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A Review of Critical Infrastructure Interdependency Simulation and Modelling for the Caribbean

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Abstract: *Caribbean Small Island Developing States (SIDS) are particularly disaster prone and, as such, disaster risk reduction and effective emergency management are crucial to sustainable development. Studying critical infrastructure interdependencies (CII) is a relatively new facet of disaster risk reduction. Computer simulation software is the most effective and economical method of studying these relationships. This paper contextualises the role of CII simulation as part of a complete disaster and emergency management programme, and reviews the state-of-the-art as pertains to utilisation of such tools among Caribbean emergency management agencies (EMAs). It finds that Caribbean EMAs do not currently utilise CII tools. The paper then reviews some of the most popular simulation tools under development such as CIPDSS, HAZUS, I2Sim/DR-NEP and ESRI Sim Disaster. Their applicability and ease of adoption to the Caribbean context is considered. I2Sim was viewed as being the best suited for Caribbean EMAs.*

Keywords: *Emergency Management, Critical Infrastructure Interdependencies, Simulation, SIDS, Caribbean, I2Sim*

1. Introduction

In the Americas alone, every year, on average, disasters kill more than five thousand people; affect more than five million lives and cause economic damage in excess of twenty billion US dollars (PreventionWeb, 2014a). Caribbean countries are among the most natural disaster prone in the world (Carby, 2011, Rasmussen, 2004); Acevedo (2013) discusses the high incidence of disasters in the region, noting that the region has been struck by 187 disasters in the last 60 years, with 26 storm impacts in the last 4 years alone (Fraser, 2013, EM-DAT, 2014). When using the number of natural disasters to land area, the six (6) Eastern Caribbean Currency Union (ECCU) countries rank among the ten (10) most disaster prone, and the rest of the Caribbean countries fall amongst the top fifty (Rasmussen, 2004).

Developing countries face much larger shock to their macro-economies following a disaster of similar relative magnitude than do developed countries (Noy, 2009). An extreme example is Hurricane David that hit Dominica in 1979 causing damage exceeding 100% of the country’s Gross Domestic Product (Benson et al., 2001). Besides the immediate fallout of a disaster, the effects can spark economic crisis and increase poverty leading to social unrest (Rasmussen, 2004). When a disaster strikes, losses are inevitable. However, lives can be saved and losses mitigated through coordinated emergency management (ISDR, 2005).

2. Phases of Emergency Management

Emergency management is typically analysed by dividing the process into four (4) phases: mitigation, preparedness, response and recovery (NGA, 1979, Waugh and Hy, 1990, Baird, 2010), although other models consisting of more or different phases have been proposed (Neal, 1997). The problem of critical infrastructure interdependency (CII) comes to the fore in both the response and recovery stages.

Response includes the execution of emergency plans and procedures, and seeks to reduce the probability of secondary damage (Baird, 2010). These actions necessitate an understanding of critical infrastructure interdependency such that complex vulnerabilities can be recognised and an informed response can be coordinated.

The issue is also apparent in the recovery stage. This stage is complex and requires coordination of a number of stakeholders as noted by Haddow, Bullock and Coppola (2007) and Phillips (2009). A critical requirement of effective disaster preparedness is that agencies and actors operate in a coordinated manner to avoid time loss and duplication of work (UN/ISDR and UN/OCHA 2008, 11). Likewise, the World

Meteorological Organisation noted that good early warning systems require coordination across many agencies to be successful (WMO, 2013).

3. Importance of Simulation Tools

The Hyogo Framework is a global blueprint for disaster risk reduction efforts during the next decade (UNISDR, 2005; PreventionWeb, 2014b). Studying Critical Infrastructure Interdependency is encapsulated in the recommendations of this framework which include using knowledge and innovation via research methods and tools for multi-risk assessment. Additionally, the United Nations Office for Disaster Risk Reduction's (UNISDR) 2015 Global Assessment Report for Disaster Risk Reduction identifies the dynamics of risk in urban settings while recognising the interconnectedness of risk as a thematic area that requires research and closer examination. An example of damage to power utilities triggering a failure in water management systems was given (UNISDR, 2013).

