Road Networks during Mega Sport Events

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Hosting a successful Mega Sport Event (MSE) such as the FIFA World Cup (WC) is a formidable expedition, especially under adverse challenges such as climate change and rapid urbanization. Today, more than half of the world's population lives in cities, and experts expect this number to reach two-thirds of the world's population by 2050. This accelerated urbanization trend has led to capital concentration in cities, converting them into development hubs. However, in many cases, ill-planned expansions increased loads on infrastructure and caused degradation in service quality. At the same time, political tensions and climate change have increased the rate, intensities, and impacts of disasters in recent years, adding more loads on the infrastructure systems. These challenges have caused a paradigm shift in design mentality and fueled the research in infrastructure resiliency in the past decade. Hosting a successful MSE with tremendous popularity, such as the WC, is an important milestone in any nation's history and a testimony to its capabilities and development. However, a critical factor in organizing a successful event of such a scale is a robust and efficient transportation network that can accommodate the influx of a huge number of fans and preserve functionality under perplexing and unpredictable threats; in other words, a resilient transportation system is required.

Keywords: management of Mega Sport Events (MSE)

1. Introduction

Hosting a successful Mega Sport Event (MSE) such as the FIFA World Cup (WC) is a formidable expedition, especially under adverse challenges such as climate change and rapid urbanization. Today, more than half of the world's population lives in cities, and experts expect this number to reach two-thirds of the world's population by 2050 [1]. This accelerated urbanization trend has led to capital concentration in cities, converting them into development hubs [2][3][4]. However, in many cases, ill-planned expansions increased loads on infrastructure and caused degradation in service quality [5][6][7]. At the same time, political tensions and climate change have increased the rate, intensities, and impacts of disasters in recent years, adding more loads on the infrastructure systems [8][9][10]. These challenges have caused a paradigm shift in design mentality and fueled the research in infrastructure resiliency in the past decade [3][4][11][12]. Hosting a successful MSE with tremendous popularity, such as the WC, is an important milestone in any nation's history and a testimony to its capabilities and development [13]. However, a critical factor in organizing a successful event of such a scale is a robust and efficient transportation network that can accommodate the influx of a huge number of fans and preserve functionality under perplexing and unpredictable threats; in other words, a resilient transportation system is required.

2. Resiliency in Transportation Systems

Resiliency is a relatively new concept in the engineering field with varying definitions and assessment methods. The first mention of system resiliency in the academic literature is by Holling [14] in 1973, where the term is used to describe an ecological system's ability to regain its original state after a disturbance. However, the concept only found its way to urban planning and engineering literature about two decades ago because of the increasing amount of unpredictable disasters and their impacts, especially with an ever-growing capital concentration in urban centers [3][15][16][17][18]. So far, there is no consensus on the definition of resiliency in engineering systems and critical infrastructures, which is attributed to the varying nature of threats and assessment frameworks [3][15][17]. According to various researchers, resiliency is a combination of several systems' properties, most notably, vulnerability, robustness, flexibility, and reliability, that describe its response and reaction to disturbances [19]. Despite the variance, most definitions proposed in the literature converge at two qualities to measure system resiliency, impact resistance, and the amount of time required for recovering an acceptable performance [3].

Transportation system resiliency assessments are distinct from other critical infrastructure resiliency assessments. For instance, water and electrical infrastructures have a directed continuous flow with a source-sink theme [3][20][21][22], while communication infrastructure has area coverage and wireless connectivity in most urban areas [3][23]. On the other hand, transportation networks usually enjoy two-way connectivity, especially on highways and main roads, with no main, distinguished source-sink [12][24][25]. Furthermore, transportation networks enjoy a discrete nature of flow, which allows for the usage of methodologies, such as agent-based modeling and simulation, to assess their performance and resiliency [26][27][28].

However, the level and scale of the transportation network that is under investigation can profoundly affect the resiliency assessment method. Many methods are proposed in the literature, ranging from analytical methods to simulation and even logical methods, depending on the available resources and addressed threats, whether it is a natural disaster, an intentional attack, something else that is affecting the city's network, or an origin-destination group of links [12][17][29]. Simulation methods, such as agent-based or Monte Carlo simulations, can provide high-resolution results that can be used to assess the effectiveness of various improvements under different scenarios, but they are resource-demanding, hard to scale up, and need calibration to reflect the real world, which makes them only suitable for small-scale networks or networks with a limited number of elements and links [30][31]. Logical methods, such as optimization and game theory, and their applications, are mainly used to address intentional attacks or to draft informed development strategies, depending on the informed payoff value; however, the accuracy of the mathematical formulation of the impacts, each strategy's actual cost, and the probability of predicting each side behavior affects their feasibility [32][33][34]. Analytical methods include complex networks theory (CN) and simple performance measurements, such as pace and shortest path length; these are the most often-used methods in resiliency studies since they are the least resource-demanding and provide metrics with a reasonably acceptable level of accuracy [35][36][37][38][39].

