Massey University

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Location Data: Mapping, Analysis and Visualisation

Assignment 2: Spatial Analysis Research Review

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Spatial Analysis Research Review

Article: "**Empirical assessment of road network resilience in natural hazards using crowdsourced traffic data**"

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1. Summary of main points

The study Qiang and Xu (2019) conducted provides an innovative empirical framework using crowdsourced data sources for evaluating the resilience of road networks during natural disasters. Their research measures the impact of natural disasters on road networks using GoogleMaps real-time traffic data. The main research problem being addressed is lack of empirical methods for real-time, location focused assessment on how roads and infrastructure reacts to extreme weather events, "in a case study of the Cleveland metropolitan area (Ohio) in Winter Storm Harper". Thus, their approach extends traditional methods which rely mainly on post-event analysis and simulations rather than real-time analysis and cannot capture the dynamic nature of real disaster scenarios.

The authors propose a novel empirical approach methodology, using the Hansen accessibility index (Hansen, 1959) and "conceptualization of resilience", to measure transport system networks resilience based on the "accumulated accessibility reduction" over time during a hazard event. This approach allows to measure how travel time to essential locations is affected in real-time, thus immediate and dynamic. It also involves lower cost compared with traditional data collection. However, quality, accuracy and coverage may vary, thus there is less control on collecting reliable data.

The case study during Winter Storm Harper in Cleveland not only leverages real-time crowdsourced data collection, but also refers it as a methodological innovation. They demonstrate the utility of real-time data assessing road network resilience during extreme weather events, distinguishing the study from traditional methods. The researchers identified considerable spatial differences in the performance of road networks within the Cleveland area, drawing insights how different areas displayed various levels of resilience during and recovering from the storm. Areas further away from essential services noted increased disruptions.

It is reported that lower socioeconomic communities displayed reduced resilience, indicating weaker recovery capacity, thus both community resources and geographic location have considerable impact on resilience of road networks.

Researchers contribute also with insights for transportation planning and disaster management, by clustering more vulnerable areas. These insights can provide important value for more effective assessment of road networks, as well as for strategic planning, and improved response and recovery, with the goal of reducing the impact of future hazards.

The authors suggest their methodology could benefit and apply to other types of natural disasters and may be extended to different geographic locations. Future research could include a larger data collection, over longer periods and more frequent, providing more accurate and detailed analysis of resilience and across different periods of hazard events.

This study integrates real-time crowdsourced traffic data and provides location specific road network resilience metrics, which has been missing in the empirical assessment, hence contributing to the field of geographical information science.

In summary, Qiang and Xu (2019) contribute with a robust novel framework to the empirical assessment of road network resilience. Simultaneously, they improve current methodologies available for the geospatial analysis in the case of extreme weather events. Study utilises innovative crowdsourced data to provide critical real-time insights aiding more informed and targeted interventions. It provides policymakers with tools to maintain and recover essential transport infrastructure during weather emergencies, but also tools for aiding communities facing higher risks from natural hazards.

2. Discussion about the problem addressed in the paper

Qiang and Xu (2019) research address an important problem, assessing and improving resilience of road networks during extreme weather events. They employed real-time crowdsourced traffic data collected from GoogleMaps, which allowed analysing how the road infrastructure coped and recovered from these weather hazards. This issue becomes even more relevant as urban areas worldwide are facing more frequent and severe weather due to climate change. It is a necessity that road networks remain functional for emergency response and public safety. Researchers address this using a novel framework that integrates spatial analysis which dynamically evaluates impacts and provides prompt assessment of road systems.

The road network resilience problem is not recent and has been broadly researched from different angles within the GIS and transportation planning fields. Berdica (2002) expanded the definition of road vulnerability to include disruptions in service levels beyond simple safety issues, which closely relates to this paper's focus on "service continuity" during weather disruptions. Similarly, Calvert and Snelder (2017) introduced a methodological framework to evaluate traffic resilience, which validates the importance of such assessments in transportation networks.

Furthermore, real-time data use in transportation analysis has been gaining more traction lately, demonstrated by Nair *et al.* (2019) and Hu *et al.* (2023) studies. This trend highlights a move towards leveraging big data technologies in transportation, as Lu *et al.* (2015) work predicting traffic flow states, and in Bi *et al.* (2023) use of advanced classification techniques for real-time traffic analysis.

This research's importance and impact comes from the ability to improve infrastructure planning and disaster response by providing a real-time metrics framework. Their approach allows for immediate responses during disasters, possibly reducing the severity of their impact on public safety, normal life and economic activities, especially within urban areas.

Implementing this research may help influence global efforts to reduce the effects from natural disasters on essential infrastructure. For example, the "depth-disruption function" created by Pregnolato *et al.* (2017), along with increased focus on optimised traffic guidance after disasters (Kaviani *et al.*, 2017), are practical tools that could be combined with Qiang and Xu framework. These could improve prediction capabilities and strategic response planning.

