contrast, conservancies focus on recruiting and deploying skilled volunteers who are willing to stay on the trail for days or weeks, working across states to complete complex projects that exceed the capacity and resources of local clubs. Reflecting this operational focus, club volunteer managers prioritize local recruitment, task scheduling, and supporting volunteers in routine maintenance, while conservancy volunteer managers oversee cross-club training, track volunteer credentials, and coordinate regional crew deployments for specialized projects. This division of labor enables each organization to contribute effectively while maintaining alignment within collaborative stewardship workflows.

4.3 Case Study in Trail Infrastructure Repair Work: Brown Mountain Creek Bridge Replacement

To examine when and why coordination overhead spikes within trail management workflows and how the crowd-sourced report from the public assists or hinders the process, we draw our attention to a recently completed capital bridge repair project. Using the Appalachian Trail's Brown Mountain

Entity	Role title	Core maintenance / support tasks
Local Trail Club / Chapter	Leadership	(1) Set club strategy (2) Approve budgets and work plans (3) Represent club to agencies / ATC
	Club Counselor	(1) Vet safety and logistics of proposed projects (2) Check regulatory fit (3) Coach leaders
	Field Ops Supervisor	(1) Schedule work trips (2) Secure permits (3) Supervise on-site technical work
	Policy Supervisor	(1) Track easements (2) Monitor NEPA / Section 106 triggers (3) File required paperwork
	Volunteer Manager	(1) Recruit and train volunteers (2) Match skills to tasks (3) Log hours and certifications
	Section Maintainer	(1) Inspect assigned miles (2) Clear blowdowns, brush, and drains (3) File condition reports
	Outreach Lead	(1) Run social media and events (2) Conduct hiker education (3) Grow membership
	Volunteer & Member	(1) Perform assigned trail work (2) Provide feedback (3) Follow safety rules
Trail Conservancy (e.g., ATC, PCTA)	Regional Manager	(1) Coordinate 30+ clubs (2) Align projects to regional plans (3) Troubleshoot permits
	Volunteer Coordinator	(1) Run crosscut, rigging, and WFA courses (2) Manage credential database (3) Track and report volunteer hours
	Crew Supervisor	(1) Lead professional and volunteer crews on bridges, reroutes, and cribbing (2) Manage heavy tools (3) Supervise field safety supervise
	Corridor Coordinator	(1) Monitor trail boundaries (2) Remove encroachments (3) Train corridor monitors
Government Land Management (e.g., NPS, USFS, BLM)	District Ranger and Manager	(1) Approve annual plans and special-use permits (2) Deploy agency crews and equipment
	Technician	(1) Build and repair tread and structures (2) Cut hazard trees (3) Demonstrate tool safety
	Resource Specialist	(1) Screen sites for species and cultural impacts (2) Monitor mitigation (3) Write compliance reports

Table 3. This table describes the cooperative work structure which helps maintain long-distance trails. The table outlines key work roles and their top-3 responsibilities across the three collaborating organizations: local trail-maintaining clubs, trail conservancies, and government land-management agencies.

Creek bridge replacement as a case, this section traces the life cycle of a single community-sourced hazard report through eight major stages (Table 4) for a capital project (explained in Table 2), illustrating how community reports serve different roles across each stage.

Our analysis of the Brown Mountain Creek bridge-replacement project deepened our understanding of trail-management workflows by pinpointing the documents, and the corresponding data, that must be collected, refined, and verified. The analysis also underscores how crowd-sourced hikers' reports serve as a critical input, sustaining each stage of the trail-management process.

In this context, crowd-sourced hikers' reports refer to observations from hikers or others in the field who notice issues and feel obligated to report them to trail authorities. These reports typically arrive via email, SMS, online forms, or phone calls. Each organization: local clubs, conservancies, and government agencies, has its own channels for receiving these reports, depending on its staffing levels and resources. Information is shared internally and across organizations when

