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Systematic Review

Mountain Logistics: A Systematic Literature Review and Future Research Directions

Mehari Beyene Teshome [1], Faisal Rasool [1] and Guido Orzes [1,2,*]

[1] Competence Centre for Mountain Innovation Ecosystems, Free University of Bozen-Bolzano, Piazzetta Franz Innerhofer, 8, 39100 Bolzano, Italy
[2] Faculty of Engineering, Free University of Bozen-Bolzano, Via Bruno Buozzi 1, 39100 Bolzano, Italy
* Correspondence: guido.orzes@unibz.it

Abstract: *Background*: The sustainable development of mountain areas, which have fragile ecosystems, has increasingly attracted the attention of researchers and practitioners. Logistics systems are crucial in supporting these regions and addressing mountainous terrain's unique challenges. While many studies have examined aspects of mountain logistics, a comprehensive and systematic review of the field is still lacking. *Design/Methodology/Approach*: This paper aims to fill the gap by systematically reviewing the existing literature on mountain logistics using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology. *Results/Conclusions*: We identify four main research foci: design of logistics infrastructure or vector, optimization of logistics systems, safety in logistics systems, and impact of logistics systems on mountain communities. In addition to categorizing these themes, we conduct a detailed descriptive analysis of published studies in this domain. Our findings highlight significant research gaps, particularly in integrating digital technologies, sustainable mass transportation solutions, and logistics systems' socioeconomic and environmental impacts. We propose targeted directions for future research to advance sustainable logistics practices in mountain regions.

Keywords: logistics; mountain; systematic literature review; transport; content analysis

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1. Introduction

The sustainable development of mountain areas has gained substantial recognition following the United Nations Conference on Environment and Development in 1992 [1,2]. Logistics systems play a significant role in meeting this goal of improving the quality of life of the local population living in mountain areas by integrating economic development with environmental protection [3,4]. This integration encompasses the efficient management of goods and passenger transport, ensuring access to remote mountain areas, enhancing social connectivity, and promoting the resilience and sustainability of mountain communities [5]. As a result, both academic and practitioner contributions in this field have steadily increased [1,2,5].

Despite the increasing number of academic publications on the topic, efforts to synthesize the overall state of research on mountain logistics are limited. The existing literature reviews mainly offer insights into general logistics systems [6–8]. However, logistics in the mountain areas have unique characteristics and challenges that need to be explicitly addressed. These include:

- Logistics operations encounter considerable hurdles due to the intricate interaction of geographical, topographical, and spatial factors [9,10];
- Steep slopes, unpredictable weather conditions, and varying altitudes significantly impact transport infrastructure [11,12];
- There exist limited accessibility and heightened safety concerns [11,13];
- The rollover stability of vehicles is a challenging concern [14,15];

- The link between mountainous road infrastructure and fuel consumption is pronounced [16,17].

Given these challenges, studying logistics systems in mountain areas is of paramount importance. This would create broader economic networks, foster economic growth, and promote social inclusion by reducing the isolation of mountain communities and improving access to essential services such as healthcare, education, and markets. In this regard, a thorough synthesis of key themes, trends, and knowledge gaps in mountain logistics holds great theoretical and practical significance for researchers, policymakers, and practitioners.

This study aims to explore the current body of knowledge within logistics in mountainous areas, disentangling prevalent trends and emerging technologies and extending the breadth of the literature for future research pursuits. The review specifically addresses the following research questions:

- What is the current state of development of the literature in mountain logistics?
- What research directions in mountain logistics should enhance the sustainable development of the regions?

This research contributes to logistics in mountain regions within sustainable development discourse. The study contributes to the literature in three significant ways. First, it presents the descriptive findings of existing studies as distributions by time, country, publication outlet, industry, and research methods. Secondly, it finely categorizes the existing literature into four coherent research themes, namely: design of logistics infrastructure or vector, optimization of logistics systems, safety in logistics systems, and impact of logistics systems. Lastly, it identifies the most relevant gaps in the literature and pinpoints directions for future inquiries.

The remainder of the paper is structured as follows: Section 2 sets the research context by defining mountains and mountain logistics. Section 3 presents a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodological procedure. Sections 4 and 5 detail the descriptive and thematic results, respectively. Section 6 summarizes the main knowledge gaps and future directions of study. Finally, in Section 7, the study makes a concluding remark.

2. Defining Mountains and Mountain Logistics

A significant challenge in exploring the literature on mountain logistics is the lack of a universally accepted definition of mountainous areas [18,19]. Researchers have employed various criteria to distinguish mountainous areas from plains, each offering a unique perspective on what constitutes a “mountain area”. Some scholars define mountain areas based on altitude-based vertical zones, where increasing elevation influences interactions between humans and the environment due to factors like temperature decrease [20,21]. Alternatively, others have considered a polycentric approach to urban development strategy as a defining characteristic of mountain areas that face geographical constraints [22]. Lastly, GIS-based raster analysis models assess mountain elevations and understand spatial variations within these areas [23]. These approaches highlight the complexity of defining mountainous regions, underscoring the diverse methodologies needed to differentiate them from other geographic contexts.

Despite varied definitions, scholars generally agree on certain defining characteristics of mountainous regions, including steep slopes, varying elevations, and rugged topography. These areas often encompass diverse ecological, climatic, and geological conditions that contribute to their distinct landscapes and ecosystems. To capture the full scope of these regions, this study adopts an altitude-based vertical elevation approach, which includes all potential mountainous zones—foothill, montane, subalpine, and alpine. Within this framework, mountain logistics is defined as the movement of goods and passengers, as well as the supporting infrastructure and services, conducted via both aerial and land transport to meet the unique needs of these challenging terrains.

