Current Science
CS 5 (2), 1787-1805 (2025)
Received 26 **Jan** 2025 | **Revised 23 Feb** 2025 | **Accepted 17 March**. 2025 | **Online Available 13 April** 2025
https://doi.org/ 10.52845/CS/2025-5-2-42

Current Science

Current Science

OPEN ACCESS

ISSN(O)2795-8639

ORIGINAL ARTICLE

Navigating the Complex Landscape of Emergency Rescue: Insights from a Co-Citation Analysis

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Abstract

The significance of emergency rescue in protecting lives and property during unforeseen events, such as natural disasters and accidental calamities, is undeniable. However, the emergency rescue knowledge domain spans multiple disciplines. While each relevant discipline offers comprehensive research progress and trend analyses, there is a lack of a holistic literature review and visual analysis grounded in the organic integration of these disciplines. This study undertook a co-citation analysis of research papers indexed in the Web of Science database using CiteSpace, with the objective of reviewing the thematic characteristics and evolutionary trajectory of the emergency rescue knowledge domain from 2009 to 2024. The results indicate that the emergency rescue knowledge domain primarily consists of nine thematic clusters, exhibiting distinct temporal evolution patterns, encompassing emergency rescue scenarios, technologies, personnel, and corresponding system developments. Notably, the largest thematic cluster is "Out-of-Hospital Cardiac Arrest (OHCA)", which continues to be an actively researched area. Research in areas such as computer vision and algorithms for real-time target detection in emergency rescue scenarios is a current frontier in research and an important development direction for emergency rescue technologies. The findings of these areas will facilitate both academic and industrial stakeholders in understanding the current research landscape in the promising field of emergency rescue and guide subsequent endeavors.

Keywords: Emergency rescue; Co-citation analysis; CiteSpace; Bibliometrics; Mapping knowledge domain

Introduction

In the English linguistic context, the verb "rescue" primarily signifies "to save sb/sth from a dangerous or harmful situation" [1], encompassing the salvage of both individuals and objects, such as the restoration of communication facilities, the acquisition of supplies, the execution of hygiene and epidemic prevention measures, and medical rescue operations. This term inherently embraces the notions of emergency response and first aid. Consequently, the expressions "rescue," "emergency rescue," and "immediate rescue" convey similar concepts. Emergency rescue pertains to the procedure of initiating measures such as early warnings, disaster evaluations, swift reactions, and urgent assistance following the occurrence of unexpected events, aimed at alleviating disaster-induced losses and safeguarding human lives and property. This encompasses the organization and coordination of emergency resources and personnel to carry out disaster relief and rescue

missions, provide emergency medical assistance, and engage in post-disaster recovery and reconstruction endeavors. From a systems theory standpoint, a disaster can be perceived as the disruption of the original intra-system and inter-system equilibria amidst the contradictory movements within and outside the disaster system [2]. The paramount objective of emergency rescue is to restore these systems to their normal operational states. Therefore, emergency rescue is a multifaceted endeavor that encompasses both natural and social domains, as well as technical and engineering aspects. It spans a broad spectrum of content and falls within a multi-disciplinary realm.

The inception and progression of emergency rescue have spanned an extensive period. In the history of knowledge domain development, scholars have persistently explored and propelled research in emergency rescue by capitalizing on prior scholarly endeavors, thereby delineating a trajectory of advancement within this knowledge domain. Conventionally, review articles serve as a conduit for gaining profound insights into a knowledge domain and tracing its evolutionary trajectory. For example, Tang et al. [] conducted a comprehensive review of the present status of visual detection and navigation technologies for unmanned aerial vehicles (UAVs), with the objective of expediting their practical deployment in disaster-response emergency rescue missions. Samanta et al. [3] presented a narrative synthesis of rescue methodologies for epileptic seizures, highlighting this specific emergency scenario that necessitates prompt rescue action. Zhang et al. [4] provided a summary and analysis of emergency medical rescue endeavors undertaken in the aftermath of the 2008 Wenchuan earthquake, emphasizing the significance of these efforts in enhancing the overall efficacy of post-earthquake rescue operations. Hatchimonji et al. [5] examined strategies aimed at minimizing failure-to-rescue (FTR) rates and delineated potential avenues for the application of the FTR indicator in the context of emergency general surgical patients. Wang et al. [6] delved into the current state and advancements in emergency communication network technology, underscoring the potential research hurdles associated with the establishment of rapidly deployable, efficient, reliable, and stable emergency communication networks capable of responding to diverse disasters and accidents. These traditional literature reviews, authored by domain experts, offer invaluable insights into the research "landscape" of the emergency rescue knowledge domain.

However, literature retrieval is akin to "the blind men and the elephant," where incomplete searches can lead to vastly differing conclusions. This is particularly concerning in fields such as emergency response and rescue, which involve personal safety and health, as incorrect conclusions could have catastrophic consequences. Traditional literature reviews often fail to provide a comprehensive view of the emergency rescue knowledge domain due to its wide range of topics and disciplines, where each topic can independently constitute a research field. Even within specific topics, traditional methods struggle to cover all relevant literature due to limitations in the number of pieces they can review and analyze. With advancements in data science and computer visualization, knowledge mining based on large-scale literature data is becoming increasingly feasible. In recent years, literature-based knowledge discovery and scientific visualization have extended beyond library information and bibliometrics into multiple disciplines. For example, in ecological and environmental protection, Hu et al. [7] reviewed the importance of reducing greenhouse gas emissions from railway transportation for global sustainable development; Xing et al. [8] provided insights and future research directions for microplastic pollution control. In technological applications, Kaur et al. [9] explored the prospects of digital twin research and its impact on Industry 4.0; Abdallat et al. [10] identified the positive effects of deep brain stimulation (DBS) on improving the prognosis and quality of life of patients with Parkinson's disease through a systematic analysis of the literature on this technique. In the field of firefighting, Tang et al. [11] and Meng et al. [12] conducted bibliometric analyses on fire risk assessment and electrical fire-related literature, respectively, constructing scientific knowledge maps.

In this context, this study employed the scientific literature platform to curate a representative collection of typical research papers within the realm of emergency rescue knowledge. These papers were subsequently fed into the literature visualization analysis system, CiteSpace, for

computational analysis. By adopting a literature analysis perspective, the study identified and detected the thematic evolution process, landmark articles, and emerging trends, thereby unveiling the intellectual landscape of emergency rescue research. The computational and visualization analysis methods offered by CiteSpace are rooted in the disciplines of scientometrics and information visualization [13,14]. Scientometrics, as the quantitative study of science, boasts two significant advantages over traditional literature reviews led by domain experts: it encompasses a broader and more diverse array of related topics, and it facilitates timely updates to the review as required, maintaining the currency of the research dynamics within the knowledge domain. The application of computer-assisted literature review methods is not meant to supersede traditional expert reviews but rather to offer additional points of reference for specific audiences. The in-depth analysis and commentary provided by domain experts remain crucial for comprehending complex topics within the knowledge domain [15].

1. Data and Methods

The literature data was sourced from Clarivate's Web of Science Core Collection, specifically utilizing the SCI database, known as "Science Citation Index Expanded (SCI-EXPANDED): 1900 - Present." The search was conducted with the "Topic" field set, using the query "emergency rescue." The publication date range was set to encompass "All Years (1900-2024)" during the search process. Utilizing the "Refine Results" module within the search results, only documents classified as "Article," "Review," and written in "English" were retained, yielding a total of 5,683 SCIE-indexed research papers on "emergency rescue."

The database includes the earliest research paper on emergency rescue, published in 1964. Figure 1 illustrates the annual output distribution of research papers on emergency rescue over the past 61 years.