Stage	Documentation	Evidence Points	Potential Role of Community-Sourced Reports
Hiker Report (Mar 2018)	ATC Public Incident Report Form Incident Email & Text Message	Brief Landmark phrase only ("near Brown Mountain Shelter")	Initial detection and location cue: Surface hazards for further investigation Anchor subsequent workflows
Club hazard Evaluation (May 2018)	Natural Bridge Appalachian Trail Club Trail Hazard Report Spreadsheet(Internal)	Correct and detailed description of location Hazard type Date + "morning/afternoon"	Incident detail enrichment: Provide narratives describing conditions Share photos to assist verification Support prioritization by the club
Temporary Reroute (May 2018)	Temporary Trail Closure Order Detour Map	Detour polyline + closure segment IDs Exact start & end date-and-time Photos of on-site signs	Verification and communication aid Confirm signage visibility and effectiveness Check clarity of reroute directions
Field survey (Jan 2019)	ATC Volunteer Work Trip Report	GPS ± 5 m Photos with scale Detail Measurements	Supplementary spatial and condition validation Report on-the-ground conditions as reference Note differences between initial reports and survey timing
Project proposal packet (Apr 2020)	a. ATC Capital-Plan Project Sheet club → ATC regional office b. Project Proposal Review Form ATC → APPA	Project Description: title, goals, problem statement Cost estimate; Funding source; Volunteer hours; Planned start finish time; Urgency ranking; Alternatives considered; Expert consultations; GPS latitude/longitude (≤1 m); Site Map; FMSS location ID; Seasonal constraints; Materials list; Equipment list; Resource-impact checklist; Required-attachments list	Evidence of necessity Demonstrate urgency and frequency of the issue Illustrate user impact to support funding and approval
Federal record check (Oct 2021)	FMSS Work-Order Accuracy Check	GPS coordinate accurate to within one metre Statement of coordinate system & accuracy Stream cross-section measurements	***(No direct role)***
Environmental review file (April 2024)	National Environmental Policy Act (NEPA) Environmental Compliance Packet	Project location map with geographic coordinates Resource tables: soil types; wildlife habitats; cultural or historic sites Geotagged photo log showing existing site conditions	***(No direct role)***
As-built close-out report (Apr 2025)	ATC Trail and Facilities Management Portal "Completed Improvements" Report	Prefilled GPS coordinate field (WGS 84) Completion date & time Before/after photo attachments	Post-completion feedback Confirm trail usability after project completion Identify lingering issues Document repair effectiveness, closing the reporting loop

Table 4. Stages in the Brown Mountain Creek bridge replacement workflow and the potential roles of community-sourced reports. The table illustrates how hiker-submitted reports can support hazard detection, verification, prioritization, and post-completion feedback, while highlighting stages where community input is less applicable.

deemed necessary, but this handoff can take days or even weeks. In the meantime, some smaller issues may already be resolved on the ground before the information fully circulates.

Crowd-sourced hikers' reports support the workflow by surfacing hazards, confirming short-term fix usefulness, provide additional evidence and collect feedback. They help clubs verify conditions, prioritize responses, and identify mismatches between signage and public information. After repairs, reports serve as post-completion feedback, confirming usability, flagging residual issues, and documenting project outcomes for accountability.

As this case study represents the most complex work scope of trail management field operation, it provides compelling evidence of how different organizations divide responsibilities and why they cannot operate in isolation. Bridge replacements, in this case, demand tightly coupled coordination: local trail clubs contribute early site documentation, routine condition monitoring, and volunteer labor during construction; conservancies step in to synthesize this ground-level input into project proposals, secure funding, and guide designs through regulatory review; and land-management agencies provide the final authority on permitting, environmental compliance, and long-term infrastructure standards. No single party holds the full set of skills, jurisdiction, or resources to see a project through alone. If clubs worked without agency approval, the project would be unauthorized; if agencies proceeded without local insight, they might misjudge field feasibility or miss site-specific risks; and without conservancy involvement, the project could stall due to gaps in technical documentation, funding, or cross-jurisdictional coordination. Together, these interlocking roles form a collaborative infrastructure that enables major repairs to succeed under legal, ecological, and practical constraints.

We unpack this workflow and discuss about effectiveness of the crowd-sourced hikers' reports in detail in the forthcoming discussion section.

4.4 Barriers to Collaboration for Local Trail Clubs

From the contextual analysis phase, we found additional evidence of inner frictions within local trail club collaborations—distinct from external coordination challenges with conservancies and agencies. These internal tensions stem from the realities of operating with minimal resources, informal infrastructures, and a highly heterogeneous volunteer base. As two interviewees explained,

> *"We don't have the staff or the budget, so we just figure it out between us"* (**U8**)
> *"He is only one who knows how to run this(database)... every document is on there...I don't know what to do if he is gone..."* (**U2**)