CN can form the base for other methods and even leverage other disciplines and technologies. CN provides a simple yet efficient abstract of a network's components and their relationships, allowing for the analysis of these relations by other methods, such as game theory or Monte Carlo simulations [30][40]. This combination of methods can significantly reduce the computational resource demands and provide comparability between various methodologies [39][41][42]. Moreover, CN can leverage other technologies, such as geographic information systems (GIS), to give the network abstract spatial meaning and more accurate representations [43][44]. This coupling of GIS with CN also allows for scenario simulations, using powerful GIS spatial analysis tools, and reflects the results on the network's connectivity and centrality measures. This application is widely applied in the literature [5][45][46]. Furthermore, GIS can measure the shortest paths and the levels of walkability in areas of interest, giving the abstract further information or weighting other than the normal connectivity of links; this potential could be employed to measure the effect on the commuting time between points of interest and used as an additional resiliency metric [47][48][49].

3. Mega Sports Events and Resilience

Mega Sport Events (MSEs) present a great opportunity and a formidable challenge to the host nation. Hosting an MSE presents a possibility of boosting the economy in multiple sectors, including tourism and construction, and creating a lasting legacy for the nation [13][50][51]. On the other hand, it also requires renovating infrastructures to meet the sudden increase in demands that is presented by the influx of spectators (which, in the case of the 2022 FIFA WC in Qatar, is expected to reach 50% of the population) without creating "white elephant projects" [13][52][53]. Furthermore, host nations are increasingly expected to apprehend strict environmental obligations and are encouraged to achieve carbon neutrality, promoting a trend of compact MSEs, as in the 2022 WC in Qatar, where all the stadia are within the Doha metropolitan area and the furthermost distance between venues is less than 60 km [13][52][54]. This compactness means concentrating the demands on the supporting infrastructures throughout the event, which in the WC case, extends over a month, and ensuring that these infrastructures can sustain the expected disturbances; such disturbances can range between natural hazards, intentional attacks, accidents, and failures propagated between interdependent infrastructures [55][56][57]. However, in the face of these disturbances, the main focus during MSEs should be on preserving functionality over recovery, as this is essential for maintaining an acceptable service level and ensuring a remarkable visitor experience. Among these infrastructures, the road networks play a critical role in providing mobility throughout the city and between points of interest, such as fan zones and event venues, and in affecting the visitors' experiences and the event's success [56].

For this study, we will focus our resilience assessment on the system's ability to preserve functionality; functionality evaluation here refers to the evaluation of suitable performance metrics for each level. For example, it is widely accepted in the literature to use, at a network level, network centrality and cohesion as performance criteria and resilience metrics [3][41][43][58][59]. While representing a small part of the system level, it is more common to use the shortest path to travel between point A and point B or to use changes in travel pace instead [7][28][60][61][62]. Both assessment methods would result in a performance degradation metric, which can easily be compared under different scenarios and generalized for other purposes and interests.

To the best of our knowledge, no published work has suggested a framework to evaluate the resilience of road networks during MSEs to date; thus, the main objective of this research is to suggest a framework for assessing the resilience of road networks during MSEs, paving the way for considering resilience as a criterion in evaluating future host cities' nomination profiles. The additional contribution of the suggested framework is addressing the network's resilience on multiple levels, rather than the common approach of focusing on a single, certain level. Furthermore, the flexibility of the suggested framework to produce a combined and weighted index under different threats of interest allows for the comparability of different development plans and the evaluation of their effectiveness under the credibility of possible threats. The suggested framework focuses on urban areas and assumes that the event's activities would be compacted to be contained in a metropolitan area. However, in the case of multiple host cities, the framework concepts could be adopted and modified to accommodate related complications, but that is out of the scope of this paper.