3. Methodology

The review aimed to explore prevailing trends, identify emerging technologies, and contribute to expanding future research. Our methodology for this endeavor followed approaches defined by Snyder [24], among other pertinent sources, in conducting a rigorous systematic literature review. The review process, which was guided by the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), consists of four stages: identification, screening, eligibility, and inclusion (Page et al. [25]) (see Figure 1). The PRISMA checklist for Systematic Review and the OSF (Open Science Framework) register of this review are listed in the Supplementary Materials section of this paper.

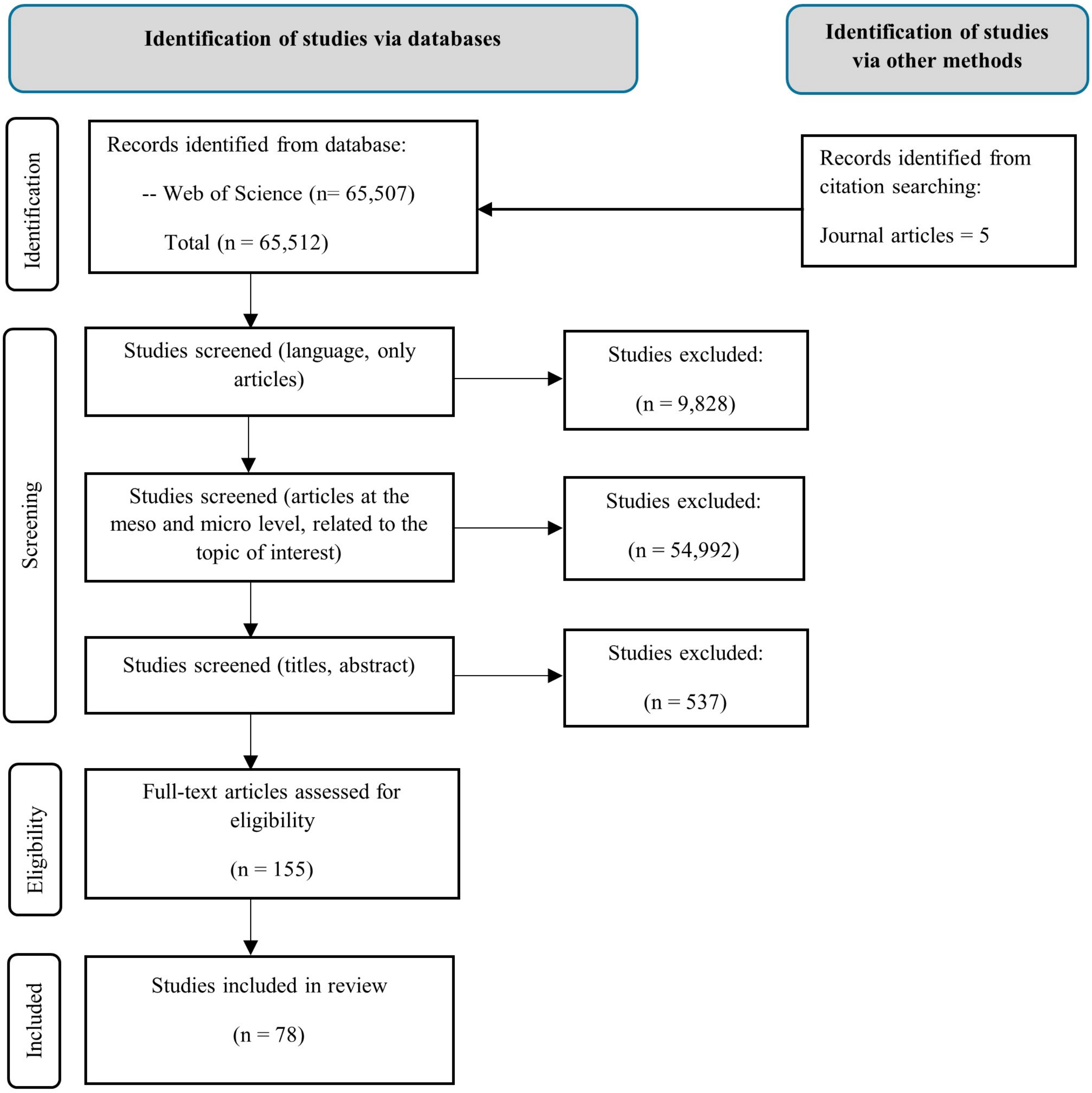

Figure 1. The PRISMA flow diagram of the study.

3.1. Search Strategy

This involves identifying relevant articles for subsequent analysis using keywords from scholarly databases [26]. In our study, the scholarly repository "Web of Science" was employed, which offers comprehensive coverage of high-quality journals across various disciplines, resulting in a diverse collection of academic literature. The search string was initially formulated based on the topic under investigation (i.e., "mountain logistics"). Later, since our focus is on mountain contexts, the keyword "mountain*" was conjoined with other study-relevant keywords, including "transport*", "logistic*", "challenge*", "enabler*", "barrier*", "system*", "technology*", and "solution*". These keywords were intertwined by employing the Boolean operator OR. This process yielded an initial dataset of 65,507 results. We also used a snowballing approach and found five additional articles. This study included publications up to 2023, reflecting the most current advancements in the field.