- **Collaboration Under Scarcity**: Not just limited to gathering information from the trail, local trail clubs also operate under persistent shortages of funding, tools, and people, such as relying on volunteers' personal trucks, chainsaws, and vacation days to keep trails open. Collaboration isn't optional under these constraints; volunteers must share rides, tools, and local knowledge to get work done, effectively pushing stewardship costs onto individuals themselves, which is not uncommon for volunteer-based organizations and nonprofit organizations [8, 26, 54, 66, 83, 96].
- **Cross-Generational Tensions and the Digital Divide**: Most club leaders are retirees with deep local knowledge, a pattern especially common in smaller clubs with limited budgets. In contrast, the primary field workforce consists of younger volunteers who perform physically demanding tasks but have limited time and experience. This cross-generational teamwork is essential but fragile. One of the most visible challenges is the digital divide. Older volunteers often struggle with reporting apps or mapping tools now expected by partner organizations. As prior research highlights, this problem is exacerbated when no IT support is available, and in many clubs, such support simply does not exist [65]. While related work shows that older adults can engage meaningfully in environmental stewardship when supported [74, 83], it does not fully address the challenges posed by digital tools. As one club noted, a longtime volunteer "loved walking the trail with clippers" but could not log GPS tracks during inspections because he lacked both a smartphone and the skills to use one.
- **Overloaded Roles and the Risk of Key-Person Dependence**: To manage under limited human resources, despite operating a club requiring the diverse work roles identified in the previous section, clubs often collapse these roles onto one or two individuals who handle reports, dispatch crews, and manage grants. They do this to reduce coordination overhead as a way of coping with the complexities of collaborative work [1], but this practice creates risks if those key individuals leave [97]. These "human APIs" bridge gaps where formal systems fall short, maintaining continuity across patchwork processes and systems. Yet their departure can abruptly disrupt workflows, knowledge transfer, and external partnerships, highlighting a critical vulnerability in volunteer-run stewardship organizations.
- **Patchwork Systems and Fragile Infrastructure**: Clubs rely on a mix of loosely connected tools for different tasks—for example, spreadsheets to track work, email threads for coordination, and messaging apps for field updates. These choices reflect volunteers' varying technical comfort and practical constraints such as limited connectivity or tool availability. However, these components were not designed for trail management and rarely integrate. Spreadsheets may log work requests but are not optimized for storing photos or location data, which often circulate separately through messaging apps or email and must be manually reconciled by coordinators. Some tools also serve multiple purposes, for example, email also used to receive hiker reports and to communicate with conservancy or government partners, making information easy to mix and difficult to trace without ongoing monitoring and labeling. Differences in technology use can further widen the gap—for instance, some

long-time members may favor pen-and-paper methods, while younger volunteers often lean toward more automated, computer-based workflows. These contrasts can complicate smooth handoffs of work and institutional knowledge across generations. This pattern is well documented in other nonprofit and volunteer-based organizations, where resource constraints drive the adoption of improvised, low-cost systems [8, 66, 96].

Overall, volunteer-run trail clubs keep trails open through collaboration under constraint, balancing limited resources, generational differences, and patchwork systems while sustaining stewardship in resource-limited environments. These everyday practices reflect a form of pragmatic collaboration, where volunteers creatively adapt to infrastructure limitations to meet stewardship goals. Yet these adaptations also surface vulnerabilities: whether in the reliance on a few "human APIs," generational technology gaps, or fragile handoffs across patchwork systems—that shape how clubs manage information and coordinate action on the ground.

5 Discussion

Our findings addressed **RQ1** in the previous section, by outlining key work roles, workflows, and coordination dynamics across local clubs, trail conservancies, and land-management agencies. This analysis, grounded in interviews, field observations, and artifact walkthroughs, revealed that trail management operates within overlapping timescales, fragmented data flows, and limited resources. In this discussion section, we build on these findings to answer **RQ2** by interpreting the data through CSCW concepts of pluritemporality, temporal sensemaking [69], and collaborative rhythms [39]. These frameworks help us examine how managers coordinate around community-sourced reports (**RQ2**) and, drawing on observed barriers and manager-suggested improvements, we identify sociotechnical design opportunities to support more effective collaboration based on these reports (**RQ3**).

5.1 Trail Managers Navigate Temporal Complexity in Trail Management

Trail management shares many similarities with prior CSCW research on the challenges of coordinating distributed, time-sensitive work across groups of stakeholders operating with different temporal rhythms and infrastructural constraints [37, 39, 76]. Applying Norris et al.'s temporal sense-making framework, we find that trail management is fundamentally a collaborative process, reflecting the four-stage in distributed crisis response work[69]: (Figure 3):

- Triage: Local trail clubs and their volunteer groups collaboratively screen incoming hiker reports, distinguishing urgent hazards (e.g., washed-out bridges, illegal trail creation) from routine maintenance needs (e.g., overgrown vegetation). This "needle-in-a-haystack" screening parallels how crisis response groups collectively identify critical issues within large volumes of community-sourced data.
- Evaluation: Clubs (conservancy and government agency if needed) in group vetting of reports through categorization, remote analysis, and field inspections. They then determine whether additional assistance is needed when an event exceeds their capacity.
- Negotiation: Stakeholder groups work to navigate constraints such as permits, funding, and overlapping jurisdictions, echoing how crisis response teams negotiate task ownership and accountability under uncertainty.
- Synchronization: Trail management requires coordinated group action, for instance, aligning volunteer crews, seasonal work windows, materials procurement, and post-repair inspections, similar to how crisis response networks orchestrate shifts and handoffs across distributed teams.