References

1. United Nations, Department of Economic and Social Affairs. World Urbanization Prospects: The 2018 Revision; United Nations: New York, NY, USA, 2019.
2. Addanki, S.C.; Venkataraman, H. Greening the economy: A review of urban sustainability measures for developing new cities. Sustain. Cities Soc. 2017, 32, 1–8.
3. Liu, W.; Song, Z. Review of studies on the resilience of urban critical infrastructure networks. Reliab. Eng. Syst. Saf. 2020, 193, 106617.
4. The Resilience Shift. The Resilience Shift Website. Available online: http://resilienceshift.org (accessed on 18 November 2019).
5. Duy, P.N.; Chapman, L.; Tight, M. Resilient transport systems to reduce urban vulnerability to floods in emerging-coastal cities: A case study of Ho Chi Minh City, Vietnam. Travel Behav. Soc. 2019, 15, 28–43.
6. Huck, A.; Monstadt, J. Urban and infrastructure resilience: Diverging concepts and the need for cross-boundary learning. Environ. Sci. Policy 2019, 100, 211–220.
7. Ilbeigi, M. Statistical process control for analyzing resilience of transportation networks. Int. J. Disaster Risk Reduct. 2019, 33, 155–161.
8. Schleussner, C.-F.; Donges, J.F.; Donner, R.V.; Schellnhuber, H.J. Armed-conflict risks enhanced by climate-related disasters in ethnically fractionalized countries. Proc. Natl. Acad. Sci. USA 2016, 113, 9216–9221.
9. Salimi, M.; Al-Ghamdi, S.G. Climate change impacts on critical urban infrastructure and urban resiliency strategies for the Middle East. Sustain. Cities Soc. 2020, 54, 101948.
10. Raleigh, C. Political Marginalization, Climate Change, and Conflict in African Sahel States. Int. Stud. Rev. 2010, 12, 69–86.
11. Raouf, A.M.; Al-Ghamdi, S.G. Effectiveness of Project Delivery Systems in Executing Green Buildings. J. Constr. Eng. Manag. 2019, 145, 03119005.
12. Wan, C.; Yang, Z.; Zhang, D.; Yan, X.; Fan, S. Resilience in transportation systems: A systematic review and future directions. Transp. Rev. 2018, 38, 479–498.
13. Meza Talavera, A.; Al-Ghamdi, S.; Koç, M. Sustainability in Mega-Events: Beyond Qatar 2022. Sustainability 2019, 11, 6407.
14. Holling, C.S. Resilience and Stability of Ecological Systems. Annu. Rev. Ecol. Syst. 1973, 4, 1–23.
15. Chan, R.; Schofer, J.L. Measuring Transportation System Resilience: Response of Rail Transit to Weather Disruptions. Nat. Hazards Rev. 2016, 17, 05015004.
16. Abedi, A.; Gaudard, L.; Romerio, F. Review of major approaches to analyze vulnerability in power system. Reliab. Eng. Syst. Saf. 2019, 183, 153–172.
17. Hosseini, S.; Barker, K.; Ramirez-Marquez, J.E. A review of definitions and measures of system resilience. Reliab. Eng. Syst. Saf. 2016, 145, 47–61.
18. Bruneau, M.; Chang, S.E.; Eguchi, R.T.; Lee, G.C.; O'Rourke, T.D.; Reinhorn, A.M.; Shinozuka, M.; Tierney, K.; Wallace, W.A.; Von Winterfeldt, D. A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. Earthq. Spectra 2003, 19, 733–752.
19. Faturechi, R.; Miller-Hooks, E. Measuring the Performance of Transportation Infrastructure Systems in Disasters: A Comprehensive Review. J. Infrastruct. Syst. 2015, 21, 04014025.

20. Gasser, P.; Suter, J.; Cinelli, M.; Spada, M.; Burgherr, P.; Hirschberg, S.; Kadziński, M.; Stojadinović, B. Comprehensive resilience assessment of electricity supply security for 140 countries. Ecol. Indic. 2020, 110, 105731.

21. Najafi, J.; Peiravi, A.; Anvari-Moghaddam, A.; Guerrero, J.M. Resilience improvement planning of power-water distribution systems with multiple microgrids against hurricanes using clean strategies. J. Clean. Prod. 2019, 223, 109–126.

22. Chakrabarti, S. Eutrophication—A Global Aquatic Environmental Problem: A Review. Res. Rev. J. Ecol. Environ. Sci. 2018, 6, 1–6.

23. Meng, Y.; Yang, Y.; Chung, H.; Lee, P.-H.; Shao, C. Enhancing Sustainability and Energy Efficiency in Smart Factories: A Review. Sustainability 2018, 10, 4779.