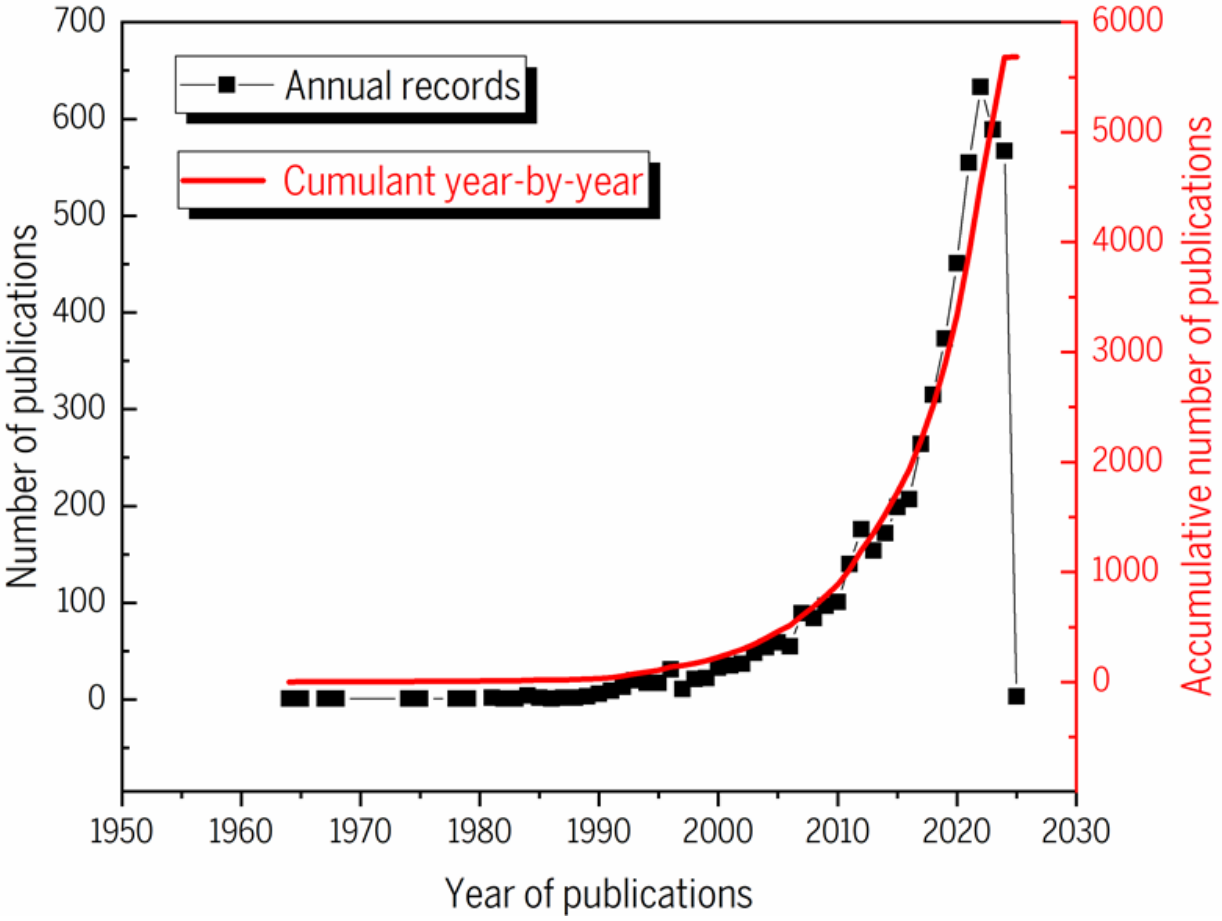

Figure 1. Number of publications from 1964 to2024.

Observing the trend of paper production, it is evident that the number of research papers on emergency rescue has demonstrated a consistent increase over time. While the number of papers published in 2023 showed a slight decline compared to 2022, it still remains within a high-production range. Notably, the retrieval date for the literature data was November 28, 2024, indicating that the 2024 paper output does not represent a complete year's worth of data. Additionally, the dataset includes three pre-published papers scheduled for 2025. Regarding the segmented temporal distribution, the number of research papers on emergency rescue grew relatively slowly before 2009, with an annual output remaining low. Specifically, the annual output was below 10 papers per year for nearly 30 years, from 1964 to 1991, and below 100 papers per year from 1992 to 2009. However, after 2009, the number of the papers increased exponentially.

The mapping knowledge domain is an analytical method that employs network analysis and visualization techniques to uncover and present the structure, relationships, and evolutionary processes of scientific knowledge based on scientific literature data. It holds significant value in conducting information retrieval and knowledge services, showcasing the development trends of a field, achieving systematic reviews, assisting in knowledge discovery, and anticipating technological advancements [16,17]. By utilizing the references from 5,683 citing literature data as knowledge units, this study constructed a mapping knowledge domain through the co-citation relationships among these references to conduct an evolutionary analysis of the emergency rescue knowledge domain.

The notion of co-citation among references was first introduced by Small [18]. The fundamental principle is that when two references are cited concurrently by the same citing article, they establish a co-citation relationship. The frequency of their joint citations, referred to as co-citation strength, serves as an indicator of the similarity between the two references. The co-citation relationship among references is inherently dynamic: references that were initially unrelated may later form a co-citation link, and for those already in such a relationship, their co-citation strength may further intensify. Consequently, employing the co-citation relationship to explore the internal connections among articles and illustrate the evolving structure of scientific development offers advantages over relying solely on the citing article coupling relationship.

The collection of references exhibiting co-citation relationships forms the research foundation within the emergency rescue knowledge domain. Conversely, the research front of this domain is delineated by the set of citing articles that reference this foundational knowledge. In this study, we employed the citation visualization analysis software CiteSpace to construct a co-citation network, grounded in the co-citation relationships among references within the emergency rescue knowledge domain, and subsequently segment it into distinct clusters. Using the log-likelihood ratio (LLR) algorithm, noun phrases were extracted from the titles of citing articles to serve as descriptive cluster labels [19], yielding a hybrid network that integrates terms from both co-cited and citing articles. By seamlessly integrating and networking the knowledge foundation with the research fronts in the emergency rescue knowledge domain, we can clearly delineate the structure of emergency rescue research, thereby providing a solid foundation for the advancement of this knowledge domain.

2. Results and Discussion

3.1 Intellectual Base of the Emergency Rescue Knowledge Domain

3.1.1 Cluster Characteristic Analysis of the Intellectual Base

Given that 2009 represents the inception of a notable surge in research publications within the field of emergency rescue, this study targeted the references cited in articles from this domain spanning the period 2009 to 2024 for analysis. With a time slice of one year and an extraction limit of Top N=30 references per slice, a co-citation network cluster visualization was constructed as depicted in Figure 2.

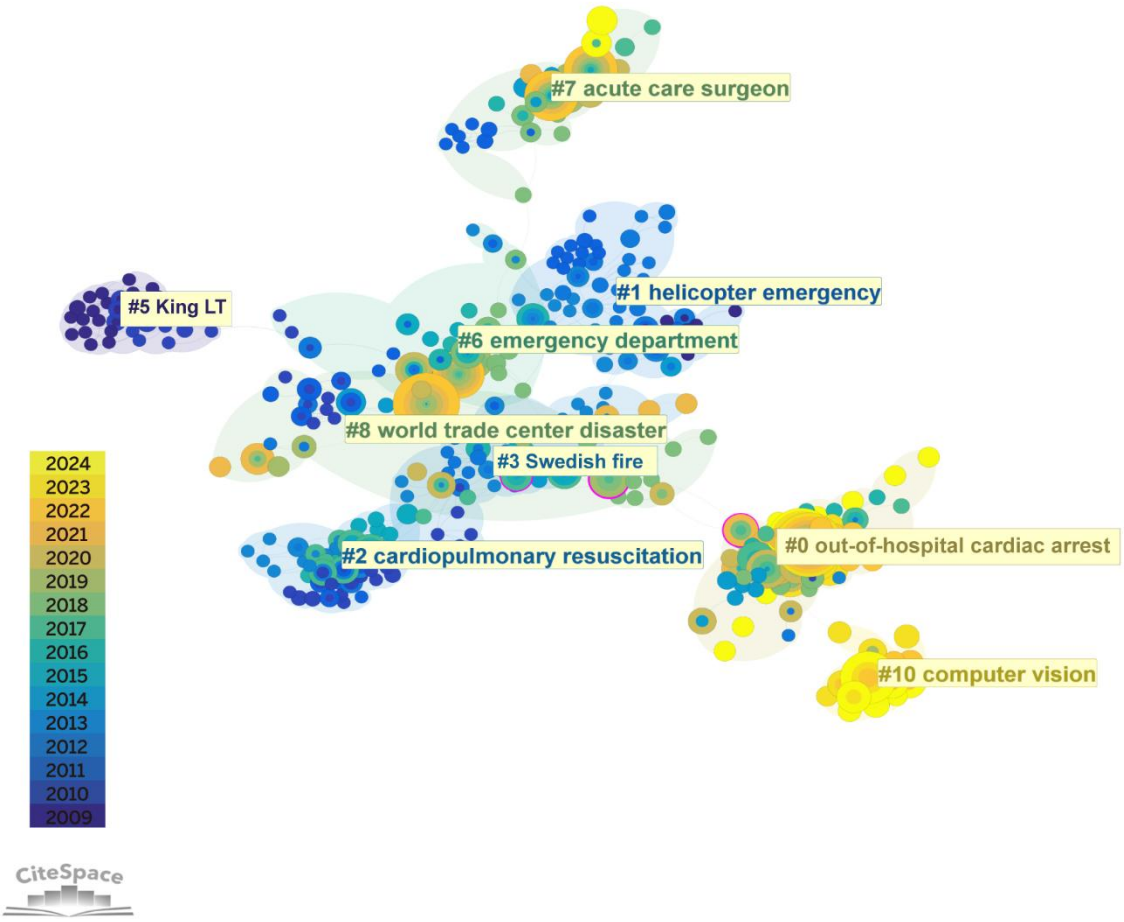

Figure 2. A co-citation references network of top 30 articles per year between 2009-2024