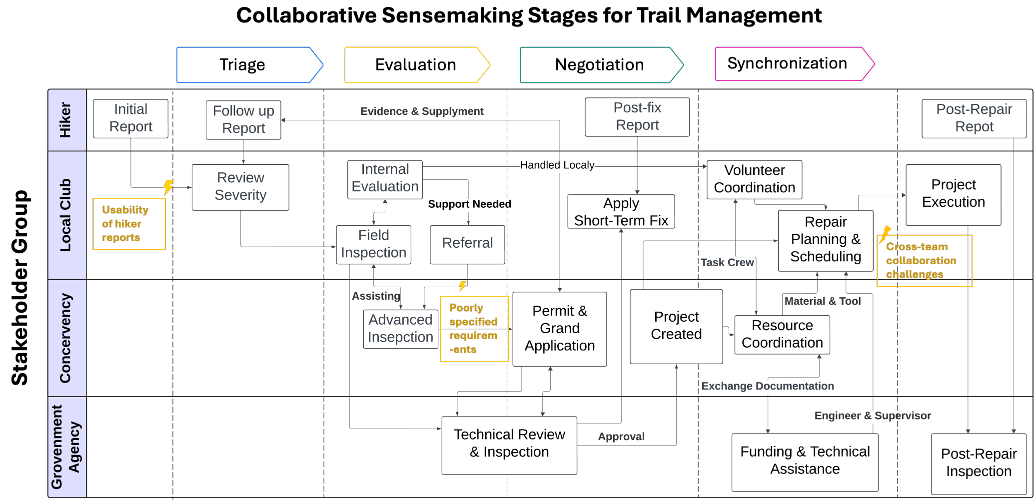

Fig. 3. Flow diagram illustrating the four-stage temporal sensemaking framework (Norris et al. [69]) applied to the work practice of trail management. Trail managers use **triage**, **evaluation**, **negotiation**, and **synchronization** in coordinating with conservancies and land-management agencies. Lightning symbols reflect key sources of friction in this collaboration.

Viewing trail management through this framework illuminates the pluritemporality inherent in collective stewardship: urgent hazards coexist with slower-moving grant cycles, seasonal constraints, and long-term conservation goals, requiring stakeholder groups to braid disparate timescales into actionable plans. The framework thus not only describes what trail managers do but also reveals how collaborative groups align and transform temporal complexity into sustained collective action by managing and overcoming rhythm dissonance across organizational, infrastructural, biographical, and phenomenal dimensions. [39]. For example:

- Phenomenal rhythms (e.g., urgent safety hazards, seasonal weather windows) often collide with
- Organizational rhythms (e.g., grant cycles, permitting processes),
- Biographical rhythms (e.g., volunteer availability), and
- Infrastructural rhythms (e.g., tool and material logistics, trail access conditions).

Managing these intersecting rhythms is not an individual task but a collective, ongoing process, requiring group improvisation, negotiation, and recalibration as conditions change. Extending Jackson et al.'s notion of collaborative rhythms to environmental stewardship, we find that trail managers and volunteer groups act as temporal mediators, transforming fragmented, multi-rhythmic conditions into coherent stewardship actions that sustain trails across seasons and crises.

This work of aligning and transforming temporal complexity into collective action often manifests as coordination overhead encountered by the local hiking club during triage, evaluation, and synchronization stages :

- ***(Triage)* Invisible Work of Clarifying and Timing Community Reports:** Clubs and volunteer groups spend substantial time clarifying hiker reports, often engaging in back-and-forth communication to determine exact locations and assess severity. Time adds another layer of complexity, as managers often struggle to determine whether an issue is already being addressed or if a new event has emerged. These micro-coordination activities align with CSCW findings on the hidden articulation work within distributed volunteer groups, where informal clarification and documentation adjustments are critical for transforming loosely structured, community-sourced data into actionable tasks [50, 87]. This mirrors long-standing challenges in citizen-science projects, where community-contributed observations require extensive validation and coordination before becoming usable data [81, 84, 99]. In both settings, the cost of validation falls disproportionately on local organizers, creating an invisible layer of interpretive and logistical work. Temporal misalignments and negotiation work are embedded in these group processes, as phenomenal rhythms of urgent hazards intersect with biographical rhythms of volunteer availability and infrastructural rhythms of accessing trailheads, often invisible within formal reporting pipelines but essential for enabling collective action [39].

- ***(Evaluation)* Cross-Organizational Coordination and Information Dependencies:** Clubs, conservancies, and agency partners engage in collaborative evaluation, conducting field inspections, gathering supplemental evidence, and negotiating responsibilities. Delays frequently occur while awaiting technical reviews, advanced inspections, or permit approvals, reflecting tensions between organizational rhythms (e.g., funding and permitting timelines) and phenomenal rhythms (e.g., seasonal weather windows requiring quick response). Groups must manage uncertainty collectively while staying prepared for short-term interventions or project initiation [39].
- ***(Synchronization)* Coordinating Behind the Scenes Amid Temporal Friction:** Stakeholder groups work together to align volunteer schedules, material logistics, and multi-party approvals to execute repairs. Coordination includes securing funding, arranging cross-club volunteer crews, and syncing seasonal windows with material readiness. What makes this more challenging is that many small clubs rely heavily on one or two "key people" to coordinate these efforts, creating bottlenecks and vulnerability when those individuals are unavailable or overwhelmed. Here, infrastructural rhythms of tool and material availability intersect with biographical rhythms of volunteer schedules, requiring clubs to align these layered timescales with the phenomenal rhythms of trail conditions. While fieldwork represents the visible outcome, much of the real work remains hidden in aligning calendars, acquiring resources, and clarifying documentation needs. This mirrors findings in CSCW and infrastructure studies showing that maintenance and repair depend on continuous, collective backstage coordination under friction-filled conditions, where such friction often prompts groups to clarify ambiguities and align expectations across organizational and temporal boundaries [39, 50].