Challenges originating from climate change have led to increased need for researching the resilience of transportation networks. Koetse and Rietveld (2009) provide a thorough view of how transport systems globally are likely to be impacted by climate variations, concluding on the need for resilient infrastructure.

Additionally, the methodology for analysing intra-network dependence as discussed by der Sarkissian *et al.* (2020), and the assessment of vulnerability to widespread disruptions by Jenelius and Mattsson (2012), increase the relevance of Qiang and Xu's research. Studies like these illustrate the broad applicability of their work across different climatic conditions and geographic locations.

In short, the problem addressed by Qiang and Xu has been widely researched but remains critical due to its relevance to global challenges in urban planning, need for climate change solutions and disaster management. Their innovative use of real-time crowdsourced data to improve road network resilience shows a significant progress in the field, offering novel tools that could lead to more robust, flexible and resilient transportation networks worldwide.

3. Discussion about the analysis method

Qiang and Xu (2019) introduced a novel method to analyse road network resilience during natural disasters, by leveraging real-time crowdsourced traffic data. Their method uses spatial analysis, allowing dynamic assessment how infrastructure responds against severe weather events by measuring accumulated accessibility reduction over time. This method is increasingly relevant as cities increasingly adapt to climate change and urban growth challenges.

Previously, road network resilience was assessed a posteriori, post-event evaluation using historical data and simulations. For instance, Jenelius and Mattsson (2012) used a structured analysis approach to understand vulnerability across large areas during disruptions, focusing on how different parts of a network handled large-scale hazards, like storms and floods. Similarly, Calvert and Snelder (2017) developed a methodology for resilience analysis that looked at a network resistance to disruptions and also its ability to recover, using traffic data to evaluate network performance under different stress scenarios.

However, this paper's method sets itself apart by incorporating real-time data, which allows for instant assessment and response. This is a clear contrast with prior methods, like those employed by Berdica (2002), which did not use live data and suffered from lag between data acquisition and analysis.

This novel use of real-time data is supported by recent works of other field researchers like Hu *et al.* (2023) and Nair *et al.* (2019), who also use crowdsourced live data to quickly assess traffic dynamics under both normal and disruptive conditions to provide relevant insights.

Additionally, the spatial component of their analysis, which helps understand how different sections of the road network react to natural disasters, is supported by technologies similar to those used by Lv *et al.* (2015) and Hu *et al.* (2023). These researchers employed big data and advanced classification techniques for predicting traffic flow and perform real-time traffic analysis. These methods highlight an increasing trend and shift towards including multiple sources (Wang *et al.*, 2020), more detailed and live data in transportation planning and disaster response strategies.

Nonetheless Qiang and Xu's real-time spatial analysis approach appears to be highly effective for immediate disaster response, other types of analysis could also complement and enhance the insights provided by their study.

For instance, predictive analytics using machine learning (ML) models to predict effects and impacts various weather hazards have on road networks could improve predictive capabilities, aiding proactive disaster planning (Lv *et al.*, 2014; Venkatesh *et al.*, 2022). Techniques like Zhou *et al.* (2017) used could analyse how weather changes affect public transportation usage and overall mobility, leading to more targeted resilience strategies. Additionally, the depth-disruption function developed by Pregnolato *et al.* (2017), could complement the live data by predicting how specific flood depths might impact road use, providing more detailed perspective of flood disruptions. Furthermore, integrating Der Sarkissian *et al.* (2020) intra-network dependency analysis, which looks at resilience through the intra-network dependencies could offer more insights into how different segments of a network interact and together affect the overall network resilience during disasters.

In conclusion, this method represents a step forward in transportation resilience field, moving beyond traditional approaches adopting real-time data integration and spatial analysis. This approach aligns with current technological progress and sets a new benchmark for dynamic, responsive urban planning and disaster management. Adding further analytical techniques could broaden this research capabilities, improving our ability to predict and mitigate the impacts of natural disasters on road networks.

4. Discussion other analysis method applications

The researchers introduced a new method of analysis using GoogleMaps real-time traffic data for assessing road network resilience during natural hazards. This novel method provides a dynamic framework adaptable to different data types and research questions across different application areas.

This study integrates historical NOAA[1] weather data and suggests integrating space-time prisms, thus incorporating real-time meteorological data could significantly improve the live resilience assessments. As Koetse and Rietveld (2009), Zhou *et al.* (2017) illustrated, weather has considerable impact on transportation systems. Hence, combining weather and traffic live data, could lead to more immediate and accurate insights during natural hazards, improving emergency response and urban planning (Zhang and Kabuka, 2018). Incorporating various other data sources, such as IoT sensor data from vehicles and roads, social media sentiment and traffic conditions, tracking mobile GPS navigation data plus additional real-time traffic data sources, would improve the live assessment of the network resilience and recovery.