The clustering network comprises 2,920 references, covering a time span from 1957 to 2022. Each node signifies a unique reference, and the connecting lines between nodes denote co-citation links. The citation history of each article is visualized through nodes featuring tree rings: the overall size of the ring mirrors the citation count of the article, while the color signifies the corresponding citation year. Bluer hues signify older publication dates, and yellower hues represent newer ones. Furthermore, the thickness of the tree rings is directly proportional to the citation frequency within the respective time periods. The clustering results were assessed using the Modularity index (Q-value), a metric for evaluating network modularity. A Q-value nearer to the peak of 1 indicates superior network clustering. In this study, the Q-value stands at 0.9013, highlighting a pronounced network clustering structure.

The co-citation network of references includes nine major clusters, numbered sequentially starting from #0. The smaller the cluster number, the greater the number of references it contains, reflecting its greater importance in emergency rescue research. Detailed information is provided in Table 1. The largest cluster, located in the bottom right corner, is "#0 out-of-hospital cardiac arrest (OHCA)" related research, indicating that a significant number of studies on OHCA have cited the references within this cluster. This cluster consists of 90 references, with an average publication year of 2009, which is relatively recent and ranks second only to "#10 computer vision" with an average publication year of 2015 among the nine major clusters. The clustering effectiveness is evaluated by the Silhouette value (S-value), which measures the homogeneity among members within the cluster. The S-value for Cluster #0 is 0.989, which is very close to the maximum value of 1.000, indicating a high degree of credibility and reliability in the clustering result.

Out-of-hospital cardiac arrest (OHCA) is one of the most critical symptoms in clinical practice, characterized by high incidence and low survival rates, making it one of the leading causes of death among patients. The effectiveness of OHCA

rescue is influenced by multiple factors, including prehospital emergency conditions, the patient's anamnesis, the personnel's rescue capabilities, the emergency medical service system, and citizens' awareness of emergency rescue. Due to its involvement in numerous research areas, OHCA has a relatively large number of cluster members, indicating that this cluster represents one of the most important research topics in emergency rescue.

The most efficacious rescue intervention for patients enduring OHCA is cardiopulmonary resuscitation (CPR), which constitutes the research focus of Cluster #2. Conventional CPR (CCPR) can be administered via manual or mechanical compression, or extracorporeal cardiopulmonary resuscitation (ECPR), by combining extracorporeal membrane oxygenation with CPR, can serve as the primary modality for providing respiratory and circulatory support to patients. Manual CPR is the most commonly used method, characterized by its simplicity, not requiring equipment, and being unaffected by factors such as time, location, and environmental conditions. However, the quality of compressions is directly related to the skill level of the person performing CPR, placing high demands on their technique, experience, and physical strength. Therefore, Cluster #5 focuses on rescuers, particularly those in aeromedical emergency rescue teams, regarding their technical proficiency in performing CPR and airway management techniques during CPR.

Aeromedical emergency rescue boasts rapid response, extensive coverage, strong mobility, high technological content, and effective rescue outcomes, making it a pivotal component of modern aerial emergency medical services. It has won invaluable golden hours for patients with critical illnesses and injuries, and in the field of emergency rescue research, Cluster #1, which focuses on aeromedical emergency rescue, ranks second in scale only to that of OHCA, highlighting its significance as a research hotspot. Aeromedical emergency rescue plays an irreplaceable role in swiftly responding to natural disasters and major accidents, which is why it is closely linked to Cluster #3 (the 2018 forest fires in Sweden) and Cluster #8 (the terrorist attacks on the World Trade Center in New York, USA). It is primarily applied in fields such as on-site emergency care, inter-hospital transfers, and rapid transportation of blood products and transplanted organs [20], all of which rely on a comprehensive aeromedical emergency rescue system, encompassing research on aeromedical emergency rescue policies, planning, infrastructure, and response mechanisms as covered by Cluster #6. Furthermore, Cluster #7, centered around the "Golden Hour" rescue concept first proposed by Maryland's medical helicopter rescue system in the USA [21], underscores the critical importance of surgical intervention within one hour of severe trauma, as it significantly improves survival rates and reduces disability rates.

The deployment of Automated External Defibrillators (AEDs) before the arrival of emergency medical services (EMS) has been proven to markedly enhance the survival rates of patients experiencing OHCA [22]. By leveraging drones to transport AEDs to OHCA scenes, we effectively tackle the "last mile" challenge in medical supply logistics [23], drastically cutting down the time rescuers need to access these critical devices. This marks a pivotal innovation in the realm of prehospital emergency care utilizing drones. Additionally, incorporating drone video footage to offer rescuers real-time guidance on CPR and AED defibrillation techniques has demonstrated improved therapeutic results [24]. Consequently, this has given rise to Cluster #10, which focuses primarily on "machine vision" and "drones" as its core research domains.

Table 1. A summary of largest clusters of co-citation references

Cluster ID	Size	Silhouette	Mean(Year)	Label(LLR)
#0	90	0.989	2009	out-of-hospital cardiac arrest; emergency department; international commission; world trade center disaster; case study
#1	54	0.994	2003	helicopter emergency; medical service; German helicopter emergency; medical system operation;

				incidents accident
#2	48	0.997	2005	cardiopulmonary resuscitation; compression-only cardiopulmonary resuscitation (CPR); non-cardiac aetiologies;
#3	47	0.944	2005	Swedish fire; rescue service; current concept; other advanced life support personnel; in-water resuscitation
#5	32	1.000	2002	King LT; flight crew performance; prehospital airway control techniques part; cricothyrotomy success rate; alternative airway device
#6	31	0.938	2008	emergency department; airway management; prehospital setting; trauma patient; possible risk factor
#7	31	1.000	2007	acute care surgeon; emergency surgery; surgical rescue; surgical patient; radiology department
#8	30	0.995	2007	world trade center disaster; international commission; disaster worker; acute stress disorder depression; tobacco use
#10	21	1.000	2015	computer vision; autonomous UAV flight safety; vision-based safe landing pipeline example; UAV search; marine casualty

3.1.2 Analysis of Core Literature in the Intellectual Base

The influential research findings within the emergency rescue knowledge domain are identified by examining the key literature that plays a crucial role in the clustering network of the intellectual base. Analyzing the literature with high citation frequencies or high betweenness centrality (i.e., core literature) helps to gain a clearer understanding of the intellectual base in popular research areas.

Papers with high citation frequencies can be considered as those frequently cited by researchers in their studies, often gaining milestone significance due to their groundbreaking contributions. Betweenness centrality refers to the number of times a node serves as a bridge between the shortest paths of two other nodes [25]. Papers with high betweenness centrality occupy an important structural position, meaning they connect other nodes or play a significant role across several different clusters. These papers can also be regarded as milestone research findings in the emergency rescue knowledge domain and are represented by nodes with purple circles in Figure 2. Figure 3 depicts the clustering network perspective on core literature, and the top 10 most cited references are listed in Table 2.