By applying Norris et al.'s temporal sensemaking framework to environmental stewardship, we show how trail managers and their collaborative networks navigate pluritemporality to transform distributed, crowd-sourced data into collective action [69]. Trail management shares strong similarities with digital humanitarian work, where coordination unfolds across asynchronous timescales, uncertain data flows, and resource constraints. The temporal rhythms shaping collaborative work, as identified by Jackson et al. [39], further illuminate key coordination challenges in trail maintenance. Together, these perspectives underscore that volunteer-led stewardship is a fundamentally group-based, temporal, and collaborative sensemaking process, one that requires aligning urgency, resources, seasonal constraints, and community contributions into the sustained collective care of shared infrastructure.

5.2 Assisting Trail Management with Community-Sourced Reports

Based on the trail management workflows identified in the previous section, we find that current crowed-sourced hiker reports, submitted through online forms, email, and SMS, can assist local hiking clubs in the following ways (**RQ2**):

- **Low-Cost Reporting Expands Situational Awareness without Patrols** Community-sourced reports significantly extend trail managers' situational awareness by enabling early detection of hazards across dispersed, rugged areas, without the need for constant patrols. At Brown Mountain Creek, hikers' reports provided the first indications of bridge surface damage and confusing reroute signage, allowing maintainers to identify and prioritize issues immediately. Compared to sensor-based systems like TrailSense [46], simple text/image reports require no extra hardware or app, opening participation to every hiker. And they also avoid sensor degradation and maintenance overhead [35]. This low-barrier approach fits perfectly within the "thin" infrastructures and resources of volunteer-run nonprofits [4, 7, 13, 71].
- **Rapid Detection Enables Timely Intervention and Validation** By crowdsourcing observations, trail managers can surface hazards within hours rather than waiting days or weeks for manual scouting. At Brown Mountain Creek, multiple hikers reported a collapsed bridge and misleading reroute notices the same day the problems occurred, prompting on-trail updates that prevented unsafe detours. Repeated reports at different stages can also serve as valuable validations for various purposes, such as confirming problem persistence, verifying conditions post-repair, or supporting documentation needs. Similar gains appear in citizen-science and crisis-mapping research, which document shorter data collection cycles, faster analysis [15], and more rapid data access compared to traditional methods [101]. These timely contributions highlight how distributed reporting can enhance operational responsiveness and reduce coordination delays in trail management.
- **Transforming Volunteer Data into Institutional Evidence** When abundant, community reports become evidence that the local club can repurpose for permits, regulatory compliance, and grant justifications. Volunteered geographic information delivers the fine-grained, place-based detail agencies require for asset inventories [25]. Integrating citizen-generated imagery and narratives into official workflows strengthens funding proposals and speeds permitting by making impacts "visible" to regulators [27]. Crowd-curated, geo-tagged datasets, like those from Project Sidewalk, have even been used as quantitative evidence in municipal budget hearings to secure infrastructure repairs [53].
- **Boosting Morale through Gratification** Many hiker-submitted reports include not only hazard alerts but also expressions of gratitude, such as thank-you notes or compliments on well-maintained sections of trail. These messages illustrate the varied nature of crowd-sourced contributions and are often shared by managers with volunteer crews to boost morale and acknowledge their efforts. This suggests that, unlike competitive crowdsourcing-contexts explored in prior work [58], volunteer-based trail management fosters a different form of hiker–manager collaboration—one in which crowdsourced participation extends beyond simple question-and-answer dynamics to encompass more nuanced, content-rich, and relational interactions.

Rather than one-off exchanges, reports often initiate an ongoing sequence of verification, coordination, and task delegation across multiple actors. This shift underscores a need for systems that support not just information sharing but also collaborative sensemaking, role-aware workflows, and feedback mechanisms that can sustain volunteer engagement and operational follow-through.

However, the current platform for hiker reports still faces notable limitations. Individual submissions are often fragmented and lack sufficient detail, requiring a critical mass of reports to build a reliable case. This mirrors the “data shadows” observed in prior GROUP work of sensor-based sense making workflows, where fragmented or missing information arises due to the absence of key metadata [36].