Furthermore, expanding the research to include more socioeconomic data could also be beneficial, as Pregnolato *et al.* (2017) demonstrated. Qiang and Xu also suggest socioeconomic factors have significant influence how communities are affected and recover from hazard events. This integration could allow more tailored equitable strategies.

Implementing predictive analytics and ML models can also provide enhanced insights. As Hu *et al.* (2023), Zhang and Kabuka (2018), Lv *et al.* (2014), and Venkatesh *et al.* (2022) suggest, these approaches could transform how cities prepare and respond to natural disasters, leading to proactive rather than reactive planning.

Additionally, this method could use spatial analysis and prior weather hazards to simulate disaster scenarios refining their real-time data, improving emergency response strategies. By predicting how road networks behave under different stress conditions, would lead to better planning and design of effective evacuation routes, emergency healthcare access

[1] NOAA: National Oceanic and Atmospheric Administration, an American scientific agency.

and response resource allocation (Kaviani *et al.*, 2017). Identifying areas with low road network resilience allows urban planners to prioritise infrastructure upgrades and maintenance to enhance overall resilience, as per Berdica's (2002) discussion on road vulnerability.

This methodology could also explore how urban design and landscape influences road network resilience during disasters. Investigating how various urban landscapes and infrastructure designs increase or decrease the impact of natural disasters, could provide important information for more resilient urban planning, as explored by Martín *et al.* (2021). Similarly, assessing environment and long term climate change impacts on road network resilience could aid planning more robust infrastructures and networks. Koetse and Rietveld (2009) discuss that understanding these impacts is crucial preparing for expected climate patterns and their effects on urban areas.

Policymakers could leverage the insights of these analyses to justify infrastructure investments. Having an understanding how specific disasters impact road networks allows for a better allocation and use of funds and resources focusing on higher risk areas, mitigating the impact and recovery of disasters. It can also benefit other multi-hazard events, such as large public event planning which affects daily traffic and crowd management, or optimising non-weather related emergency management (seismic events, fires, industrial accidents, etc).

In summary, the method Qiang and Xu used is flexible and can likely be adapted to address a wide range of research questions and different application areas. Its novel use of real-time crowdsourced data improves current resilience assessments, and simultaneously offers potential use for a MCDA[2] improving transportation planning and disaster management. This approach sets a new benchmark for dynamic, responsive urban planning and disaster readiness.

[2] Multi-Criteria Decision Analysis

5. Opinion about the paper

The research paper by Qiang and Xu (2019) offers a significant contribution to GIS and transportation planning, especially in the disaster management field. Addresses the important topic of how road network resilience cope during natural disasters using a novel data-driven approach.

The methodology is innovative, leverages GoogleMaps real-time crowdsourced traffic data to assess how road networks handle and function under the stress of natural hazards. It significantly improves previous methods that only rely on simulations or historical data, leading to dynamic and accurate evaluation of road networks.

The relevance of this research is undeniable, moreover as in recent years natural disasters are becoming more frequent and intense due to climate change. The crucial real-time data collection is highly relevant for improved disaster responses and urban planning.

There is considerable scientific contribution, filling a gap in existing literature by introducing a novel method to quantify road network resilience. It expands GIS applications in disaster management whilst offering an adaptable framework to different natural hazards and different geospatial locations and contexts.

The clarity of the paper is another strong point. The paper is well written and logically organised with clear sections guiding the reader throughout, from introduction to conclusion. The use of the Hansen accessibility index and the thorough explanation of data collection and analysis methods makes the paper clear and easy to understand.

Conversely, the generalisation of the findings could however become a limitation. The research is based on a case study in Cleveland and the specific geographical and socioeconomic characteristics of this area may not be relevant nor directly apply to other areas or different kinds of hazards.

Similarly, reduced data collection due to budget constraints and reliance on GoogleMaps data has drawbacks. The accuracy and completeness of crowdsourced data can vary and might lead to biased results.

The paper mentions socioeconomic factors related to resilience but could explore this further. A more detailed analysis of how socioeconomic status influences resilience could provide more valuable insights, especially for policymakers and urban planning.

Incorporating more types of data sources such as IoT sensor data and cooperating with emergency services could improve the robustness and depth of the resilience assessments, helping confirm crowdsourced data accuracy and adding extra context information.

Expanding research to include more diverse case studies, different hazards, geographic and socioeconomic backgrounds would improve generalisation of the results. Studies including and comparing urban and rural or different climate regions could help understand how the framework applies in different areas.

A broader exploration of socioeconomic backgrounds focusing on influence some specific communities, and cooperating with them on what potential interventions should be taken, could offer practical strategies for improving resilience.

Using advanced GIS visualisation tools to present data and findings could make the results easier to understand and interesting for a broader audience, including the public and policymakers.

In conclusion, Qiang and Xu's paper is a valuable addition to disaster management and GIS literature, introducing an innovative methodology for assessing road network resilience. While there are areas for further development, in particular regarding data diversity and socioeconomic studies, the research sets a strong foundation for future work and practical implementations in disaster readiness and urban planning.

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