As such, understanding CII should be an integral facet of any emergency management programme. Since the relationship between critical infrastructures cannot be tested in the real-world without disruption of those infrastructures, and because CIIs can become quite complex, software simulation is the preferred method of analysis.

The U.S. established the National Infrastructure Simulation and Analysis Center (NISAC), within the U.S. Department of Homeland Security, to provide strategic, multidisciplinary analyses of interdependencies and the consequences of infrastructure disruptions (NISAC, 2015). Additionally, increased attention to this field has increased governmental and private funding to universities, laboratories, and private companies involved in modelling and simulation of critical interdependencies, thus even though this field is relatively new, a great deal of valuable work has been done (Pederson et al., 2006). Using the example of the Critical Infrastructure Protection Decision Support System (CIPDSS, 2015) produced at NISAC, Figure 1 outlines the role such simulation software plays in formulating a disaster response plan.

This paper examines both the existing use of CII simulation tools in the Caribbean, and identifies tools that can be most beneficial to the Caribbean given the current operational constraints of their emergency management agencies.

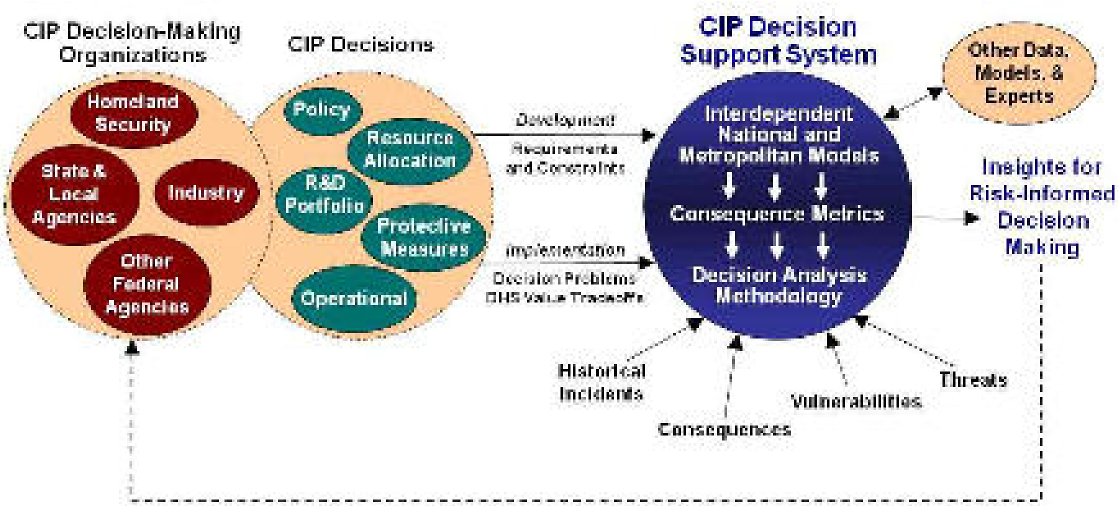

Figure 1: Role of Simulation Software - Case of CIPDSS
Source: NISAC (2006)

4. Usage of CII Tools in the Caribbean

In the Caribbean, little seems to be done in the field of CII Simulation by emergency management bodies. By contrast, in the United States the need for research in the field CII and its importance in preparing for disasters and emergencies has long been recognised and pursued. In the year 2000, the National Infrastructure Simulation and Analysis Center (NISAC) – now under the US Department of Homeland Security – was established, engaging technical staff from the Los Alamos National Laboratory (LANL, 2015) and Sandia National Laboratories (SNL). The Caribbean, however, does not enjoy the financial resources to establish such centres and Emergency Management Agencies are often pressed with more immediate concerns, leaving them little time for extending themselves into less established fields such as CII simulation.

To gauge the penetration of CII simulation usage in the region, attempts were made to reach all of the member agencies of the CDEMA via contact information provided by the CDEMA website (CDEMA, 2014). A survey (by emails) was conducted with each agency asking about their use of CII simulation software and plans for using such software. Numerous phone calls were made to agencies who did not reply to the initial emails. Table 1 summarises the information gleaned via this exercise.