3.2. Inclusion and Exclusion Criteria

To ensure the eligibility of each included article within the review, the selected studies underwent a rigorous, multi-stage exclusion process, each stage applying specific criteria. In the first two rounds of exclusion, we filtered studies to include only articles published in peer-reviewed, English-language journals, ensuring a high standard of quality and accessibility. Additionally, these studies should have a clear focus on logistics within mountainous regions, specifically addressing logistics challenges, sustainable practices, or infrastructure. Studies focused on broader logistics topics without regional or thematic relevance were excluded. Figure 1 illustrates the process in detail. In the third round of exclusion, we retrieved an initial dataset of 692 articles. These were then filtered by titles and abstracts to exclude studies with a different focus, even if relevant keywords were present in their topics. This stage ensured alignment with the core themes of mountain logistics, reducing the dataset to 155 eligible articles for full-text assessment. Finally, through a thorough review of the full texts of these 155 articles, we narrowed down the focus to 78 articles that met all inclusion criteria and provided the most direct contributions to the understanding of logistics in mountainous areas. This comprehensive screening process ensured that the final set of studies included only the most relevant and high-quality articles for our systematic review.

3.3. Paper Coding and Data Analysis

Following Snyder's [24] approach, a comprehensive framework was developed to categorize and organize information systematically, identifying underlying themes, sub-themes, and elements within each source. Relevant data were tabulated and extracted based on the framework to provide a complete understanding of the study field. After completing the coding process, we conducted in-depth data analysis to uncover patterns, trends, and insights. A thematic analysis revealed four key themes: logistics infrastructure or vector design, system optimization, safety, and impact. The study also pinpoints research gaps for future directions.

4. Descriptive Results

This section discusses the temporal trends of reviewed studies, distribution across various geographic areas, journal outlets, industries type, and the employed research methodologies.

4.1. Chronology of the Reviewed Papers

While our search was not restricted by publication years, the distribution of published papers spans from 1997 to 2023. This temporal range aligns harmoniously with the heightened emphasis on the sustainable development of mountain regions [1,2]. Figure 2 portrays an apparent upward trajectory in published papers throughout the period.

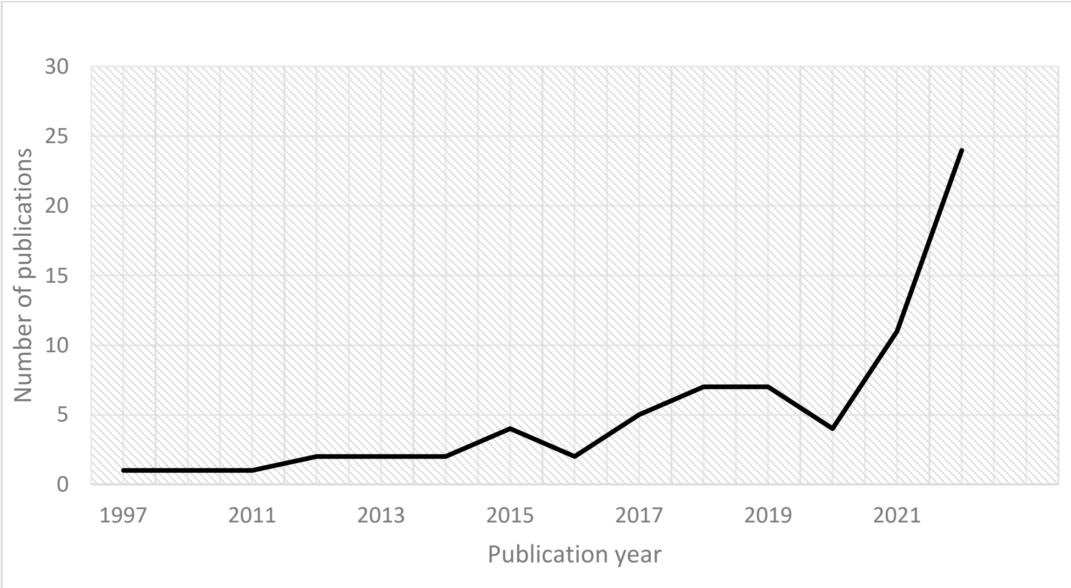

Figure 2. Distribution of published articles over time.

4.2. Distribution of Articles by Journal Outlet

Figure 3 illustrates the distribution of published papers across 54 distinct journals, with 42 journals having only one publication each. Notably, the journal *Journal of Mountain Science* features the highest number of sampled papers, closely followed by *Accident Analysis and Prevention*, *Transport Research*, *Journal of Transport Geography*, and *Sustainability*. In addition, the remaining seven journals each accommodate two publications.

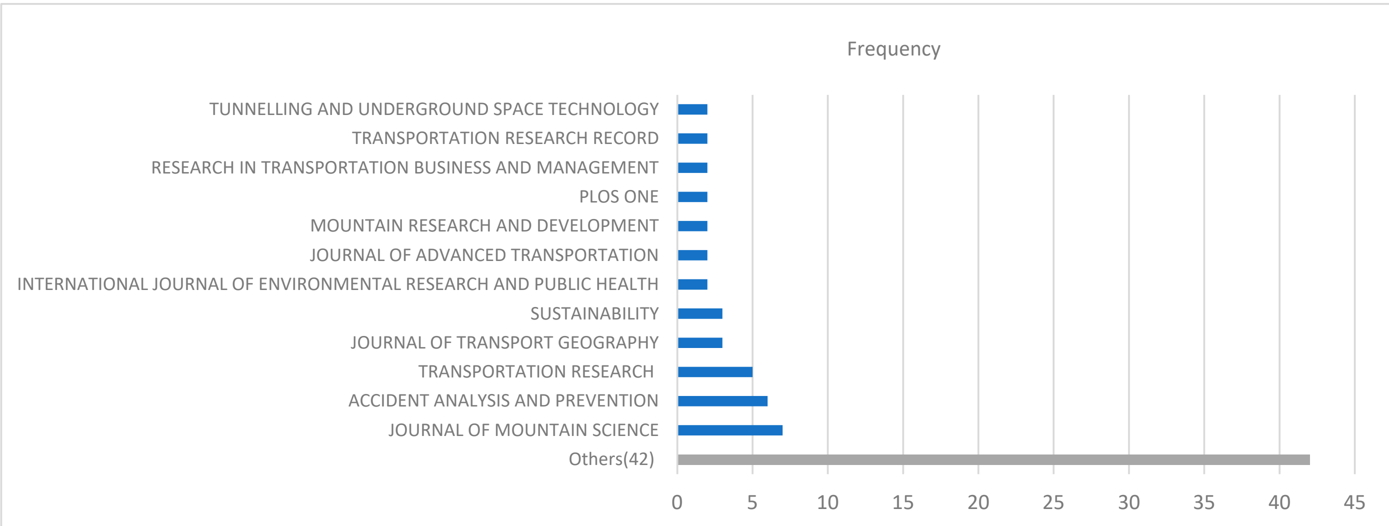

Figure 3. Distribution of published articles by outlet.