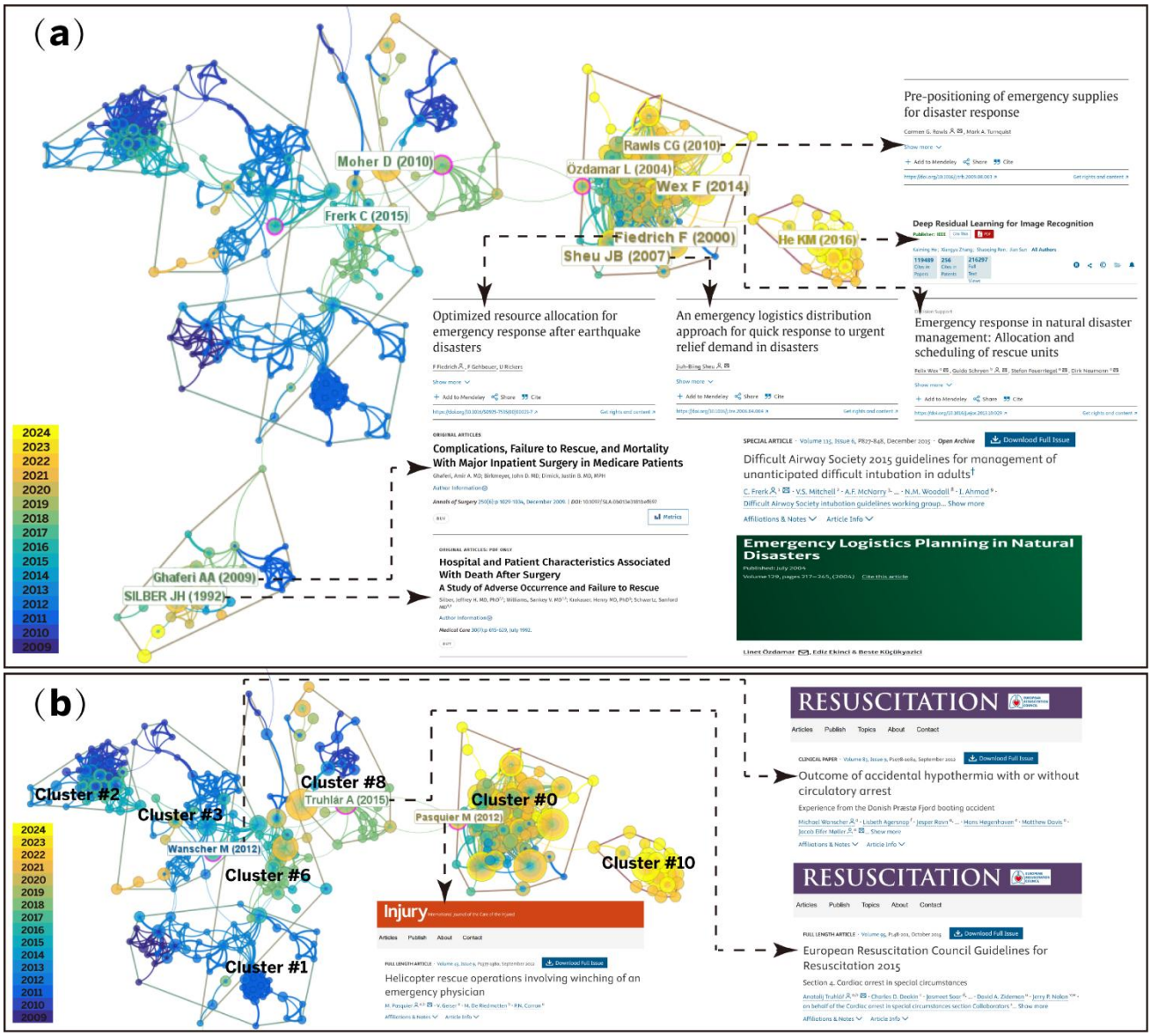

Figure 3. Local plot graph of reference information on key nodes between clusters. (a) high cited references; (b) references with betweenness centrality.

The citation frequencies of the top 10 references all exceed 30 times, with Cluster #0 containing 5 papers, Cluster #7 containing 2 papers, and Clusters #8, #6, and #10 each containing 1 paper. As shown in Figure 3(a), the research content of these 10 highly cited references in the emergency rescue knowledge domain mainly covers two aspects: seven papers focus on models and algorithms to address resource allocation and scheduling during natural disaster emergency responses, as well as rapid response and distribution issues in emergency logistics. The top three papers in this category are Fiedrich F (2000), Wex F (2014), and Sheu JB (2007); three papers are specialized medical literature focusing on postoperative mortality rates and tracheal intubation techniques, such as Silber JH (1992), Ghaferi AA (2009), and Frerk C (2015).

Table 2. High cited references as knowledge base articles of emergency rescue research.

Total citations	Publication year	First author	Source	Cluster
56	2000	Fiedrich F	SAFETY SCI	0
53	2014	Wex F	EUR J OPER RES	0
52	2007	Sheu JB	TRANSPORT RES E-LOG	0
50	2010	Moher D	INT J SURG	8
37	2010	Rawls CG	TRANSPORT RES B-METH	0

35	2016	He KM	PROC CVPR IEEE	10
35	1992	Silber JH	MED CARE	7
34	2009	Ghaferi AA	ANN SURG	7
34	2004	Ozdamar L	ANN OPER RES	0
32	2015	Frerk C	BRIT J ANAESTH	6

As shown in Figure 3(b), the three references with relatively high betweenness centrality come from Clusters #0, #3, and #8, respectively. The reference with the highest betweenness centrality, with a centrality score of 0.21, is Truhlář A (2015) [26], which focuses on resuscitation guidelines for cardiac arrest in special situations. These special situations mainly include specific causes such as oxygen deficiency, electrolyte disturbances, abnormal body temperature, and hypovolemia, as well as medically induced cardiac arrest scenarios, closely related to the main research content of Cluster #0.

It also covers disposal mechanisms and technical issues for cardiac arrest in special patients, such as those with severe complications, acute asthma, and pregnant women, which is closely linked to the research of Cluster #6. The primary emphasis of this paper lies on special environmental factors encountered in unique situations, encompassing both in-hospital contexts such as operating rooms, dialysis rooms, and catheterization laboratories, and out-of-hospital environments, including drownings, complex terrains, high altitudes, avalanches, lightning strikes, and mass casualty scenes involving cardiac arrest emergencies. Consequently, this reference is categorized under Cluster #8 and connects to Clusters #0 and #6. The second-ranked reference, with a centrality score of 0.19, is Pasquier M (2012) [27]. This paper delves into the epidemiological and medical impacts of utilizing a winch to transport emergency physicians to patients for immediate on-site rescue during helicopter-assisted mountain rescue missions. It has been revealed that this approach can markedly enhance emergency response efficiency, particularly in high-risk environments like mountains and ski resorts. Prompt medical intervention for patients experiencing out-of-hospital cardiac arrest is vital for survival. Consequently, this reference bridges Cluster #0 with Cluster #8, which is centered on disaster scenarios. The third-ranked reference, with a centrality score of 0.11, is Wanscher M (2012) [28], which focuses on cardiopulmonary resuscitation techniques for cardiac arrest caused by accidental hypothermia. This research is based on a real-life water accident case, the "Danish Præstø Fjord boating accident." A keyword in Cluster #3 is "water rescue," and thus, this reference establishes a connection between Clusters #3 and #2.

3.2 Research Trends in the Knowledge Domain of Emergency Rescue

3.2.1 Analysis of Evolutionary Characteristics of Research Fronts

A research front denotes an emerging and dynamic research direction or topic prevalent within a specific timeframe in scientific research [29]. Activities within these fronts not only yield novel scientific discoveries but also potentially spawn one or multiple new research fronts. However, once the "scientific puzzles" associated with these fronts are resolved or deemed insignificant, it signifies the end of the research front. Consequently, research fronts exhibit discontinuity, abruptly commencing and gradually concluding as scientists transition from one "puzzle" to another [30].

The timeline method was chosen to visualize the co-citation network within the knowledge domain of emergency rescue, as depicted in Figure 4. By comparing the time spans of diverse literature types on the timeline, we analyzed the emergence, peak, and decline of research fronts in this field, gaining insights into the evolution of emergency rescue research. Crucially, this approach aids in pinpointing potential future research fronts within the domain. In the timeline view, clusters were arranged from top to bottom based on their size. Literature within the same cluster was organized chronologically from left to right on the same horizontal line, clearly indicating the number of publications and their respective publication time spans within each cluster. The number of publications serves as an indicator of the cluster's field importance, while the time span reflects the cluster's duration.