These entries typically arrive through thin infrastructure channels, such as SMS, email, or basic web forms, and must be verified and structured by staff through a difficult process. This finding echoes Misra et al.’s study on the Appalachian Trail [68] and suggests that similar challenges persist across other trail systems. Since this collaboration is volunteer-based and lacks observable direct incentives like the financial rewards studied in prior GROUP work [58], the resulting contributions often show uneven quality. Without structured guidance, shared documentation standards, or immediate feedback, hikers may submit reports that are vague, incomplete, or duplicated—placing additional triage burdens on trail managers. While systems like CrowdMonitor demonstrate that hazards can be flagged in real time when multiple users report anomalies [57], existing reporting channels—unlike those in related work—often restrict rich media uploads such as photos or videos, limiting the ability of trail managers to quickly verify and assess reported issues.

As a result, maintainers still face follow-up inquiries and site visits to verify conditions, reintroducing coordination overhead and delaying timely interventions.

5.3 Designing a Communication and Decision-Support System for Trail Clubs

Building on our interviews, field observations, and lessons from prior trail-focused ICT design (notably Patel’s SmarTrail Board [73]), we argue for a more structured system with a (1) a hiker-facing reporting UI and (2) a back-end system architecture that supports the sensemaking workflows of local trail organizations (See figure 3 and its discussion in Section 5.1). Patel’s study reports the administrator-perceived impact of centralized forums for visitor-manager communication[73]). Our findings expand this work, thoroughly model the trail management work roles and tasks, and highlight the rationales for addressing frequent coordination burdens across stakeholder groups.

We propose a two-part system: a **lightweight, public-facing communication interface** that lowers barriers for hikers to share trail observations and directly communicate with local trail organizations, and a **decision-support backend** that enables trail clubs to triage, evaluate, and synchronize related information (**RQ3**). Below, we outline key design principles that extend prior work to address practical gaps in real-world trail stewardship workflows.

5.3.1 Triage. Local maintainers routinely sift through disjointed e-mails, text messages, and social media posts, none of which arrive as a structured, detailed information package that is easy to categorize, assess for severity, or pinpoint on the map. As one interviewee suggested:

> *"Write and sent email on the trail is difficult...If they don’t submit it on-site, it may left in the (email) draft folder, and we will never know... And we don’t even know if they know our email address."* (**U2**)

The result is triage fatigue: crew leaders spend more time decoding reports than fixing hazards. So, a communication interface should be equipped with features like

1. **Lower Reporting Burden with Structured, Context-Aware, Photo-First Inputs**: Trail managers suggest hikers will only file a report if it *takes seconds, not minutes* (**U4,U6,U7**). Free-text e-mails and generic web forms fail on four fronts: users must decide what to say, thumb-type on a small screen, hand-enter location, and figure out who to send it to—each step a new drop-off point. To potenally overcome those barrier, we recommend the following workflow for the hiker to report an event:
   (a) App opens directly in **camera mode**.

(b) After the shot, the timestamp and GPS are auto-attached.
(c) A three-to-five-tap panel (hazard type, severity, passability) to enrich the report.

Even without the final form inputs, the PHOTO + GPS + TIME bundle constitutes a "minimum actionable dataset" that enables trail managers to make preliminary decisions. This design aligns with findings from prior GROUP work emphasizing the need for clear documentation and structured workflows in crowdsourced collaboration [58]. Similar systems—such as CrowdMonitor, CommuniSense, and Open Data Kit (ODK)—demonstrate that combining structured prompts with embedded sensor metadata leads to high-quality, verifiable reports [30, 57, 80]. In our context, EXIF headers embedded in the photo feed integrate directly into clubs' daily planning pipelines, transforming ad hoc, text-based messages into structured data streams. This contributes to ongoing efforts in the CSCW literature around standardization mechanisms and quality assurance infrastructure in crowed-sourced data systems [12, 15, 67].

(2) **Support Remote Use with Offline-First, Sync-Later Workflow**: Cell coverage along backcountry corridors is often nonexistent for hours or even days, making real-time uploads infeasible. Patel et al. explicitly call for offline-capable designs that tolerate intermittent reception [73]. We extend their recommendation by pairing our photo-first, metadata-rich capture flow with a store-and-forward architecture: the app caches photos, GPS fixes, and form inputs locally, then pushes the bundle automatically when connectivity returns. This approach, well proven in various contexts [10, 30], can prevent data loss, reduce contributor frustration, and preserve the "minimum actionable dataset" even in signal shadows. Open Data Kit (ODK) offers a concrete template, showing how offline-first clients can transform ad hoc observations into structured data streams ready for trail-club planning pipelines [10, 30].

With support from the communication interface, the decision-support backend should help conserve limited volunteer capacity by automatically clustering and labeling incoming reports into event cases [32, 45] based on location and timestamp. As related GROUP work suggests, grouping raw sensor or system logs into meaningful clusters can help workers quickly identify coordination gaps and surface hidden information [75]. Lightweight filters can assist in merging duplicates and flagging outdated entries, creating a manageable database for triage. With this design, club managers can use signals such as report volume and data richness to identify high-priority hazards at an early stage, streamlining decision-making and reducing manual processing overhead. This approach parallels prior GROUP findings on "data transducers" that translate messy or misleading sensor outputs into actionable information [36]. And potentially solve the problem that organizations lack the analytic capacity and leave behind 'a pile of unused numbers' to process [9].

