Temporal Multi-Hazard Risk Assessment of the Interconnected Infrastructure Systems Using Dynamic Bayesian Network

Soheil Bakhtiari[a], M. Reza Najafi[a], Katsuichiro Goda[b], Hassan Peerhossaini[a]

[a] Department of Civil and Environmental Engineering, Western University, London, ON, Canada (sbakhti4@uwo.ca; mnajafi7@uwo.ca; hpeerhos@uwo.ca)

[b] Department of Earth Sciences, Western University, London, ON, Canada (kgoda2@uwo.ca)

1. Introduction

- This study proposes a novel risk assessment framework to address dynamic and cascading disruptions caused by natural hazards.
- Utilizing Dynamic Bayesian Networks (DBNs) tailored for multi-hazard contexts, it captures complex scenarios often missed by static assessments.

Main Objective:
To assess multi-hazard risks in interconnected infrastructure, this study uses Dynamic Bayesian Networks (DBNs) for enhanced resilience strategies.

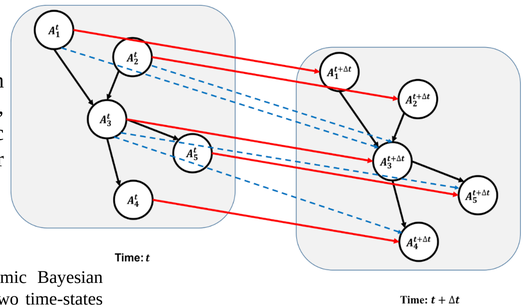

Figure 1. Schematic Dynamic Bayesian Network (DBN) including two time-states (slices), called 2TBN

2. Study Area & Methodology

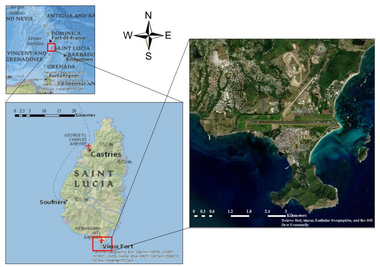

Figure 2. The location of the study area

- Saint Lucia, a volcanic island in the cyclone belt, deals with frequent flooding, worsened by steep terrain, landslides, and fallen trees.
- The southern coast, including Hewanorra International Airport (HIA), faced severe flooding during Tropical Storm Matthew (TSM) in September 2016."

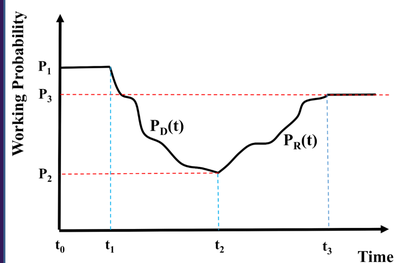

Figure 3. A Schematic representation illustrating the temporal performance of an entity

The resilience index is quantified by calculating the integral of the performance curve:

$$R = \int_{t_1}^{t_3} P(t)dt$$

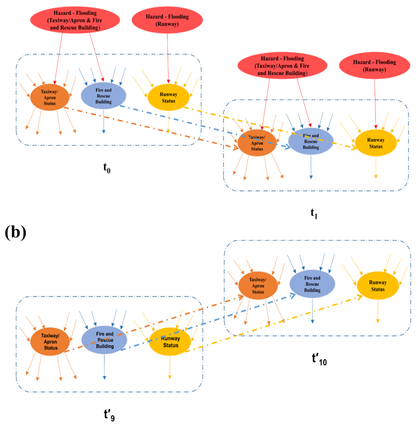

Figure 4. The close-up view of a 2TBN depicting target nodes during (a) the disruption caused by flooding at time slices t_0 and t_1, (b) the restoration at time slices t'_9 and t'_{10}

3. Results

Flooding Hazard Scenario;

- Figure 5 illustrates entities affected by flooding and their cascading pathways based on network dependencies.
- The study focuses on "Airport's Normal Operations" and "Tourism".
- Figure 6 shows the impacts of disruptions and restorations of target entities on affected ones.

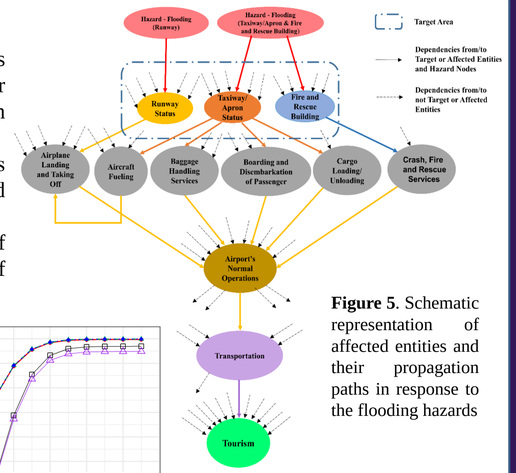

Figure 5. Schematic representation of affected entities and their propagation paths in response to the flooding hazards