24. Ferrari, P. The dynamics of the competition between cars and trucks on motorways. Transp. Res. Part C Emerg. Technol. 2011, 19, 579–592.

25. Serulle, N.U.; Heaslip, K.; Brady, B.; Louisell, W.C.; Collura, J. Resiliency of Transportation Network of Santo Domingo, Dominican Republic. Transp. Res. Rec. J. Transp. Res. Board 2011, 2234, 22–30.

26. Casalicchio, E.; Galli, E.; Tucci, S. Agent-based modelling of interdependent critical infrastructures. Int. J. Syst. Syst. Eng. 2010, 2, 60.

27. Sun, W.; Bocchini, P.; Davison, B.D. Resilience metrics and measurement methods for transportation infrastructure: The state of the art. Sustain. Resilient Infrastruct. 2020, 5, 168–199.

28. Donovan, B.; Work, D.B. Empirically quantifying city-scale transportation system resilience to extreme events. Transp. Res. Part C Emerg. Technol. 2017, 79, 333–346.

29. Serdar, M.Z.; Koç, M.; Al-Ghamdi, S.G. Urban Transportation Networks Resilience: Indicators, Disturbances, and Assessment Methods. Sustain. Cities Soc. 2021, 76, 103452.

30. Aydin, N.Y.; Duzgun, H.S.; Heinimann, H.R.; Wenzel, F.; Gnyawali, K.R. Framework for improving the resilience and recovery of transportation networks under geohazard risks. Int. J. Disaster Risk Reduct. 2018, 31, 832–843.

31. Wang, Y.; Zhan, J.; Xu, X.; Li, L.; Chen, P.; Hansen, M. Measuring the resilience of an airport network. Chinese J. Aeronaut. 2019, 32, 2694–2705.

32. Liao, T.-Y.; Hu, T.-Y.; Ko, Y.-N. A resilience optimization model for transportation networks under disasters. Nat. Hazards 2018, 93, 469–489.

33. Sommer, M.; Tomforde, S.; Hähner, J. An Organic Computing Approach to Resilient Traffic Management. In Autonomic Road Transport Support Systems; Springer International Publishing: Cham, Switzerland, 2016; pp. 113–130.

34. Ye, Q.; Ukkusuri, S.V. Resilience as an Objective in the Optimal Reconstruction Sequence for Transportation Networks. J. Transp. Saf. Secur. 2015, 7, 91–105.

35. Haznagy, A.; Fi, I.; London, A.; Nemeth, T. Complex network analysis of public transportation networks: A comprehensive study. In Proceedings of the 2015 International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), Budapest, Hungary, 3–5 June 2015; IEEE: Piscataway, NJ, USA, 2015; pp. 371–378.

36. Zhang, J.; Wang, S.; Wang, X. Comparison analysis on vulnerability of metro networks based on complex network. Phys. A Stat. Mech. Appl. 2018, 496, 72–78.

37. Zhenwu, S.; Xianyu, T.; Huiyu, L.; Hui, L.; Jie, L.; Xunguo, L. Quantitative Study on the Waterlogging Resilience of Road Transportation System Based on the Validity View of System Functions. J. Eng. Sci. Technol. Rev. 2019, 12, 117–125.

38. Cerqueti, R.; Ferraro, G.; Iovanella, A. Measuring network resilience through connection patterns. Reliab. Eng. Syst. Saf. 2019, 188, 320–329.

39. Testa, A.C.; Furtado, M.N.; Alipour, A. Resilience of Coastal Transportation Networks Faced with Extreme Climatic Events. Transp. Res. Rec. J. Transp. Res. Board 2015, 2532, 29–36.

40. Bell, M.G.H. Measuring network reliability: A game theoretic approach. J. Adv. Transp. 1999, 33, 135–146.

41. Akbarzadeh, M.; Memarmontazerin, S.; Derrible, S.; Salehi Reihani, S.F. The role of travel demand and network centrality on the connectivity and resilience of an urban street system. Transportation 2019, 46, 1127–1141.

42. Cheng, M.X.; Crow, M.; Ye, Q. A game theory approach to vulnerability analysis: Integrating power flows with topological analysis. Int. J. Electr. Power Energy Syst. 2016, 82, 29–36.

43. Sarlas, G.; Páez, A.; Axhausen, K.W. Betweenness-accessibility: Estimating impacts of accessibility on networks. J. Transp. Geogr. 2020, 84, 102680.