"No, I won't send my crew until I have enough evidence (to show there is a case)." (**U5**)

Prior work shows the potential of this design, where clustering crowdsourced reports sharply cuts triage time and speeds official action during disasters [69, 105], while crowd-led labeling systems like CLAMShell further reduce latency through active learning [42]. Integrating these techniques lets clubs surface urgent issues quickly, defer lower-priority items without losing track, and ultimately respond faster with less manual overhead.

5.3.2 Evaluation. Local clubs often face significant coordination overhead due to differing information requirements (e.g. type, standard) between themselves and their conservancy or agency partners. These mismatches frequently require clubs to conduct multiple field visits to collect the same information in different formats, adding burden and slowing progress. To address this, we propose that the system support **data translation and conversion**, converting collected information into useful formats for various stakeholders and using gaps as cues to generate actionable task lists.

> *"Most of the time, I'm piecing together scraps: texts from hikers, a photo in an email, maybe a voicemail if I'm lucky. Half the info I need is missing ... I don't know it until I send someone out (to verify)..."* (**U2**)

The decision-support system can offer the following features to assist trail clubs in navigating these challenges:

- **Gap Detection & Task Generation**: When information is incomplete, the system should flag missing data and convert it into targeted field tasks for maintainers (e.g., "Confirm diameter of fallen tree," "Check extent of water damage"). When sufficient data is available, the system can assist supervisors by generating actionable outputs, such as matching tree diameter to saw size, identifying permit requirements, or creating crew checklists.
- **Localized Data Translation**: To reduce the burden of bridge differences in reporting requirements, the system should translate between formats commonly used by clubs, conservancies, and agencies. For instance, while GPS coordinates offer precision, field crews rarely use raw coordinates to navigate. They prefer familiar references like 'half a mile north of Parking Lot A.' The system should automatically link GPS data to nearby landmarks or mile markers. Prior work in wildfire response shows that such translations improve situational awareness, reduce confusion, and accelerate field deployment [54]. This feature helps align formal reporting standards with the practical needs of on-the-ground crews.

Together, these features reduce the manual coordination work local clubs currently face, ensure that tasks don't stall due to resource gaps, and support smooth cross-organizational handoffs, helping maintain momentum on critical repairs that require multi-agency collaboration.

5.3.3 Synchronization. Once hazards have been triaged and evaluated, the real challenge is no longer collecting more information but aligning the task with the right people, tools, and time, which often crosses organizational boundaries. Earlier prototypes (e.g., SmarTrail Board [73]) surfaced issues in a central forum, yet most scheduling still flowed through a handful of experienced "human APIs." As one maintainer put it:

> *"Back in the day I'd call around and scribble prep notes on paper...who's got a crosscut, who needs a permit, that kind of thing…"* (**U8**)

To break this information bottleneck and sync hikers in the loop to motivate them for further participation, the communication system should add two capabilities:

- **Role-Aware Task Transparency**: Open work items should live in a shared, filterable queue rather than in private e-mail threads. Related GROUP work highlights how exposing decision rationales can prevent subgroups from forming isolated interpretations of "who has information" [75]. A certified sawyer, for instance, could sort tasks by "chainsaw-qualified" and claim a nearby blow-down without waiting for a coordinator's phone call. Similar dashboards and claim-based task pools have been shown to accelerate volunteer mobilization in crisis response and crowd-tasking systems [5, 14, 88]. Inner transparency can reduce the burden on managers and help avoid delays caused by routing operations through a single point person [97].
- **Public Progress Signals**: Hiker reports often vanish into a black box, causing duplicate submissions and eroding trust. A peer-visible feed that displays recent reports, and their life-cycle state (RECEIVED→ IN PROGRESS→ RESOLVED)) which lets hikers confirm an issue is already logged, add evidence, or celebrate its closure. Similar Waze-style transparency

reduces redundancy [38, 55, 77], while timely acknowledgements on civic platforms such as FixMyStreet have been linked to sustained participation [6, 85]. This aligns with findings from GROUP research, which show that peer support—both emotional and instrumental—is essential for maintaining volunteer engagement in high-effort environments. In misinformation response communities, members share encouragement, celebrate successful interventions, and create a sense of shared purpose to prevent burnout [104]. Applied to trail reporting, even small cues of acknowledgment—such as a "marked as received" badge or public resolution status—can reinforce the social value of participation and foster a stronger sense of contribution among hikers. We think this can be a potential solution to the motivation problem—serving as a social and relational alternative to the financial incentives seen in prior crowd sourced collaboration studies [58].