4.3. Geographical Distribution of Published Articles by Country

Based on our literature review, most of the contributions in the field of mountain logistics have been conducted in China, encompassing 47% of the research coverage. Italy follows with 13%, while the United States contributes 10%. Austria and Colombia collectively account for 6% of the research; the remaining 24% is distributed across 18 countries, see Figure 4.

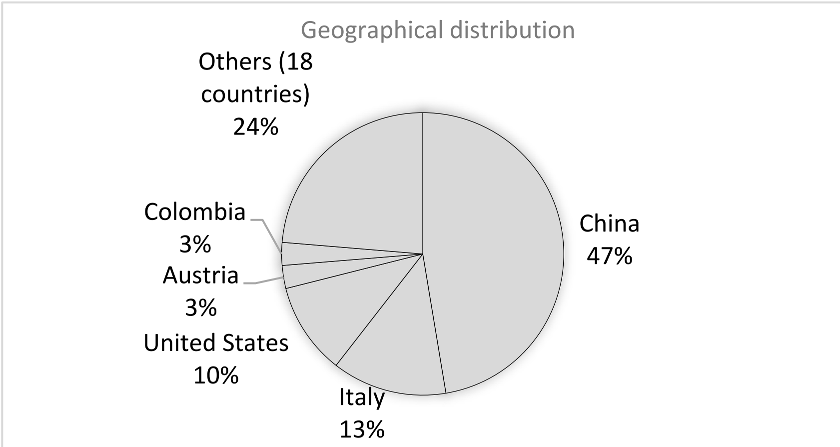

Figure 4. Distribution of publications by country.

4.4. Distribution by Industry and Research Method

Table 1 outlines the distribution of papers by industry and research method, presenting valuable insight into the specific industries and initiatives addressed and researchers' methodological approaches.

Table 1. Classification of papers by industry and research method.

Classification			**Number of Papers**
Application sectors	Transport	UAVs or Drones	6
		Helicopter, aircraft	4
		Cableway/ropeway	6
		Railway	3
		Bicycles	2
		Combined	31
	Infrastructure	Highways	9
		Freeways	4
		Other roads	11
Research Methodologies		Surveys	4
		Case study	21
		Secondary data	4
		Mathematical models	24
		Simulation	6
		Others	19

5. Thematic Results

The literature review identified four main themes: design of logistics infrastructure or vector, optimization of logistics systems, safety in logistics systems, and impact of logistics systems (see, Figure 5). These themes covered a wide range of subtopics for a comprehensive exploration.

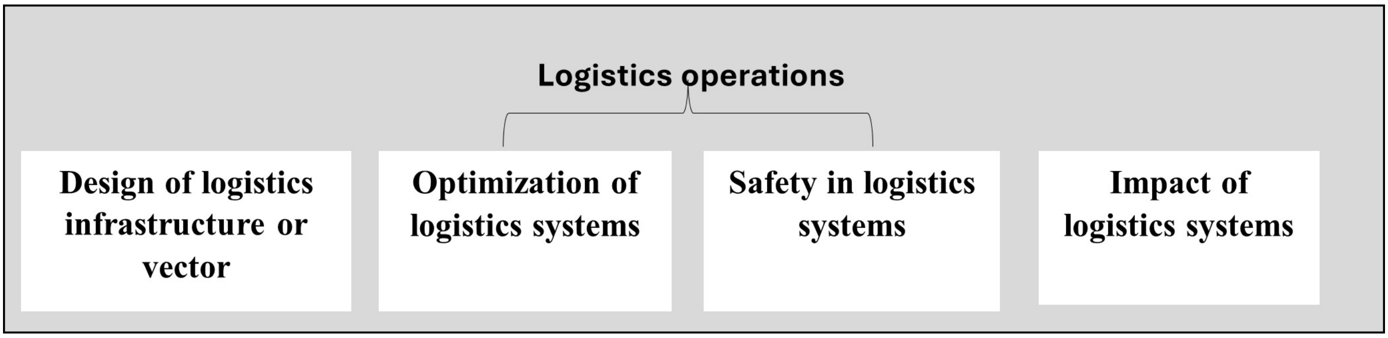

Figure 5. General framework for emerging mountain logistics themes.

5.1. Design of Logistics Infrastructure or Vector

Studies in this category emphasize the following three application areas: the design of unmanned aerial vehicle (UAV) system control, urban ropeway system design, and electric vehicle charging infrastructure design (see Appendix A, Table A1).

The design of unmanned aerial vehicle (UAV) system control mainly focuses on advancing mobility, accuracy, and stabilization in challenging mountainous terrain [27]. Thus, researchers like [27,28] focused on UAV flight control, accuracy prediction, and mitigation of errors occurring during landing to mitigate environmental requirements for mountainous terrain successfully. On the other hand, other scholars focused on the transition of ropeway transport systems in urban settings [29,30]. This shift necessitates the design of integrated passenger and freight ropeway systems to improve delivery capacity [31]. Lastly, electric vehicles are emerging in the transport sector, which needs further examination and infrastructure design. To this end, D'Alonzo et al. [32] developed decision support tools for integrated charging infrastructure for the mountain regions' private and public electric transport.