44. Ortega, E.; Martín, B.; Aparicio, Á. Identification of critical sections of the Spanish transport system due to climate scenarios. J. Transp. Geogr. 2020, 84, 102691.

45. Twumasi-Boakye, R.; Sobanjo, J.O. Resilience of Regional Transportation Networks Subjected to Hazard-Induced Bridge Damages. J. Transp. Eng. Part A Syst. 2018, 144, 04018062.

46. Yang, Y.; Ng, S.T.; Zhou, S.; Xu, F.J.; Li, H. Physics-driven based resilience analysis of interdependent civil infrastructure systems—A Case study in Hong Kong. In Proceedings of the Computing in Civil Engineering 2019, Atlanta, GA, USA, 17–19 June 2019; American Society of Civil Engineers: Reston, VA, USA, 2019; pp. 563–569.

47. Pagani, G.A.; Aiello, M. A complex network approach for identifying vulnerabilities of the medium and low voltage grid. Int. J. Crit. Infrastruct. 2015, 11, 36.

48. Zio, E.; Golea, L.R. Analyzing the topological, electrical and reliability characteristics of a power transmission system for identifying its critical elements. Reliab. Eng. Syst. Saf. 2012, 101, 67–74.

49. Cuadra, L.; Salcedo-Sanz, S.; Del Ser, J.; Jiménez-Fernández, S.; Geem, Z. A Critical Review of Robustness in Power Grids Using Complex Networks Concepts. Energies 2015, 8, 9211–9265.

50. Preuss, H. The Contribution of the FIFA World Cup and the Olympic Games to Green Economy. Sustainability 2013, 5, 3581–3600.

51. Borchers, M.; Kedia, S.; Trusen, C. Sustainable Mega-Events in Developing Countries: Experiences and Insights from Host Cities in South Africa, India and Brazil; Konrad Adenauer Stiftung: Johannesburg, South Africa, 2011; ISBN 978-0-9870243-0-5.

52. The Supreme Committee for Delivery and Legacy. The Supreme Committee for Delivery and Legacy (Sustainability Policy). Available online: https://www.qatar2022.qa/en/about/sustainability (accessed on 10 October 2020).

53. Azzali, S. Mega-events and urban planning: Doha as a case study. URBAN Des. Int. 2017, 22, 3–12.

54. Weiler, J.; Mohan, A. The Olympic Games and the Triple Bottom Line of Sustainability: Opportunities and Challenges. Int. J. Sport Soc. 2010, 1, 187–202.

55. Butry, D.; Davis, C.A.; Malushte, S.R.; Medina, R.A.; Taha, M.R.; van de Lindt, J.W.; Brett, C.R.; Daghash, S.; Field, C.; Fung, J.; et al. Hazard-Resilient Infrastructure; Ayyub, B.M., Ed.; American Society of Civil Engineers: Reston, VA, USA, 2021; ISBN 9780784415757.

56. Serdar, M.Z.; Koc, M.; Al-Ghamdi, S.G. Urban Infrastructure Resilience Assessment During Mega Sport Events Using a Multi-Criteria Approach. Front. Sustain. 2021, 2, 41.

57. Serdar, M.Z.; Al-Ghamdi, S.G. Preparing for the Unpredicted: A Resiliency Approach in Energy System Assessment. In Green Energy and Technology; Ren, J., Ed.; Springer International Publishing: Cham, Switzerland, 2021; pp. 183–201. ISBN 978-3-030-67529-5.

58. Yadav, N.; Chatterjee, S.; Ganguly, A.R. Resilience of Urban Transport Network-of-Networks under Intense Flood Hazards Exacerbated by Targeted Attacks. Sci. Rep. 2020, 10, 10350.

59. Zhang, D.; Du, F.; Huang, H.; Zhang, F.; Ayyub, B.M.; Beer, M. Resiliency assessment of urban rail transit networks: Shanghai metro as an example. Saf. Sci. 2018, 106, 230–243.

60. Soltani-Sobh, A.; Heaslip, K.; El Khoury, J. Estimation of road network reliability on resiliency: An uncertain based model. Int. J. Disaster Risk Reduct. 2015, 14, 536–544.

61. Ukkusuri, S.V.; Yushimito, W.F. A methodology to assess the criticality of highway transportation networks. J. Transp. Secur. 2009, 2, 29–46.

62. Yin, Y.; Ieda, H. Assessing Performance Reliability of Road Networks Under Nonrecurrent Congestion. Transp. Res. Rec. J. Transp. Res. Board 2001, 1771, 148–155.