As evident from Table 1, CII simulation tools are not currently being used by any responding state as part of their Disaster Risk Reduction programme. To underscore this problem, it is important to note that responding agencies often were not aware of the CII simulation as a field of study or its importance to their activities, and would associate the words "software tools" with platforms such as WebEOC (WebEOC, 2015) for emergency reporting and ArcGIS (ESRI, 2015) for geo-spatial data management and analysis and decision support or the DEWTERA Platform (CIMA, 2015) for weather related risk forecasting and monitoring. The word "simulation" was also often associated with first responder exercises and not computer simulation.

Furthermore, most responding agencies – with the exception of the Office for Disaster Preparedness and Management (ODPM) of Trinidad – had no short term plans to introduce this facet of risk assessment into their DRR (Disaster Risk Reduction) Schemes. Some agencies did not respond to attempts made at contact, which seems to further highlight the problem of limited resources from which many of the organisations suffer.

Table 1: Use of CII simulation tools by CDEMA member states

Country	Agency Name	**Does your organisation use Critical Infrastructure Interdependency simulation software?**	
		Yes? Which software and why?	*No? Are there plans?*
Anguilla	Department of Disaster Management	Unknown	Unsure
Antigua and Barbuda	National Office of Disaster Services	Unknown	Unsure
Bahamas	National Emergency Management Agency	No	No Plans
Barbados	Department of Emergency Management	No	No Plans
Virgin Islands (UK)	Department of Disaster Management	No	Interest shown.
Dominica	Office of Disaster Management	Unknown	Unsure
Grenada	National Disaster Management Agency	No	No Plans
Guyana	Civil Defence Commission	Unknown	Unsure
Haiti	Directorate of Civil Protection	Unknown	Unknown
Jamaica	Office of Disaster Preparedness and Emergency Management	No response	Unknown
Montserrat	Disaster Management Coordination Agency	No response	Unknown
St. Kitts and Nevis	National Disaster Management Agency	No response	Unknown
St. Lucia	National Emergency Management Organisation	No	No Plans
St. Vincent and the Grenadines	National Emergency Management Organisation	No response	Unknown
Trinidad and Tobago	Office of Disaster Preparedness and Management	No	In the process
Turks and Caicos Islands	Department of Disaster Management and Emergencies	Unknown	Unsure
Suriname	National Coordination Center for Disaster Relief (NCCR)	No response	Unknown

Two of the Caribbean stakeholders (Trinidad and Tobago and the British Virgin Islands) have shown marked interest in including CII Simulation in the Disaster Risk Reduction schemes. Trinidad and Tobago has already initiated steps towards this via coordination with The University of the West Indies (UWI) while the Department of Disaster Management of the British Virgin Islands has also indicated interest in doing the same. These findings corroborate the observation made by Carby (2011) that no Caribbean disaster management office reported a budget for research.

5. Survey of Critical Infrastructure Interdependency Simulation Tools

Since the emergence of CII modelling and simulation, a number of tools have been produced. Many of these tools were reviewed in Pederson et al. (2006). Further investigation revealed that a significant number of these tools were either proprietary software, not available for procurement, or are now defunct. This section highlights some of the software tools which include aspects of CII simulation and modelling for which information was available and which are actively maintained by their companies.

5.1 HAZUS

HAZUS is a geographic information system-based natural hazard developed and freely distributed by the Federal Emergency Management Agency (FEMA). It is an auxiliary tool for estimating physical, economic and social impacts of disasters which are critical data for generating scenarios for CII simulations (FEMA, 2014). It graphically highlights locations at high risk of earthquake, hurricane and floods. Users can then view how population densities relate to assets and resources thus providing data that can inform decisions on resource management and risk mitigation. After the analysis is run, the details of the extent of damage expected to specific structures, infrastructures and loss of resources are shown along with the overall economic impact of an event.

HAZUS operates on ESRI's ArcGIS software, a tool that some Caribbean agencies are already equipped with. It also has the advantage of already being compatible with the SUMMIT Platform for visualisation (SUMMIT, 2015). The technical support and training for HAZUS is available through FEMA.