5.2. Optimization of Logistics Systems

This involves optimizing transport networks, traffic flow monitoring and optimization, and last-mile logistics optimization (see, Appendix A. Table A2).

Optimizing transport networks in mountainous areas is essential to address the unique logistical challenges and limitations associated with various transport modes [31]. Effective optimization considers cost, time, and facility locations to facilitate the efficient movement of goods and passengers. For example, Kelley et al. [33] proposed a mixed-integer programming model aimed at minimizing costs by accounting for constraints such as vehicle capacity. In mountain cities, resilience in transport networks is especially important during disruptions, requiring robust systems that accommodate structural characteristics and unique mobility patterns [34]. For this purpose, high-speed railway networks were used as a case study by Ravazzoli et al. [35]. The authors used multidimensional scaling algorithms and Geographic Information Systems (GIS) to optimize travel times between stations. Furthermore, facility location optimization plays a critical role in mountain logistics, and recent studies have contributed significant advancements in this area. Scholars have developed linear programming models to allocate transport nodes optimally, focusing on minimizing average travel times, particularly in emergency scenarios [36,37] and for agricultural supply chains [38]. These models highlight the strategic importance of facility location for enhancing operational efficiency and response times in mountainous areas. These scholarly endeavors underline the role of mathematical modeling and optimization techniques in addressing logistical challenges in mountain areas.

Another logistical challenge in mountainous regions is real-time **traffic flow monitoring**, considering congestion, accidents, and incidents. This is essential for acquiring current traffic information but becomes particularly challenging due to topographic features. Some researchers, Liu et al. [39,40], have developed a comprehensive strategy for enhancing traffic flow monitoring through path optimization. Their approach integrates various mathematical models such as multi-objective optimization, penalty-based boundary intersection optimization algorithm, and the Pareto technique.

The last subcategory in optimizing logistics systems is **last-mile logistics optimization**, which primarily emphasizes two aspects: (a) the optimization of delivery amount and (b) the optimization of delivery routes. In the former domain (a), Jung and Kim [41] proposed a robust optimization-based drone scheduling model specifically tailored to deliver small parcels in mountainous islands efficiently. Complementing this perspective, Liu et al. [42] proposed a stochastic model for relief logistics to mobilize relief supply levels and plans within challenging terrain optimally. On the latter (b) dimension, Liu et al. [43] developed a collaborative delivery approach utilizing a genetic algorithm and optimizing single distribution terminals by combining UAVs and ground vehicles. Additionally, Yang et al. [44] employed a modified reinforcement-learning approach to automate the generation of optimal road trajectories in emergency logistics scenarios. Their model excels in selecting the shortest and most efficient road routes among the possible alternatives, thus enhancing the overall effectiveness of rescue operations.

5.3. Safety in Logistics Systems

Safety is crucial for logistics operational activities within mountainous regions. As shown in Appendix A. Table A3, it encompasses three dimensions: accident analysis, safety improvements, and technological solutions to improve logistics operational activities.

The **accident analysis** dimension specifically focused on two aspects: (a) accident investigation and (b) accident prediction. Looking at (a), accident investigation, some studies focus on incidents occurring within mountain tunnels, others emphasize road traffic accidents, and the remainder consider a single type of transportation mode. In this regard, using a random parameter logit model, authors like Alrejjal et al. [45], Pervez et al. [46], Pervez, Lee, et al. [47], and Yang et al. [48] explored potential risk factors and severity levels of injuries within tunnel crashes. These studies reveal the presence of curves, speeding, crash time, and downgrade as potential indicators. Other experimental studies Huang et al. [49] and Jia et al. [50] showed that aggressive driving behavior was the significant contributing factor to the severity of crashes in mountain freeway tunnels. In addition, weather factors like visibility and precipitation have a potential impact on crash occurrence on mountain freeways [12]. (Gu et al. [51] emphasized the need for a framework to analyze multi-fatality crashes in road traffic accidents, which are often the result of complex interactions between human-vehicle-road-environment factors. Chen et al. [52,53] employed principal component analysis and hierarchical clustering to identify critical factors in road traffic crash severity, finding speeding and passenger overloading as primary contributors, with road conditions as secondary factors. Wang et al. [54,55] highlighted the fundamental causes of truck crashes, linking driver traits, vehicle features, roadway design, and environmental factors. Aguiar et al. [56] noted that controlled flight into mountainous terrain and wind gusts are common causes of accidents in general aviation.

Research on accident prediction on mountainous roads is growing, aiming to develop accident prevention strategies. Gaweesh et al. [15] developed a crash prediction model to better predict fatalities and injury-related crashes. Chen et al. [53] utilized a count regression model to analyze crash frequency and influencing factors on these roads, whereas Nguyen et al. [57] introduced an agent-based model to enhance landslide warnings and rescue systems for improved safety of mountain road users.

Logistics safety improvement encompasses four sub-elements: (i) enhancing quality within transport infrastructure, (ii) maintaining vehicle safety, (iii) improving road network vulnerability, and (iv) use of advanced guide signs to reduce accident occurrence.