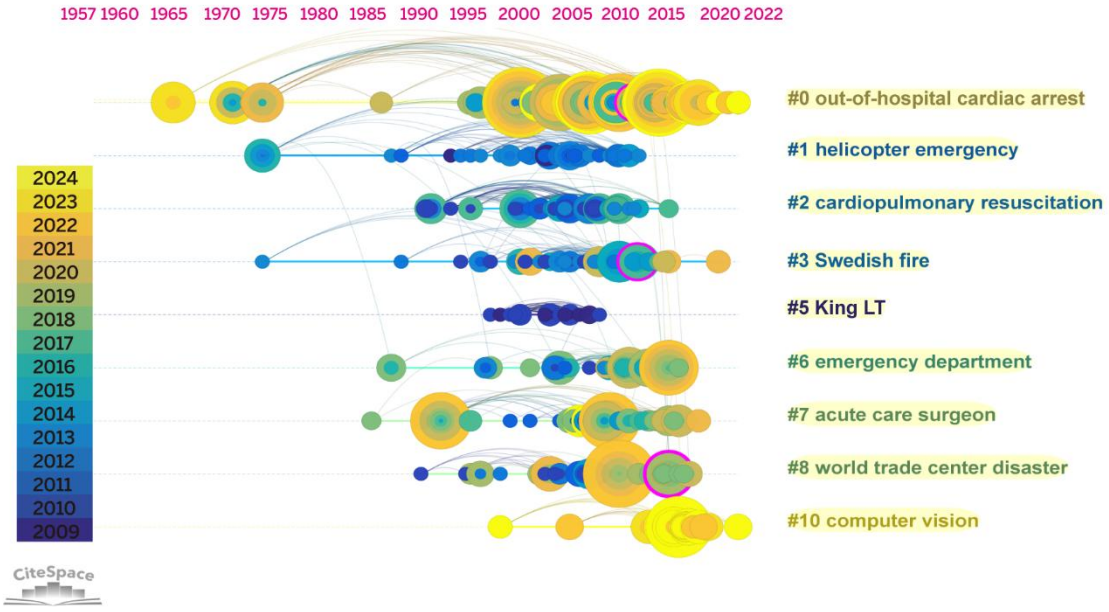

Figure 4 A timeline visualization of the largest clusters

As seen in Figure 4, the largest cluster in the co-citation network, Cluster #0 related to "Out-of-hospital Cardiac Arrest," has maintained an active research foundation for 57 years (1965-2022) and remains vibrant. Another cluster that remains active is Cluster #10, "Machine Vision," which began in 1998 and is among the newer research clusters among the nine major ones, with its research foundation continuing until 2022, indicating that recently published papers are still citing relevant references from this cluster. However, Cluster #5, associated with "King LT Laryngoscope," started around the same time as Cluster #10 in 1997 but lost attention after only 11 years (1997-2008), making it a declining research cluster.

Clusters #1 "Helicopter Emergency" (1974-2012), #2 "Cardiopulmonary Resuscitation" (1991-2015), #3 "Fire Disaster in Sweden" (1974-2020), #6 "Emergency Department" (1987-2016), #7 "Emergency Physicians" (1985-2018), and #8 "World Trade Center Attack" (1990-2017) belong to the category of research clusters that flourished within a certain period. Although these seven clusters surpass Cluster #10 in terms of both research duration and the number of articles, researchers' attention to their intellectual bases has gradually decreased after 2018, which is the opposite trend of attention to Cluster #10. Consequently, they are gradually transitioning into "outdated" research clusters.

The primary citing article information associated with the references in Cluster #10 is illustrated in Figure 5. The cited articles, published between 2022 and 2024, represent the cutting-edge of current research in the emergency rescue field. These articles primarily focus on several areas: victim search and rescue utilizing deep-learning-based human detection technology; addressing unmanned aerial vehicle (UAV) flight safety issues with computer vision technology; achieving automatic, accurate, and rapid object detection in UAV-captured imagery during disaster events, including the complex task of identifying small humans in maritime emergency rescue operations; and enhancing target detection in UAV thermal infrared (TIR) video streams through neural network-based algorithm optimization.

Broadly speaking, the evolution of a research field typically spans four stages: the nascent conceptualization stage (Stage I), the research capability augmentation stage (Stage II) characterized by the utilization of diverse tools for research purposes, the expansion stage (Stage III) where researchers extend their methodologies beyond the original domain, and the eventual decline stage (Stage IV) [31].

The main aspects of computer vision and UAV technology have matured and are widely utilized, such as path planning, navigation control, landing control, surveying and mapping, positioning, target detection/tracking, etc. The research front

focused on by Cluster #10 is not the primary aspects of these technologies mentioned above, but rather their applications in the field of emergency rescue, with potential for application in other fields such as film production, news gathering, wildlife monitoring, and so on. On the other hand, the research front of Cluster #10 also includes some algorithmic research. For instance, existing human detection models are only trained using everyday photos, which typically show full bodies. However, in real disaster scenarios, victims are often buried under rubble and only parts of their bodies are visible. Additionally, the colors of victims' skin and clothing often resemble the colors of surrounding dust and soil. These differences lead to unsatisfactory results when using human detection models trained on everyday photo datasets to detect disaster victims. This research falls under the category of continuously enhancing the maturity of technology, and thus Cluster #10 can be considered to be in a vigorous development stage between Stage II and Stage III.

The citing literature within Cluster #0, spanning the years 2014 to 2024, centers on the research front of resource allocation in disaster emergency rescue. Various techniques and methodologies have emerged, including the use of mixed-integer programming models for coordinating medical teams and supplies, integer programming for optimizing fire truck dispatch during forest fire suppression, and multi-objective optimization models based on updated disaster scenario information to determine emergency response vehicle routes and rescue supply allocation. Significant attention has been devoted to enhancing the effectiveness of models and algorithms in addressing OHCA scenarios within disaster settings. This represents Stage II of research capability growth within the OHCA research field. It is foreseeable that this cluster will maintain its vigorous development for an extended period.

The main citing literature for Cluster #1 was published between 2009 and 2013, focusing on the improvement of clinical outcomes for OHCA patients since the introduction of helicopter emergency medical services into civilian rescue systems. The main citing literature for Cluster #2 spans from 2010 to 2017, concentrating on issues related to the use of CPR techniques by lay rescuers in addressing non-cardiac OHCA. The main citing literature for Cluster #3, published between 2010 and 2017, revolves around the effectiveness of CPR administration to OHCA patients during water, avalanche, and mountain emergency rescues, based on local conditions in Sweden. The main citing literature for Cluster #5, published between 2009 and 2010, focuses on issues related to prehospital airway control techniques. Although CPR and early defibrillation are prioritized for OHCA patients, airway management remains a critical component of OHCA treatment.

The research fronts of the five aforementioned clusters are centered around OHCA. Specifically, Clusters #1, #2, and #5 concentrate on enhancing the survival rates of OHCA patients through various techniques and methodologies. Conversely, Cluster #3 emphasizes the enhancement of OHCA patient survival rates in diverse disaster scenarios, thereby extending the research into techniques and methodologies. From another vantage point, these five research clusters have not undergone decline or disappearance; rather, they have contributed to the synergistic development of Cluster #0 during its Stage II and potential Stage III.

Among the main citing literature of Clusters #6, #7, and #8, a small portion was published after 2020, representing relatively novel research fronts. Specifically, the newer research content in Cluster #6 focuses on airway management for critically ill patients in emergency departments. The newer research content in Cluster #8 centers on the intravenous administration of chlorpromazine or prochlorperazine for the treatment of acute migraine. Notably, Cluster #7 includes a literature published in 2024 that addresses the issue of close collaboration between medical personnel, firefighters, and police handler trainers during urban search and rescue operations, with the relevant citing literature also presented in Figure 5. Cluster #6 focuses on the treatment of various patient types in emergency departments, with critically ill patients being a particularly important subset. Cluster #8, on the other hand, focuses on individuals who developed acute stress disorder (ASD) following the "9/11" terrorist attacks, with migraine being a common clinical symptom among this population. The newer research frontiers in these two clusters

belong to methodological research within their respective fields and are at Stage II of scientific development. Cluster #7 focuses on "surgeons", and its latest research front clearly belongs to the expansion of this field, representing Stage III. Therefore, the possibility of continued development for these three clusters cannot be ruled out.