5.2 Critical Infrastructure Protection Decision Support System

Critical Infrastructure Protection Decision Support System (CIPDSS) is a decision support tool that aids the user in assessing candidate decisions (CIPDSS, 2015). The tool combines simulating the event and assessing risk while considering threats and vulnerabilities associated with the emergency scenario whether manmade or natural (see Figure 2). CIPDSS models the interdependencies of up to 17 types of Critical Infrastructures and Key Resources (DHS, 2015) and the mutual impacts upon each other. The model includes critical infrastructure sectors - energy, communications, transport, agriculture and economy.

CIPDSS Simulations model the use of resources such as hospital beds, and the operation of emergency personnel. Results of the simulation can include hospital bed usage, average time waiting for care, a count of fatalities and the cost of damage. CIPDSS has been reviewed by academia and industry analysts. However the software is the property of Los Alamos Laboratories and requires procurement and licensing.

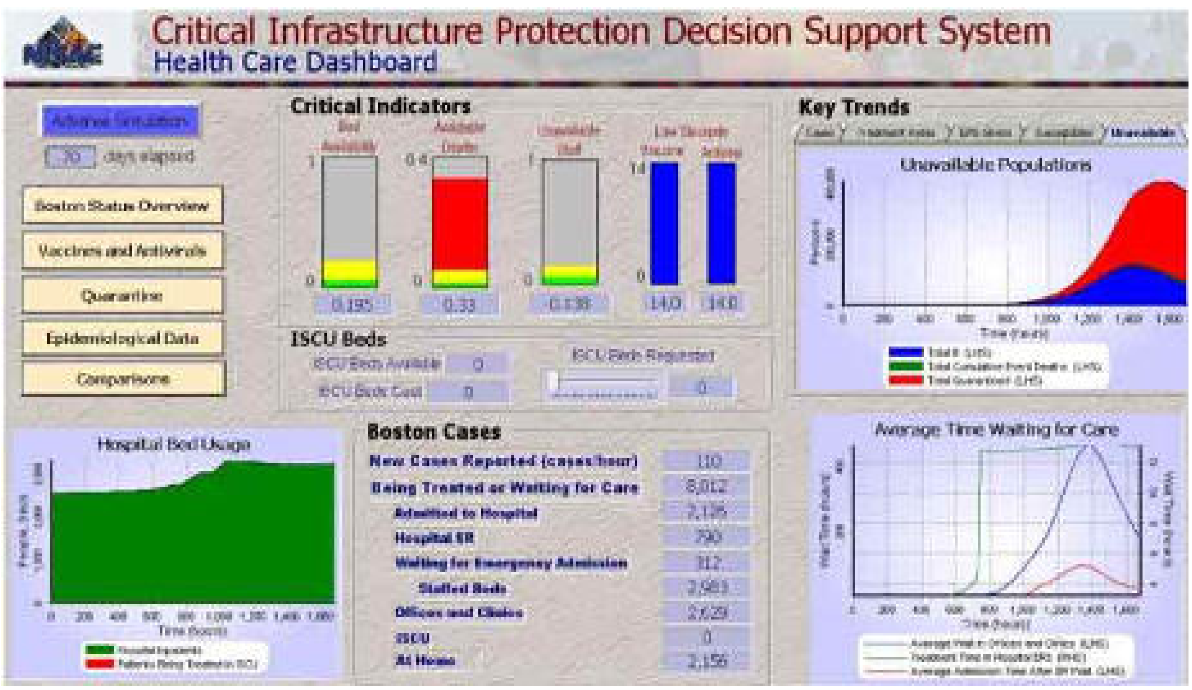

Figure 2: CIPDSS Screenshot

5.3 Disaster Response Network Enabled Platform

Disaster Response Network Enabled Platform (DR-NEP/I2Sim) was developed by the I2Sim/DR-NEP group of The University of British Columbia (UBC, 2015; Martí et al., 2008) to model the interdependencies among critical infrastructure (CI). It allows coordinated decision making to inform allocation of resources and helps to identify the parts of the system which carry the highest priority for restoration after a disaster (see Figure 3)