The first sub-element (i), infrastructure quality assessment, aims to promote safety and efficiency while constructing transport infrastructure. For instance, Zhang et al. [58] introduced a GIS-based design quality assessment model tailored explicitly for mountain highways. The second sub-element (ii) is mainly focused on investigating rollover propensity, by utilizing vehicle dynamics simulation modeling [14]. In the third sub-element (iii), given the vulnerability of traffic systems to abnormal events in mountainous urban transportation networks, researchers are equally concerned with enhancing the resilience of road networks. Considering road network vulnerability, Wu et al. [59] developed a route choice model to correlate travelers' behavior with route preferences within complex networks. Additionally, Wei et al. [60] employed complex network analysis to assess the correlation between mountainous road characteristics and the degree of earthquake impacts. Road network vulnerability improvement also needs a methodology for prioritizing links within a mountainous road and their significance in maintaining seamless connectivity between origin–destination pairs [61]. The fourth sub-element (iv) focuses on assessing the safety of exit advance guide signs within mountain highway tunnels. Lu et al. [13] evaluated the effectiveness of exit advance signs through simulation experiments employing eye-tracking technology and Markov chains and reported that proper setting of location signs reduced traffic accidents. On the other hand, studies like [62,63] employ negative binomial modeling to predict crashes in steep-grade mountainous roads and propose to place advanced warning signs within mountain passes to enhance safety. Saha et al. [64] suggest variable speed limit strategies in challenging mountainous road segments, citing significant interactions between grades, horizontal curves, and weather variables on crash occurrence. Liu et al. [65] considered traffic flow and drivers' light adaptation in mountainous expressway tunnels and proposed a theoretical model to evaluate design scheme indexes for highway-adjacent tunnels and exit connection sections.

The last safety dimension, **technological solutions,** addresses studies focused on technological solutions for enhancing emergency response. Considering the unique topographical challenges in mountainous regions, researchers propose drones or UAVs as alternative solutions for rescue missions. Pedersen et al. [66] introduce a heuristic approach that automates search and rescue operations and effectively addresses the challenges associated with covering variable likelihood target areas by integrating UAVs with optical sensors. This transport solution can potentially improve operational performance and safeguard the safety of mountain rescue personnel [37]. In addition, Karani et al. [67] and Zilio et al. [68] proposed employing helicopters as an alternative medical transport solution to bridge critical healthcare gaps in mountainous regions. On the other hand, drawing from the unified theory of acceptance and use of technology, Holzmann et al. [69] studied the behavioral aspect of mountain rescuers' acceptance and adoption of drone technology in their operations.

5.4. Impact of Logistics Systems

The fourth research theme focuses on logistics systems' economic, environmental, and social impacts (see Appendix A. Table A4).

The **economic impact** encompasses factors that contribute to economic growth. It is important to consider the geographical, topographical, spatial, and geological conditions to understand logistics systems' role in economic development in these areas [70,71]. These elements significantly affect the selection and development of transport infrastructure. Transport accessibility is closely linked with economic development in these regions, where enhanced connectivity through highways, railways, and airports can spur economic growth [23]. For instance, Zuber [72] advocated for mountain railway systems with tunnels through mountain bases to unlock economic potential. Likewise, highway infrastructure promotes tourism, which stimulates the service sector and fosters a self-sustaining, monetized economy among mountain communities [73]. Sustainable economic development in these fragile areas also involves innovations such as integrated cycle mobility networks [74]. However, not all transportation systems are equally efficient in mountain areas. For instance, Brida et al. [75] found that cableway systems are economically inefficient. Furthermore, Yang et al. [76] highlight the effects and consequences of different types of road infrastructure on economic growth in mountainous regions. National and provincial roads tend to generate more economic benefits in high-elevation areas as the development of agricultural production [77] and regional land use changes [78,79]. In contrast, county and village roads are more advantageous in plains cities. This shows the importance of integrating transportation strategies to the specific characteristics of mountain areas for optimal economic return.

On the other hand, studies on the **environmental impact** of logistics in mountain areas highlight two critical findings: (a) emissions and (b) green transportation. In a comparative study on truck transportation, Pandur et al. [80] showed the influence of elevation (altitude) on emissions (i.e., CO_2 emissions). To this end, significant temporal and spatial variability exists in emission patterns from transport vehicles [9], so it is necessary to tailor location-specific mitigation measures to address these variable emission patterns effectively. In addition, studies highlight the importance of implementing green transportation solutions [74] through the development of evaluation index systems [81] and estimation methods for transport emission contributions [82]. Addressing both emissions and green transportation issues offers a foundation for informed decision-making in logistics, intending to reduce the environmental footprint of logistical activities and promote sustainability in mountainous areas.

Lastly, studies on the **social impact** of logistics in mountain areas show how accessibility influences different aspects of resident life. Public transport accessibility through metro and street systems has significant nonlinear effects on shaping urban development within mountain cities [83]. Through accessibility evaluation models, it is possible to determine the attractiveness of potential destinations that help with urban planning and mobility policies, benefiting residents and tourists [16,84] in mountainous regions. The mobility policies here also consider the factors influencing the preference for paratransit services among mobility-impaired people in mountain areas [85].

In addition, the construction of transport infrastructure in mountainous areas leads to shifts in rural settlement patterns, transforming weak industrial zones into stable industrial clusters [9]. For this purpose, high-speed railways have substantial positive effects on local accessibility [35] and spatial equity [86] in mountainous regions, emphasizing the role of transportation infrastructure in regional development. The improvements in transport services mitigate depopulation and marginality challenges in mountainous areas [87], showcasing the social importance of accessibility in these regions.

6. Knowledge Gaps and Future Directions

Despite substantial progress in the theory and practice of mountain logistics, some research gaps still need further investigation in future studies. The following subsection highlights the primary research gaps identified through general descriptive analysis and within each of the four thematic categories, offering proposed directions for future studies (see Table 2).

6.1. Research Approaches

As shown in Figure 4, the research on mountain logistics is notably concentrated in three countries: China (47%), Italy, and the United States, which together account for 70% of the studies. In contrast, the other twenty countries make up the remaining 30%. This lack of geographical diversity raises concerns about the applicability and generalizability of the findings. Therefore, comparative studies on mountain logistics and exploring regional cooperation are essential. In addition, the descriptive analysis revealed a significant research gap in mountain area logistics, mainly due to the scarcity of conceptual papers. With 85.53% of the reviewed contributions being empirical studies, there is a clear need for more conceptual research. Such papers are essential for strengthening the theoretical framework and expanding knowledge in this unique logistical context.