Figure 5. Number and publication years of references covered by main citing articles in each Cluster. Details of the latest citing articles in some Clusters are also shown in the figure.

3.2.2 Emerging Theme Analysis of Intellectual Base

CiteSpace identifies emerging themes by analyzing citation bursts within the literature. These citation burst articles are sourced through burst detection algorithms, which are methods used to model and pinpoint deviations in time series data that are notably distinct from the baseline state [32]. For example, a term might be extracted from the titles or abstracts of articles, and a graphical representation of its annual occurrence frequency over time would be plotted. The burst detection algorithm then pinpoints the time periods where the term's frequency spikes significantly above other times. Similarly, if the citation count of one article escalates rapidly, it is deemed to have undergone a citation burst. The emergence of a citation burst signifies that the scientific community is already focusing or is beginning to focus on the potential contributions of the content published in that article, thereby serving as a pivotal indicator for identifying emerging themes.

In the emergency rescue knowledge domain, there are 77 references with citation bursts. The top 25 with the strongest citation bursts are selected for analysis. Detailed information related to the parameters of citation bursts, such as the strength index, start time, and duration, is shown in Figure 6.

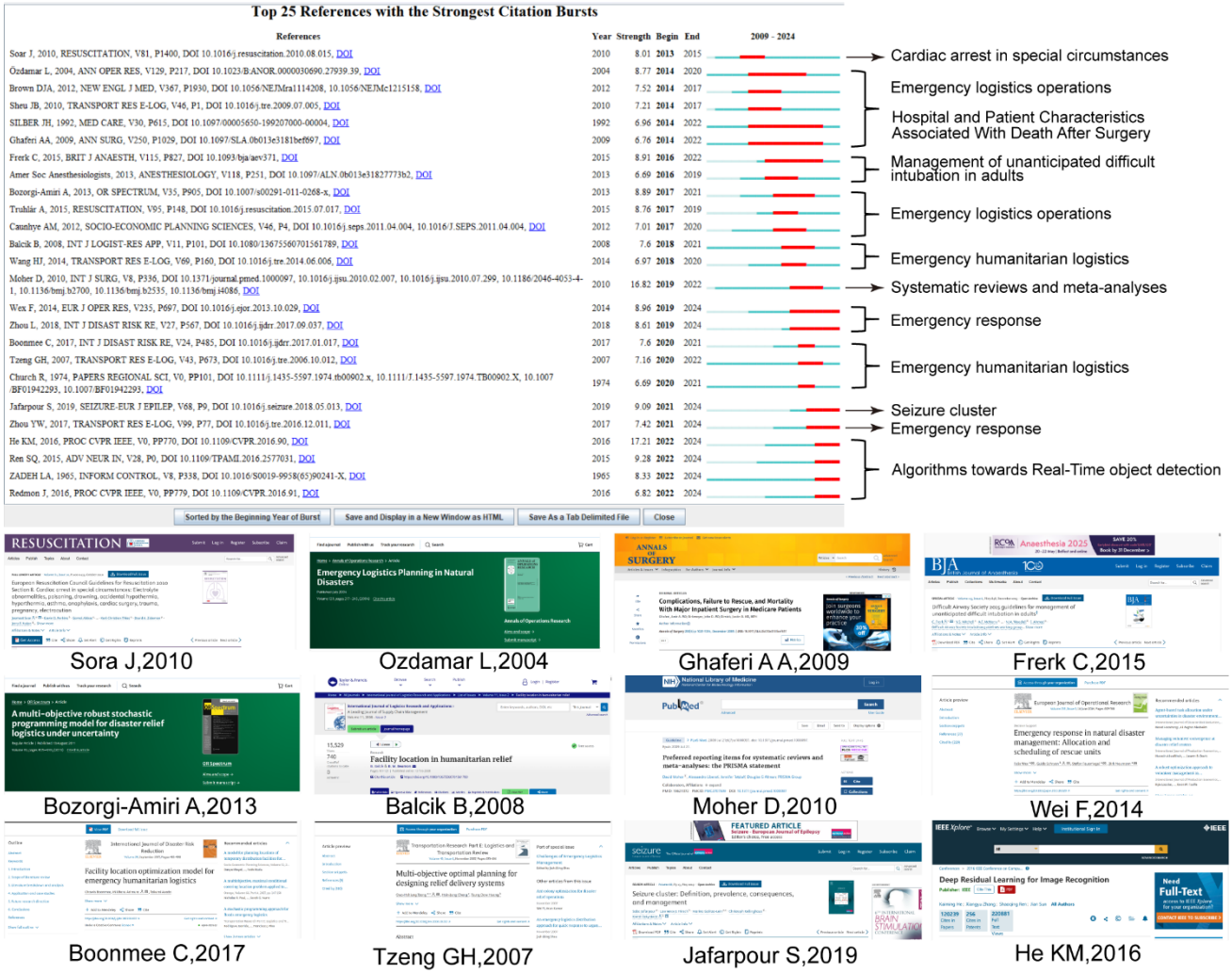

Figure 6. Top 25 references with the strongest citation bursts sorted by the beginning year of burst.

From the intellectual base dimension, the emerging theme in 2013 centered on CPR following OHCA in unique circumstances, predominantly in disaster scenarios such as poisoning, drowning, hypothermia, trauma, electric shock, etc. In 2014, the emerging themes encompassed two key areas: those with significant citation bursts emphasized logistics planning and modeling within disaster emergency responses, addressing the timely delivery of various items, including medical supplies, healthcare professionals, specialized rescue equipment and teams, food, and other essentials, to disaster zones and affected individuals; whereas those with prolonged citation bursts examined the correlation between surgical mortality and hospital and patient characteristics.

In 2016, research on intubation techniques for managing difficult airways in adults saw a notable citation burst. Subsequently, the emerging theme in 2017 shifted back to models and algorithms associated with emergency response, a trend that has persisted until 2021. Among the articles with the strongest citation bursts in 2017, 2018, and 2020, the primary focus was on model optimization. Specifically, the theme in 2017 involved optimizing disaster relief logistics distribution under uncertain conditions using a multi-objective robust stochastic programming model. In contrast, in 2018 and 2020, model optimization was more focused on humanitarian aid facility deployment.

The emerging themes in emergency response from 2019 to 2021 revolved around disaster emergency decision-making. Although these themes did not dominate in terms of citation bursts during those years, they demonstrated consistent citation growth and have endured to the present day, indicating their relevance as a key intellectual base at the forefront of current research. Notably, the study conducted by Wei et al.[33], which

utilized a disaster emergency decision-making model to tackle the allocation and scheduling of relief units, emerged as the most frequently cited (Strength=8.96) in emergency response modeling research spanning from 2017 to 2021. In 2021, there was a heightened interest in the "multi-period" optimization of emergency decision-making models, with a sharper focus on the nuances of disasters. This encompassed addressing practical challenges associated with multi-period emergency resource scheduling, particularly those stemming from the disruption of transportation systems due to infrastructure damage (such as roads) during disasters.

Serving as the foundation for clinical practice guidelines, systematic reviews and epidemiological meta-analyses centered on topics that garnered the highest citation burst strength in 2019. By 2021, the most cited articles in terms of citation burst intensity shifted attention to the definition, prevalence, risk factors of seizure clusters, and the efficacy of emergency medications in treating them, a trend that has continued to the present.

The research themes that emerged in 2022 have all continued to the present, primarily concentrating on algorithm research for target real-time detection applications, encompassing Deep Residual Networks (DRN), Region Proposal Networks (RPN), and the YOLO (You Only Look Once) algorithm. Fuzzy mathematics, which forms the theoretical bedrock for fields like pattern recognition, machine learning, and deep learning, has its origins in a groundbreaking paper titled "Fuzzy Sets" authored by American cyberneticist Professor L.A. Zadeh in 1965 [34]. In this seminal work, concepts such as "degree of membership" and "membership function" were introduced to delineate the intermediate transitions between differences and tackle fuzzy phenomena, predominantly addressing numerous ambiguous problems in the real world. Upon its release, this classic literature garnered sustained attention and has been extensively utilized across various domains as a branch of applied mathematics. In the emergency rescue knowledge domain, the literature witnessed a surge in citations in 2022.