By coupling an internal task board with outward-facing status updates, the system turns what used to be private email/phone-tree logistics into a trail-wide, data-driven collaboration, and gives reporters visible proof that their effort mattered.

5.3.4 Integration with Existing Systems and Volunteer Practices. While the proposed communication and decision-support system aims to streamline reporting and coordination, our fieldwork shows that many clubs currently rely on patchwork ecosystems—spreadsheets, shared Google Docs, email chains, and messaging groups—that, despite their fragmentation, are valued for their familiarity, inclusivity, and offline accessibility. Rather than replacing these systems, the proposed framework should interoperate with them. For instance, reports can auto-export to shared sheets or summary emails, maintaining continuity while gradually standardizing data collection. The system should also ingest and harmonize existing spreadsheets or other datasets from clubs, enabling cross-club standardization without forcing immediate tool changes. To sustain adoption, the unified platform must support multiple entry points: a mobile app for hikers, a web dashboard for coordinators, and email or SMS inputs for low-connectivity users. Moreover, by embedding lightweight automation (e.g., auto-filled forms, photo-based metadata capture) and guided templates, the backend explicitly reduces dependence on "key individuals" who currently perform manual sorting, formatting, and data cleaning. Ultimately, the system acts as a bridge—preserving the flexibility and accessibility of existing tools while layering structure, automation, and transparency over them to build a sustainable, collaborative workflow for modern trail stewardship.

6 Limitations and Future Work

While our study surfaces rich, practice-grounded insights into trail management workflows and coordination challenges, several limitations must be acknowledged. First, our interview window coincided with peak fieldwork season. Many clubs were understaffed, and several trail managers, particularly those serving in volunteer capacities, declined interviews due to time constraints or competing professional obligations. As a result, our sample may under represent certain perspectives.

Second, during interviews and field observations, we noticed several factors that shape collaboration models among trail organizations, introducing meaningful variation in how coordination unfolds. Differences in funding, labor capacity, and technical expertise influence not only the frequency of maintenance activities but also the degree of formalization in communication and decision-making. Geographic factors further compound these contrasts—for example, prescribed burns as a seasonal practice in Florida differ markedly from snow-dependent inspection schedules in Colorado. While our interviews captured a cross-section of these practices, our in-depth field engagement was limited to one club, constraining the ability to directly compare organizations at different scales or in different regions. To address this, we identified recurring challenges and coordination patterns that appeared consistently across contexts and present these as generalizable themes for local trail management organizations.

Third, as a qualitative study grounded in in-situ interviews and contextual observations, our findings offer depth and nuance but are not intended for statistical generalization. These insights should be viewed as exploratory and illustrative of broader patterns rather than universally representative. Finally, our design contributions are conceptual. We did not deploy or evaluate a working prototype during the course of this study. As such, our proposed sociotechnical design principles remain hypothetical until tested in practice.

Future work should extend this research in several directions. First, iterative prototyping and in-situ testing with trail clubs and hikers can refine the proposed tools to better accommodate real-world constraints such as intermittent connectivity, offline workflows, and volunteer availability. In parallel, future work will explore the design of a sociotechnical dashboard prototype that aggregates and summarizes trail-related information from social media and community reports [79], helping trail managers make timely, data-informed decisions while enabling hikers to view, validate, and contribute updates in real time. Second, comparative studies across a broader range of trail organizations could investigate how collaboration and decision-making practices evolve under varying organizational capacities, geographic terrains, and institutional structures. Such work would help clarify which coordination challenges are context-specific—arising from funding, staffing, or environmental constraints—and which are systemic across the broader trail stewardship network. Finally, future research might explore how digital systems can strengthen feedback loops between hikers and maintainers, enhancing trust and sustaining long-term engagement in distributed stewardship efforts.

7 Conclusion

Trail management is a profoundly collaborative endeavor shaped by overlapping timescales, institutional constraints, and the lived realities of volunteer-run organizations. Through interviews, field observations, and artifact walkthrough with trail administrators and local club volunteers, we examined how temporal sense-making unfolds in practice—specifically, how triage, evaluation, negotiation, and synchronization are performed, and where coordination overhead intensifies within these stages. Community-sourced reports play a critical role in extending situational awareness and surfacing timely observations. However, they often arrive fragmented, vague, or misaligned with institutional workflows. As a result, local clubs which already operating under significant human resource constraints, must conduct repeated field visits to verify and contextualize these reports, increasing workload and delaying response efforts. To bridge this sociotechnical gap, we propose design directions that address the informational needs, collaborative practices, and infrastructural limitations faced by local trail managers. A lightweight communication client could help standardize and structure hiker-submitted reports while keeping contributors informed, motivating continued participation through transparency and feedback loops. In parallel, a decision-support system could assist local clubs in organizing, prioritizing, and escalating issues across organizational boundaries. Together, these tools can reduce hidden-work behind the trail management work flow, enhance inter-agency coordination, and ultimately support more timely and effective maintenance of long-distance trails.

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