Table 2. Research gaps and proposed directions in mountain logistics.

Focus Areas	Identified Research Gaps	Possible Future Research Avenues
Research approach	- Limited geographical scope in studies; - Scarcity of conceptual frameworks.	- Expand comparative and cross-regional analysis; - Conduct deeper conceptual investigation.
Infrastructure design	- Few design solutions tailored for logistical challenges in mountainous areas; - Limited focus on mass transportation of goods and passengers; - Minimal integration of emerging digital technologies (e.g., AI, blockchain); - Lack of coordination with existing systems (e.g., cableways with public transport).	- Develop innovative infrastructure and transport solutions for goods and passenger movement; - Investigate digital technology; integration to enhance efficiency, resilience, and transparency.
Logistics system optimization	- Insufficient integration of optimization models considering terrain, vehicle capacity, and topology; - Limited multi-modal transportation integration; - Underutilized digital tools (e.g., AI) for system optimization.	- Study integration of various optimization models; - Enhancing the integration of transportation modes; - Analyze the role of digital technologies in logistics optimization.
Safety in logistics	- Emphasis on post-incident safety analysis, with limited focus on preventive measures; - Lack of holistic safety evaluations tailored for mountainous conditions; - Sparse attention to human factors and organizational impacts.	- Develop predictive safety models and integrated safety evaluation methods; - Explore technology acceptance and data security considerations.
Impact of logistics systems	- Limited insights on logistics operations' connection to local manufacturing and economic sustainability; - Lack of impact assessment tools for transportation types on economic growth; - Few studies on ecosystem impacts of logistics infrastructure.	- Investigate trade-offs and synergies between environmental and economic objectives in mountain logistics; - Conduct feasibility studies on environmental costs and benefits of infrastructure.

6.2. Design of Infrastructure or Vector for Mountain Areas

A notable research gap in this field is the lack of studies on effective methods for addressing the unique logistical challenges of mountainous regions through strategic logistics infrastructure design. While the literature identifies these challenges (e.g., [36,51,65]), few studies (e.g., [31,32]) focus on design solutions. Most existing research targets small-scale logistics in healthcare, emergency response [42,66,67,69], and last-mile logistics [41,43,44], leaving a critical void in mass transportation studies. Addressing these gaps offers opportunities for innovative design solutions for logistics in mountain regions.

Furthermore, exploring design solutions for specific modes of transportation, such as eco-friendly cableways, presents a valuable research opportunity. Existing studies indicate their potential in urban areas [29,30,75,88], yet there is limited research on integrating them with urban public transport systems or addressing privacy concerns related to their operation over private properties. Additionally, unmanned aerial vehicles (UAVs) have potential in mountainous regions but are constrained by limitations in load capacity, battery life, and flight distance. Addressing these research gaps could enhance UAV designs, making them more practical for transportation in challenging terrains.

Lastly, the potential of digital technologies like big data, AI, blockchain, and intelligent logistics to enhance mountain logistics remains unexplored. Future research could focus on how these innovations improve efficiency, resilience, and transparency and the challenges and opportunities of adopting them in mountain regions.

6.3. Optimization of Logistics Systems in Mountain Areas

Research on logistics system optimization in mountain areas primarily focuses on mountain rescue operations using unmanned aerial vehicles, leaving a gap in the study of freight and passenger transport. This oversight may contribute to the perception of mountains as less productive compared to plains. There is a pressing need to explore efficient logistics operations and integration of various optimization models, considering terrain characteristics, vehicle capacity, and topological features.

Aside from one study by Li et al. [34] on bus–metro networks, there is a lack of research integrating diverse transportation modes (e.g., buses, railways, cableways) for efficient movement of goods and people. Further exploration of multimodal transportation and the role of digital technologies, such as AI optimization tools, in enhancing logistics efficiency is also warranted.

6.4. The Safety of Logistics in Mountain Areas

Research gaps in mountain logistics safety have been identified in three main categories. First, while many studies focus on post-incident analyses, there is a significant lack of emphasis on preventive safety measures. Future research should prioritize the development of proactive strategies specifically designed for mountainous regions. Additionally, there has been an insufficient exploration of specific transportation modes, integrated risk factors, and human behavior related to accidents. Second, under the **safety improvement** subcategory, the current literature lacks evaluation methods specific to mountain passes, highlighting the need for research on the interconnections between safety improvements in infrastructure, vehicles, and road networks. Third, studies **on technological solutions** often overlook societal and organizational impacts, with little focus on the long-term acceptance and sustainability of technologies such as drones. Research should also address data and information security challenges in logistics, exploring innovative solutions to enhance safety in mountain regions.

6.5. The Impact of Logistics in Mountain Areas

The research gaps on impact of logistics in mountain areas focuses on the economic, environmental, and social dimensions. The **economic impact** of logistics in mountainous areas has primarily focused on tourism, leaving a gap in understanding logistics related to the manufacturing sector. Further studies are needed to assess how logistics operations support economic sustainability and consider various factors such as geographical conditions and demographics. Previous work (e.g., Walsh [20]) indicates a link between transport accessibility and economic growth, yet there is a lack of comprehensive research on how different types of transport infrastructure affect development in these regions. The economic benefits of these transport infrastructures vary across different types of roads and geographical features [89,90]. This brings future research avenues to tailor transport strategies with economic return in mountainous regions.