Unlike Professor L.A. Zadeh's paper, some significant scientific discoveries and achievements were overlooked by the scientific community at the time and remained unnoticed until years later. In 2004, Dutch scientometrist A.F.J. Van Raan coined the term "Sleeping Beauty Literature" to describe such publications: a paper that experiences zero or low citations for an extended period after publication, akin to a sleeping beauty in a slumber, and then suddenly experiences a high citation rate later on, as if the sleeping beauty has been awakened. The literature that awakens the "Sleeping Beauty Literature" is referred to as the "Prince Literature" [35].

Drawing upon W. Glänzel's statistical insights regarding the timing of a literature's first citation [36], which indicate that over 90% of publications receive their initial citation within five years of publication, most scholars define the "initial publication period" as spanning 3-5 years. However, defining the threshold for "sudden high citation" varies widely, partly due to the significant disparities among different disciplines. Additionally, certain classic papers may not exhibit the "Sleeping Beauty" trait within the broader scientific landscape but do so within a specific discipline. Taking Professor L.A. Zadeh's seminal paper "Fuzzy Sets" as an example, since its publication in the Web of Science Core Collection, it has demonstrated a steady, linear growth in citations, amassing a total of 55,537 citations to date. This linear growth trend poses another significant challenge in identifying "Sleeping Beauty Literature". Hence, examining "Sleeping Beauty Literature" within the context of specific disciplines holds greater significance. Indeed, by scrutinizing citation bursts within the reference list, one can uncover "Sleeping Beauty Literature" within the emergency rescue knowledge domain. Among the top 25 references ranked by citation bursts, those experiencing citation bursts more than five years post-publication are designated as "Sleeping Beauty Literature" within the emergency rescue knowledge domain, as illustrated in Figure 7.

(a)

Top 25 References with the Strongest Citation Bursts

References	Year	Strength	Begin	End	2009 - 2024
He KM, 2016, PROC CVPR IEEE, V0, PP770, DOI 10.1109/CVPR.2016.90, DOI	2016	17.21	2022	2024	
Moher D, 2010, INT J SURG, V8, P336, DOI 10.1371/journal.pmed.1000097, 10.1016/j.ijsu.2010.02.007, 10.1016/j.ijsu.2010.07.299, 10.1186/2046-4053-4-1, 10.1136/bmj.b2700, 10.1136/bmj.b2535, 10.1136/bmj.i4086, DOI	2010	16.82	2019	2022	
Ren SQ, 2015, ADV NEUR IN, V28, P0, DOI 10.1109/TPAMI.2016.2577031, DOI	2015	9.28	2022	2024	
Jafarpour S, 2019, SEIZURE-EUR J EPILEP, V68, P9, DOI 10.1016/j.seizure.2018.05.013, DOI	2019	9.09	2021	2024	
Wex F, 2014, EUR J OPER RES, V235, P697, DOI 10.1016/j.ejor.2013.10.029, DOI	2014	8.96	2019	2024	
Frerk C, 2015, BRIT J ANAESTH, V115, P827, DOI 10.1093/bja/aev371, DOI	2015	8.91	2016	2022	
Bozorgi-Amiri A, 2013, OR SPECTRUM, V35, P905, DOI 10.1007/s00291-011-0268-x, DOI	2013	8.89	2017	2021	
Özdamar L, 2004, ANN OPER RES, V129, P217, DOI 10.1023/B:ANOR.0000030690.27939.39, DOI	2004	8.77	2014	2020	
Truhlár A, 2015, RESUSCITATION, V95, P148, DOI 10.1016/j.resuscitation.2015.07.017, DOI	2015	8.76	2017	2019	
Zhou L, 2018, INT J DISAST RISK RE, V27, P567, DOI 10.1016/j.ijdrr.2017.09.037, DOI	2018	8.61	2019	2024	
ZADEH LA, 1965, INFORM CONTROL, V8, P338, DOI 10.1016/S0019-9958(65)90241-X, DOI	1965	8.33	2022	2024	
Soar J, 2010, RESUSCITATION, V81, P1400, DOI 10.1016/j.resuscitation.2010.08.015, DOI	2010	8.01	2013	2015	
Boonmee C, 2017, INT J DISAST RISK RE, V24, P485, DOI 10.1016/j.ijdrr.2017.01.017, DOI	2017	7.6	2020	2021	
Balcik B, 2008, INT J LOGIST-RES APP, V11, P101, DOI 10.1080/13675560701561789, DOI	2008	7.6	2018	2021	
Brown DJA, 2012, NEW ENGL J MED, V367, P1930, DOI 10.1056/NEJMra1114208, 10.1056/NEJMc1215158, DOI	2012	7.52	2014	2017	
Zhou YW, 2017, TRANSPORT RES E-LOG, V99, P77, DOI 10.1016/j.tre.2016.12.011, DOI	2017	7.42	2021	2024	
Sheu JB, 2010, TRANSPORT RES E-LOG, V46, P1, DOI 10.1016/j.tre.2009.07.005, DOI	2010	7.21	2014	2017	
Tzeng GH, 2007, TRANSPORT RES E-LOG, V43, P673, DOI 10.1016/j.tre.2006.10.012, DOI	2007	7.16	2020	2022	
Caunhye AM, 2012, SOCIO-ECONOMIC PLANNING SCIENCES, V46, P4, DOI 10.1016/j.seps.2011.04.004, 10.1016/J.SEPS.2011.04.004, DOI	2012	7.01	2017	2020	
Wang HJ, 2014, TRANSPORT RES E-LOG, V69, P160, DOI 10.1016/j.tre.2014.06.006, DOI	2014	6.97	2018	2020	
SILBER JH, 1992, MED CARE, V30, P615, DOI 10.1097/00005650-199207000-00004, DOI	1992	6.96	2014	2022	
Redmon J, 2016, PROC CVPR IEEE, V0, PP779, DOI 10.1109/CVPR.2016.91, DOI	2016	6.82	2022	2024	
Ghaferi AA, 2009, ANN SURG, V250, P1029, DOI 10.1097/SLA.0b013e3181bef697, DOI	2009	6.76	2014	2022	
Church R, 1974, PAPERS REGIONAL SCI, V0, PP101, DOI 10.1111/j.1435-5597.1974.tb00902.x, 10.1111/J.1435-5597.1974.TB00902.X, 10.1007/BF01942293, 10.1007/BF01942293, DOI	1974	6.69	2020	2021	
Amer Soc Anesthesiologists, 2013, ANESTHESIOLOGY, V118, P251, DOI 10.1097/ALN.0b013e31827773b2, DOI	2013	6.69	2016	2019	

Sorted by Strengths of Burst | Save and Display in a New Window as HTML | Save As a Tab Delimited File | Close

(b1)

First Author	Affiliation	Title
Kaiming He	Microsoft Research	Deep Residual Learning for Image Recognition
David Moher	Ottawa Hospital Research Institute	Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement
Shaoqing Ren	University of Science and Technology of China	Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks
Linet Özdamar	Nanyang Technological University	Emergency Logistics Planning in Natural Disasters
Lofti A Zadeh	University of California	Fuzzy sets

(b2)

First Author	Affiliation	Title
Burcu Balcik	University of Washington	Facility location in humanitarian relief
Gwo-Hshiung Tzeng	Kainan University	Multi-objective optimal planning for designing relief delivery systems
Silber Jeffrey H	The University of Pennsylvania	Hospital and Patient Characteristics Associated With Death After Surgery A Study of Adverse Occurrence and Failure to Rescue
Joseph Redmon	University of Washington	You Only Look Once: Unified, Real-Time Object Detection
Richard Church	The Johns Hopkins University	The maximal covering location problem

Figure 7. Sleeping beauty of emergency rescue domain. (a) References with citation bursts sorted by strengths;(b1)-(b2) Details of sleeping beauty paper.

There isn't yet a single, accepted definition of "Prince Literature." According to bibliometrics, "Prince Literature" typically has a number of typical traits, including having cited "Sleeping Beauty Literature," being published around the time of the citation burst, having a comparatively high number of citations, and showing a notable "pulling effect" on "Sleeping Beauty Literature."