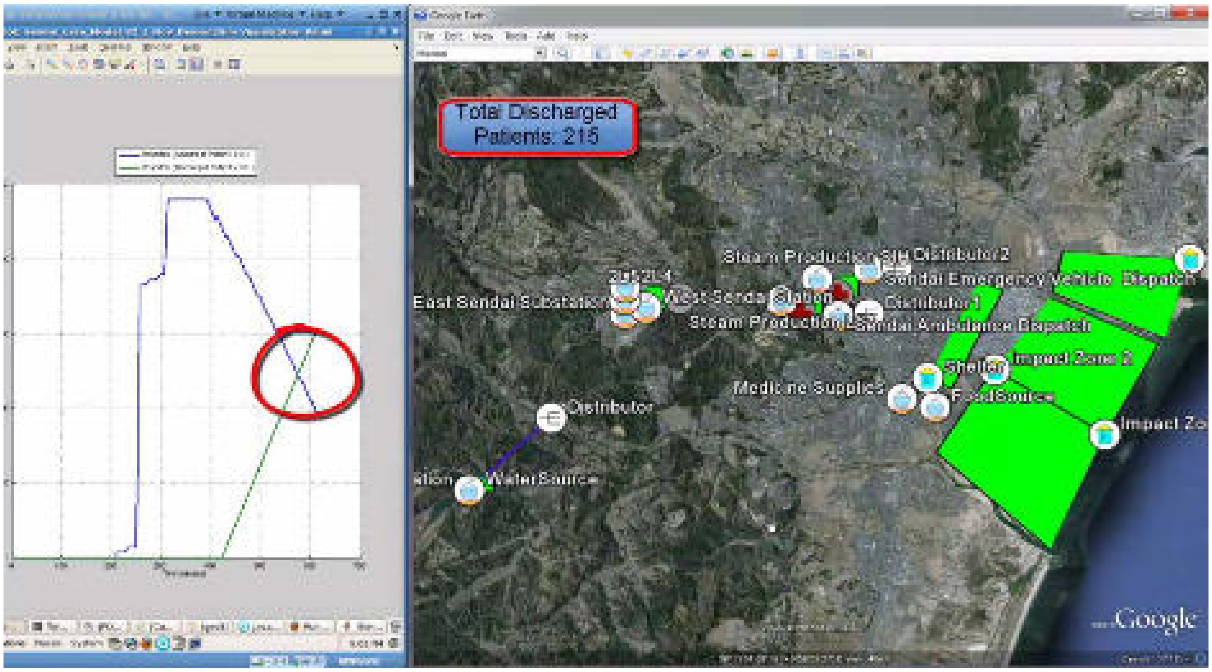

Figure 3: I2Sim/DR-NEP screenshot

A variety of case studies have been performed using I2Sim. These include an earthquake in Guadeloupe, and various scenarios for the Vancouver 2010 Winter Olympics. I2Sim has also been successfully utilised for modelling the failure of a municipal water system (Shypanski et al., 2011). The tool is continually under development and the power of I2Sim lies in its abstraction of critical infrastructure problems such that a wide variety of infrastructures can be modelled using a common framework. The results are viewed via monitoring the output of any combination of particular infrastructures in the network, such as the number of treated patients discharged by a hospital.

Since I2Sim simulates the interaction between different infrastructures and resources, it can easily be used to assess policies and disaster response procedures concerning coordination of these entities. I2Sim's developers have indicated that steps are being taken towards enhancing the tool with the capability to automate this type of assessment and find best-fit solutions for policy makers. I2Sim is not distributed commercially but is available via collaboration with participating academic and research institutions. Of the region's institutions, The University of the West Indies has an on-going collaboration with The University of British Columbia on this project and has commenced research and software development in the field of CII.

5.4 SIM Disaster - Modelling and Simulation Consequence Management System

This is a FEMA-funded tool inspired by the popular videogame Sim City (MATRIC, 2011). It was developed to assist in planning for preparation, recovery and response to a crisis that requires mass evacuation. The simulations depict how mass evacuation will impact critical infrastructure and resource consumption such as fuel, water, first aid, and shelter. The simulator is built on ArcGIS and simulates congestion considering time and geographical information. Results take the form of resource consumption figures and charts showing the number of affected people receiving treatment and finding shelter.