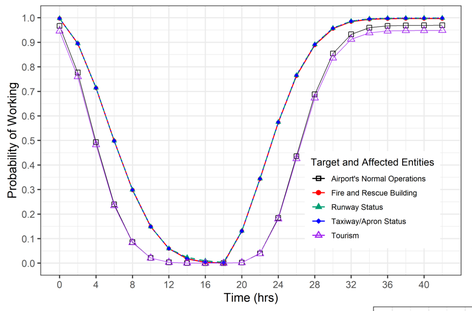

Figure 6. Disruption and restoration process of the target and affected entities

Multi-Hazard Scenario (Flooding + Landslide);

- "Inter-City Road Transportation" is a target entity influenced by flooding-triggered landslide hazards.

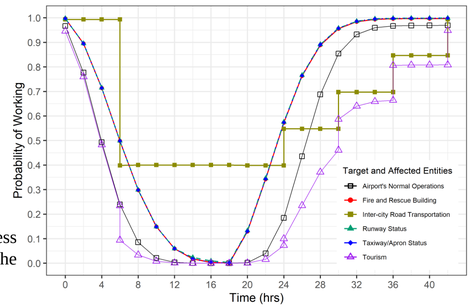

Figure 7. Disruption and restoration process of the target and affected entities under the multi-hazard scenario

Scenario	Effective Hazard(s)	Failed Target Entities
#1	Hazard - Flooding (Taxiway/Apron & Fire and Rescue Building) Hazard - Flooding (Runway)	Taxiway/Apron Status Fire and Rescue Building Runway Status
#2	Hazard - Flooding (Taxiway/Apron & Fire and Rescue Building)* Hazard - Flooding (Runway)	Fire and Rescue Building Runway Status
#3	Hazard - Flooding (Taxiway/Apron & Fire and Rescue Building)	Taxiway/Apron Status Fire and Rescue Building
#4	Hazard - Flooding (Taxiway/Apron & Fire and Rescue Building)* Hazard - Flooding (Runway)	Taxiway/Apron Status Runway Status
#5	Hazard - Flooding (Taxiway/Apron & Fire and Rescue Building)*	Fire and Rescue Building
#6	Hazard - Flooding (Runway)	Runway Status
#7	Hazard - Flooding (Taxiway/Apron & Fire and Rescue Building)*	Taxiway/Apron Status
Multi-Hazard	Hazard - Flooding (Taxiway/Apron & Fire and Rescue Building) Hazard - Flooding (Runway) Landslide	Taxiway/Apron Status Fire and Rescue Building Runway Status Inter-City Road Transportation

*The effective hazard just impacts one of the entities mentioned in the hazard description

Table 1. Scenario descriptions and failed target entities

- Eight distinct scenarios, including scenario #1 illustrated in Figure 6, and the multi-hazard scenario presented in Figure 7, are evaluated for resilience index assessment.

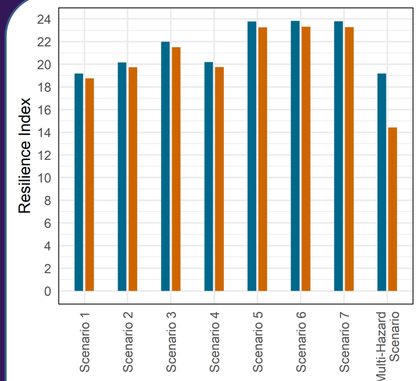

Figure 8. Resilience index of the affected entities under different scenarios described in Table 1

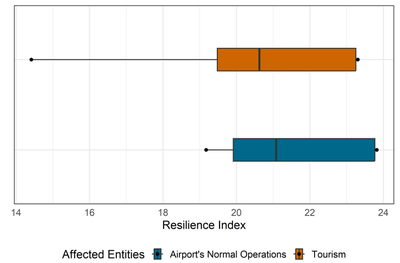

Figure 9. The resilience index variation among affected entities across different scenarios

- The multi-hazard scenario is the most critical, resulting in the lowest resilience index for "Tourism".

4. Conclusions

- Applied Dynamic Bayesian Network (DBN) for multi-hazard resilience assessment, capturing complex temporal disruptions and guiding effective mitigation strategies.
- Quantified cascading effects, highlighting vulnerabilities in "Airport's Normal Operations" and its impact on "Tourism".
- Revealed system vulnerabilities under simultaneous hazards, emphasizing the need for robust multi-hazard resilience planning and response strategies.
- Advocated for proactive, data-informed policies, considering both direct and indirect dependencies, guiding policymakers and stakeholders in disaster preparedness and response.
- Expanded future research initiatives to investigate a wide range of hazards, utilize diverse resilience metrics, and enhance data accuracy, thereby shaping comprehensive risk and resilience assessments for complex infrastructures.

References

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