Taking the Sleeping Beauty literature with the largest citation burst strength as an example, He et al.[37] first proposed the deep residual network (DRN) algorithm in 2016. The core idea was to address the gradient vanishing/exploding problem encountered in the training of deep neural networks, with potential application areas highlighted as image recognition. However, this article received zero citations within the emergency rescue knowledge domain (5,683 citing articles) for six years after its publication, until a sudden citation burst occurred in 2022. An analysis of the highly cited articles within the period of the citation burst for He et al.'s paper (i.e., 2022-2024) reveals that the cited articles focused on issues related to image recognition of victims during emergency rescue operations using drones. These citing articles can all be considered as Princes awakening the Sleeping Beauty. The awakening schematic is shown in Figure 8. Therefore, for Sleeping Beauty literature, its corresponding Prince literature actually consists of multiple citing articles, forming a "Sleeping Beauty-Prince" literature set. This set plays a significant role in identifying classic literature within the emergency rescue knowledge domain and constructing the mapping relationship between the intellectual base and research fronts in this domain.

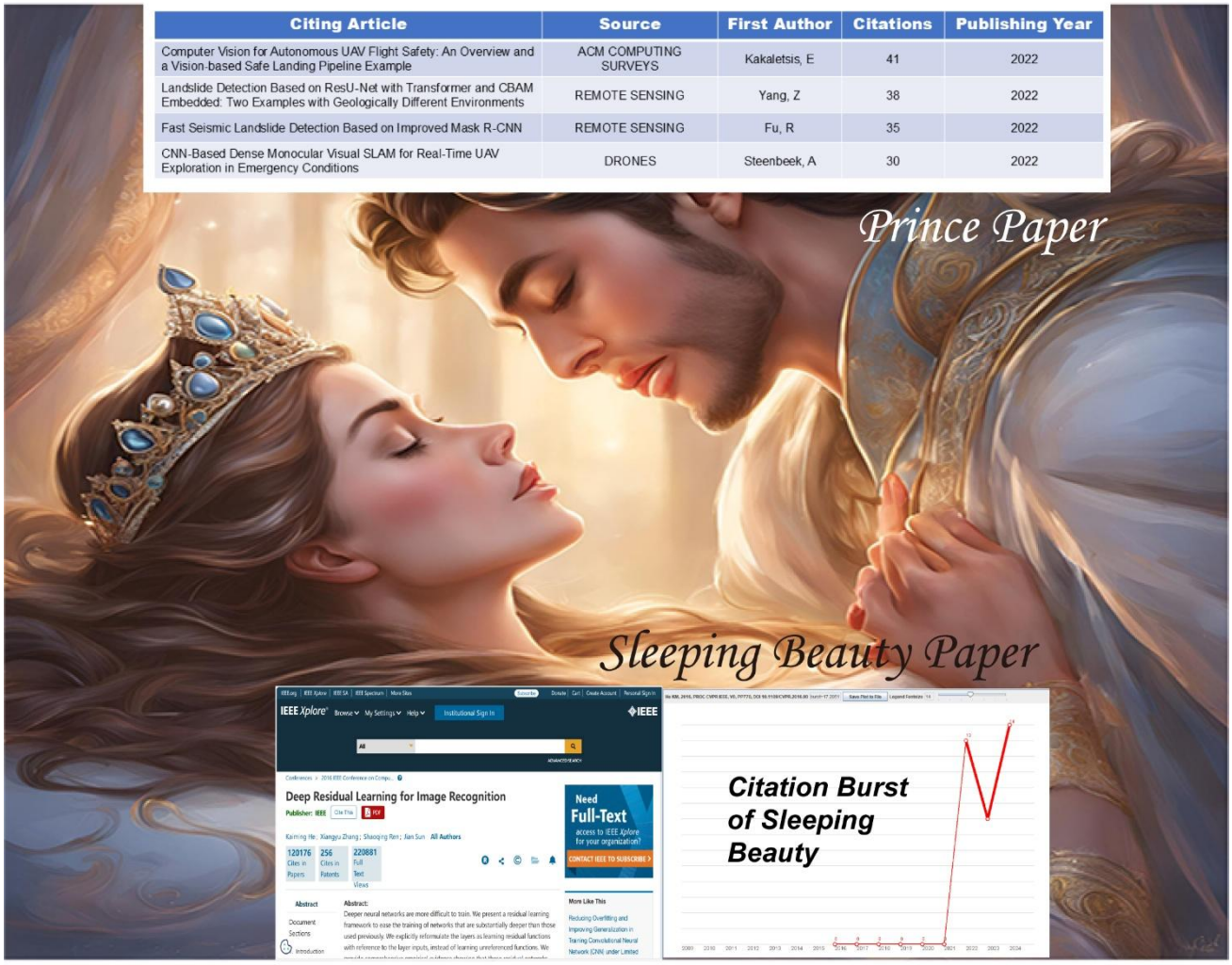

Figure 8. Schematic representation of the arousal relationship between sleeping beauty and prince paper.

3. Conclusions

Addressing the prevalent shortfall of comprehensive literature reviews and visual analyses in the field of emergency rescue from a holistic viewpoint, this study utilized CiteSpace to undertake a co-citation analysis of research papers pertaining to the emergency rescue knowledge domain, which are indexed in the Web of Science database. The objective is to delve into the thematic clustering traits, pivotal core literature, and the progression of research fronts within this knowledge domain, while also establishing a holistic "intellectual base-research front" mapping relationship for emergency rescue. The principal conclusions derived from this study are outlined below:

(1) The research foundation in the emergency rescue knowledge domain can be divided into nine clusters. Among them, Out-of-Hospital Cardiac Arrest (OHCA) is a global public health issue, thus forming the largest cluster. The other eight clusters focus on emergency rescue research related to OHCA, mainly covering cardiopulmonary resuscitation, aeromedical emergency rescue, and the use of drones for emergency rescue, which encompass various aspects of emergency rescue, including scenarios, technologies, personnel, and corresponding system construction.

(2) Among the top 10 most cited references, 70% focus on research combining models and algorithms with emergency rescue scenarios, while 30% relate to medical field studies. Three of these references exhibit significant betweenness centrality, effectively integrating research content on victims, rescuers, and corresponding medical technologies in emergency rescue scenarios.

(3) OHCA (Cluster #0) represents a continuously active research front within the emergency rescue knowledge domain. Considering the temporal span of both cited and citing literature, the evolution of research fronts in this domain

initially revolves around prehospital airway control techniques and related airway management studies (Cluster #5). Subsequently, it transitions through research on the effectiveness of helicopters in emergency rescue (Cluster #1), the impact of CPR performed by lay rescuers (Cluster #2), and the reliability of CPR in special disaster scenarios (Cluster #3). This progression gradually leads to studies on airway control techniques for critically ill patients in emergency departments (Cluster #6), collaborative rescue efforts between surgeons and firefighters or police (Cluster #7), and the treatment of migraines in ASD populations triggered by a disaster event (Cluster #8). With further evolution of the knowledge domain, the current cutting-edge research front focuses on computer vision and algorithms utilizing drones as a platform for emergency rescue (Cluster #10).

(4) By selecting the 25 most highly cited references with the strongest citation bursts as typical representatives of the intellectual base, it was found that the emerging themes within the intellectual base exhibit temporal evolution characteristics, primarily in terms of disaster emergency response and medicine. As for disaster emergency response, the emerging themes between 2014 and 2021 focused on model establishment and optimization: specifically, emergency logistics planning in 2014 and 2017; humanitarian aid facility deployment in 2018 and 2020; and disaster emergency decision-making in 2019 and 2021. Starting in 2022, the emerging themes in disaster emergency response have gradually evolved towards algorithm research serving real-time target detection applications. On the medical front, the emerging themes evolved through various stages, including CPR techniques for OHCA patients in special situations in 2013; the correlation between surgical mortality and hospital and patient characteristics in 2014; intubation techniques for difficult adult airway cases in 2016; comprehensive analysis of systematic reviews and epidemiological meta-analyses in 2019; and seizure cluster in 2021. Among these, disaster emergency decision-making models, theories of seizure clusters, and real-time target detection algorithms are currently hotspots within the intellectual base.

Acknowledgements

Financial support by Natural Science Foundation of Hebei Provence (E2023507001), Science and Technology Program of Guangdong Province (2023A1111120002), Key R&D Program of Hebei Province (22375417D), National Natural Science Foundation of China (52174224,51804314).

Declaration of Interest Statement

The authors declared that they have no conflicts of interest to this work.

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