Even though this software is closely related to the field of CII and covers some of the same metrics as a CII simulator does (such as hospital beds available), the emphasis of Sim Disaster is on evacuation and egress. Infrastructure such as electricity lines, water pipelines and gas pipelines are not considered in the model (see Figure 4). This software must also be paid for.

6. Comparative Analysis

A comparison of simulation software was made to determine which would be suitable for CII simulation in the Caribbean (see Table 2). Non-proprietary software is preferred, since Caribbean agencies do not have the budgets of larger, more developed nations. The flexibility offered through open source solutions is preferable given the diverse operational contexts; additionally, they allow for regional innovation through customisation to meet local needs. The software should be able to simulate CII in the strictest sense. Furthermore, since data collection infrastructure in the Caribbean is weak the software should not require very detailed data input. Finally, the availability of local or regional support is paramount to the longevity of any technology based disaster risk reduction programme.

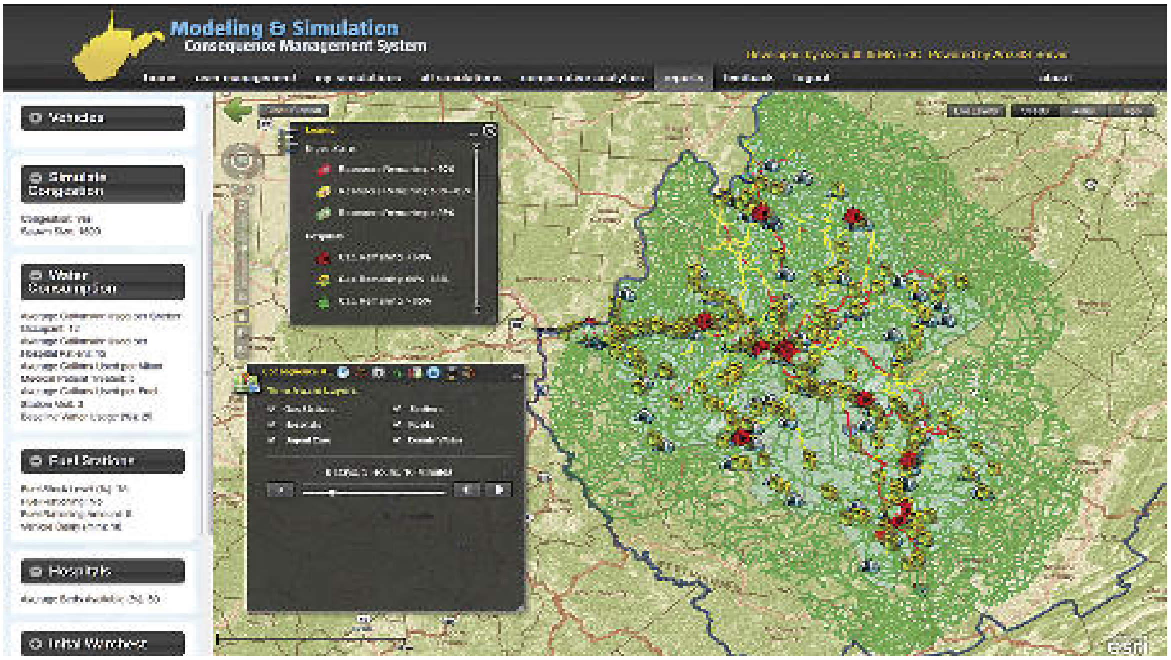

Figure 4: Sim Disaster Screenshot

6.1 Critical Infrastructure Sectors modelled

Additionally, a key metric for comparing CII simulation tools is the number of critical infrastructure sectors which are facilitated. The tool should ideally facilitate modelling the sixteen critical infrastructure sectors as envisaged by The White House's Presidential Policy Directive on Critical Infrastructure Security and Resilience (DHS, 2015, PPD, 2013) listed in Table 3. It is noted that this acknowledges a tool's modelling of damage sustained in a particular sector even if the information does not translate into modelling the dependency of other critical infrastructures on that sector.