Moreover, existing studies on the **environmental impacts of logistics** have mostly addressed emissions [9,80,82] and green transportation [74,81]), while neglecting how the construction and maintenance of logistics infrastructure impact natural ecosystems. While some studies [74] have pointed out the benefits of eco-friendly transport, there is an opportunity for further investigation into how these solutions can positively influence economic competitiveness in mountain areas.

Socially, studies (e.g., Lima et al. [35]; Márquez et al. [84]; Ravazzoli et al. [85]) emphasize accessibility's role in the development of mountain communities but lack empirical analyses on how different accessibility levels affect residents' quality of life. Exploring stakeholder engagement, including local communities and logistics providers, can enhance the sustainability and acceptance of logistics initiatives.

7. Conclusions

The review findings indicate a growing focus on research related to mountain logistics. Most studies used quantitative research methods, with a significant number conducted in China. This trend aligns with Du [91]'s observation that over half of Chinese cities are in mountainous regions. Our thematic analysis identified four primary categories:

- Logistics infrastructure design;
- Optimization of logistics systems;
- Safety within logistics systems;
- The impact of logistics systems.

We also uncovered several knowledge gaps and potential research areas, particularly concerning the unique logistical challenges of mountainous regions and the integration of various transport modes.

However, this study has certain limitations. It focuses on a detailed examination of descriptive and thematic analyses based on existing studies. The literature review is restricted to articles indexed in the Web of Science. While WoS is the most extensive database for scientific research, we recognize that some relevant studies may have been omitted. Additionally, our reliance on English-language publications introduces a language bias, potentially excluding valuable research published in other languages.

Our paper is designed to be a foundational resource for researchers, policymakers, and practitioners interested in understanding and addressing the complexities of logistics operations in mountainous areas. By providing a synthesized overview of current knowledge, highlighting critical gaps, and proposing actionable recommendations, we aim to advance both the theory and practice of mountain logistics.

Supplementary Materials: The PRISMA checklist for Systematic Review can be downloaded at: https://osf.io/qpw8u/files/osfstorage/66e1c501552b79f039a3d70b/?pid=qpw8u (accessed on 12 September 2024). The OSF (Open Science Framework) register of reviews can be accessed at: https://osf.io/qpw8u/ (accessed on 5 November 2024).

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Appendix A

Distribution of papers for each theme and sub-themes

Table A1. Design of Logistics Infrastructure or Vector.

	Reference	UAV System Control Design	Electric Vehicle Charging Infrastructure Design	Urban Ropeway System Design	
		Flight Control, Quality of Prediction, and Elimination of Error During Maneuvers	Investigation of Alpine Regional Requirements	Investigation of Challenges	Delivery Capacity
Empirical	[31]				E
	[29]			E	
	[32]		E		
	[27]	E			
	[28]	E			
	Total E	2	1	1	1
Conceptual	[30]			C	
	Total C			1	

Note: E = Empirical contributions; C = Conceptual contributions; Number in the table refers total contributions.

Table A2. Optimization of logistics systems.

	References	Transport Network Optimization			Traffic Flow Monitoring and Optimization	Last-Mile Logistics Optimization	
		Cost Optimization	Time Optimization	Facility Location Optimization	Path Optimization	Optimization of Delivery Amount	Optimization of Delivery Routes
Empirical	[37]		E	E			
	[33]	E		E			
	[41]					E	
	[43]						E
	[44]						E
	[40]				E		
	[42]					E	
	[34]		E	E			
	[38]			E			
	[35]		E	E			
	[92]				E		
	[93]				E		
	[39]				E		
	Total E	1	3	5	4	2	2

Note: E = Empirical contributions; C = Conceptual contributions; Number in the table refers total contributions.

Table A3. Safety in Logistics Systems.

	References	Accident Analysis		Safety Improvement				Technological Solutions
		Accident Investigation	Accident Prediction	Infrastructure Quality Improvement	Vehicle Safety	Road Network Vulnerability Improvement	Advance Guide Sign	Drones in Emergency Response
Empirical	[48]	E		E				
	[58]			E				
	[65]						E	
	[51]	E						
	[67]							E
	[14]				E			
	[13]						E	
	[68]							E
	[54]	E						
	[15]		E					
	[62]						E	
	[53]		E					
	[52]	E						
	[57]		E					
	[64]						E	
	[12]	E						
	[46]	E						
	[47]	E						
	[59]					E		
	[60]				E			
	[45]	E						
	[55]	E						
	[63]						E	
	[50]	E						
	[49]	E						
	[56]	E						
Conceptual	[36]							E
	[66]							C
	[69]							C
	[61]					C		
	Total E	12	3	2	2	1	5	3
	Total C					1		2

Note: E = Empirical contributions; C = Conceptual contributions; Number in the table refers total contributions.

Table A4. Impact of Logistics Systems.

	Reference	Economic Impact	Environmental Impact		Social Impact
		Economic Growth	Emissions	Green Transportation	Accessibility
Empirical	[94]				E
	[83]				E
	[95]				E
	[23]	E			
	[84]				E
	[81]			E	
	[34]				E
	[96]				E
	[35]				E
	[9]		E		
	[75]	E			
	[72]	E			
	[10]				E

Table A4. *Cont.*

	Reference	Economic Impact	Environmental Impact		Social Impact
		Economic Growth	Emissions	Green Transportation	Accessibility
Empirical	[85]				E
	[16]				E
	[80]		E		
	[79]	E			
	[71]	E			
	[86]				E
	[70]	E			
	[82]		E		
	[76]	E			
Conceptual	[78]	C			
	[74]	C		C	
	[11]				C
	[73]	C			
	[77]	C			
	[88]	C			
	[87]				C
	Total E	7	3	1	11
	Total C	5		1	2

Note: E = Empirical contributions; C = Conceptual contributions; Number in the table refers total contributions.

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