Table 2: Basic Comparison of Simulation Tools

Simulation Tool	Proprietary	Open Source	CII Modelling (in the strict sense) enabled	Local/Regional Support
HAZUS	Freely available	No	No	No
CIPDSS	Yes	No	Yes	No
I2Sim	No	Yes	Yes	Yes
Sim Disaster	Yes	No	No	No

Table 3: Comparison of CI Sectors facilitated by each tool

Simulation Tool	Chemical and Hazardous Materials	Commercial Facilities	Communications	Critical Manufacturing	Dams	Defence
HAZUS	Yes	-	-	-	-	-
CIPDSS	Yes	-	-	Yes	-	Yes
I2Sim	Yes	-	Yes	Yes	Yes	Yes
Sim Disaster	-	-	-	-	-	-

Simulation Tool	Emergency Services	Energy	Financial Services	Food and Agriculture	Government Services	Healthcare
HAZUS	Yes	Yes	-	Yes	-	Yes
CIPDSS	Yes	Yes	Yes	Yes	-	Yes
I2Sim	Yes	Yes	-	Yes	-	Yes
Sim Disaster	Yes	-	-	-	-	-

Simulation Tool	Information Technology	Nuclear	Transport	Water and Wastewater	Postal and Shipping
HAZUS	-	-	Yes	Yes	-
CIPDSS	Yes	-	Yes	Yes	Yes
I2Sim	Yes	Yes	Yes	Yes	Yes
Sim Disaster	-	-	Yes	Yes	-

6.2 CII Software Features

Another way of comparing these simulation tools is by comparing the features afforded by each (see Table 4). A comprehensive CII tool would include features such as:

- Physical Disaster Models, so that the effect of a particular disaster type can be automated and randomised when running simulations.
- Empirical Data Models, where the simulator facilitates automated incorporation of collected infrastructure data and third party data into the model.
- Egress modelling, to simulate the movement of people and its effect on infrastructures and resources.
- Spatial data-source integration, where GIS information can be incorporated into the model and there is compatibility with widely used software such as ArcGIS or even Google Earth.

It is worth noting that although two tools may include the same feature, they may vary in the level of sophistication with which the feature is implemented. For example, I2Sim's egress modelling is rudimentary compared to that of Sim Disaster.

6.3 Summary of the Analysis

The two tools that provide CII modelling functionality in the stricter sense, such that the cascading effect of infrastructure failures upon other infrastructures is specifically modelled, are I2Sim and CIPDSS. When considering the number of CI sectors facilitated by each tool I2Sim surpasses CIPDSS, whereas when the special features of tools are compared CIPDSS offers the advantage. As the comparison is aimed at assessing suitability for the Caribbean context, accessibility and support are of significance. I2Sim carries an advantage in this regard since it is non-proprietary, open source and is regionally supported through academia.

Table 4: Comparison of CII Software Features

CII Simulation Tool	Physical Disaster Models	Empirical Data Models	Egress modelling	Spatial Data-source integration
HAZUS	Yes	Yes	No	Yes
CIPDSS	No	Yes	No	Yes
I2Sim	No	No	Yes	Yes
Sim Disaster	No	No	Yes (Detailed)	Yes

7. Conclusion

Critical Infrastructure Interdependency has been identified as an important field in assessing a nation's or community's vulnerability to disaster in the Hyogo Framework for Action as well as by the UNISDR and the WMO. Caribbean disaster management agencies, however, have not yet initiated research in this field or incorporated this facet of DRR in their programs. Some agencies have indicated their interest or intention in pursuing this, while others have not. The Caribbean is behind on research on CII and such efforts need to be initiated.

Towards this objective, examples of available tools which offer aspects of CII simulation were presented. At this stage of development, use of open source, highly customisable tools such as I2Sim are the best options for Caribbean countries since they rely on reduced order data sets that do not demand detailed knowledge of infrastructure operations and are supported by academic institutions in the region.

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