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Towards a holistic modeling of the humanitarian crisis complex relief system

Chantal Cherifi · Guillaume Bouleux ·
Aurélié Charles

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Abstract A humanitarian crisis relief system involves many entities of various types in interaction. To study such a system, the complex network framework is a good candidate. Some authors proposed mono-layered networks to model and analyze a single aspect of the system. To offer a broader view, we propose a multilayer model. Hence, the multifaced aspect of the system appears in a unified manner.

Keywords Humanitarian Crisis Relief · Complex Systems · Multilayer Networks

1 Introduction

Humanitarian crisis relief is driven by post-disaster governance, and relies on organizations in the field. Many actors can be involved like governments, institutions, aid organizations, firms or even universities. Field workers deliver aid to affected people according to their needs, deal with damages on roads, on existing infrastructures, build temporary infrastructures, store and dispatch material, food, various goods. During the last 20 years, the CRED counted 1.23 million deaths caused by natural disasters, and over 4 billion people affected. To improve the coordination of the response, its complexity must be unpacked. In [1], the author model and analyze the landscape of humanitarian actors through the lens of complex networks. In [2], the road network is represented by a monolayer network. The status of the roads is dynamically updated based on real-time data from the field. These two approaches focus on a particular aspect of the system. It would be beneficial to represent the system as a whole, and to also analyze relationships between elements of different types. As examples, let mention the presence of infrastructures in cities or the presence of organizations in particular infrastructures. To that end, we propose a multilayer network [3].

2 Multilayer network model

The network model is based on the study of reports and maps related to 2010 Haiti earthquake. These documents are retrieved from Reliefweb.int, an open online database, which centralizes humanitarian operations reports. Entities that come into play are represented with their relationships in Figure 1. According to the definition of a multilayer network [3], two classes of relationships are modeled, intra-layer and inter-layer relationships. The intra-layer relationships connect nodes of the same type within a layer, like two cities being connected by a road. The inter-layer relationships capture the interactions between nodes of different types in two different layers, like a warehouse located in a particular city. Let V the set of nodes and E the set of edges, the multilayer network $G = (V;E)$ is defined as follows:

- V_C : the set of cities such as $V_C \subseteq V$ and $c \in V_C$
- V_{HO} : the set of humanitarian organizations such as $V_{HO} \subseteq V$ and $ho \in V_{HO}$
- V_D : the set of donors such as $V_D \subseteq V$ and $d \in V_D$
- V_{HI} : the set of health infrastructures such as $V_{HI} \subseteq V$ and $hi \in V_{HI}$
- V_{AI} : the set of air infrastructures such as $V_{AI} \subseteq V$ and $ai \in V_{AI}$
- V_{RI} : the set of road infrastructures such as $V_{RI} \subseteq V$ and $ri \in V_{RI}$
- V_W : the set of warehouses such as $V_W \subseteq V$ and $w \in V_W$

Intra-layer relationships are defined as:

- $e \in E_{CC} \subseteq E$ between cities such that $e = (c_i, c_j) \in V_C^2$, when a city $c_i \in V_C$ is linked by a road to another city $c_j \in V_C$
- $e \in E_{HOHO} \subseteq E$ between humanitarian organizations such that $e = (ho_i, ho_j) \in V_{HO}^2$, when an organization $ho_i \in V_{HO}$ provide similar services than an organization $ho_j \in V_{HO}$
- $e \in E_{DD} \subseteq E$ between donors such that $e = (d_i, d_j) \in V_D^2$, when a donor $d_i \in V_D$ belong to the same cluster than another donor $d_j \in V_D$
- $e \in E_{HIHI} \subseteq E$ between health infrastructures such that $e = (hi_i, hi_j) \in V_{HI}^2$, when a health infrastructure $hi_i \in V_{HI}$ provide similar services than a health infrastructure $hi_j \in V_{HI}$
- $e \in E_{AIAI} \subseteq E$ between air infrastructures such that $e = (ai_i, ai_j) \in V_{AI}^2$, when an air infrastructure $ai_i \in V_{AI}$ is of same type than an air infrastructure $ai_j \in V_{AI}$
- $e \in E_{RIRI} \subseteq E$ between road infrastructures such that $e = (ri_i, ri_j) \in V_{RI}^2$, when an road infrastructure $ri_i \in V_{RI}$ crosses another road infrastructure $ri_j \in V_{RI}$
- $e \in E_W \subseteq E$ between warehouses such that $e = (w_i, w_j) \in V_W^2$, when a warehouse $w_i \in V_W$ stores the same type of goods than a warehouse $w_j \in V_W$.

Inter-layer relationships are defined as:

- $e \in E_{HIC} \subseteq E$ between a health infrastructure and a city such that $e = (hi_i, c_j) \in V_{HI} \times V_C$, when a health infrastructure $hi_i \in V_{HI}$ is located in a city $c_j \in V_C$

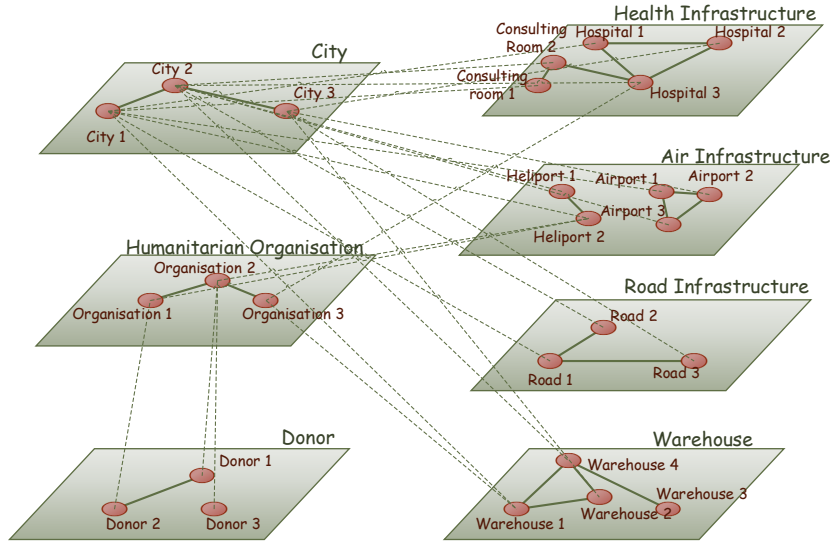


Fig. 1 Multilayer network model: 7 layers of nodes, intra-layer edges and inter-layer edges. Note that the first version of the model is an undirected and unweighted network.

- $e \in E_{HIHO} \subseteq E$ between a health infrastructure and a humanitarian organization such that $e = (hi_i, ho_j) \in V_{HI} \times V_{HO}$, when a humanitarian organization $ho_j \in V_{HO}$ has activities in a health infrastructure $hi_i \in V_{HI}$
- $e \in E_{AIC} \subseteq E$ between an air infrastructure and a city such that $e = (ai_i, c_j) \in V_{AI} \times V_C$, when an air infrastructure $ai_i \in V_{AI}$ is located in a city $c_j \in V_C$.
- $e \in E_{AIHO} \subseteq E$ between an air infrastructure and a humanitarian organization such that $e = (ai_i, ho_j) \in V_{AI} \times V_{HO}$, when a humanitarian organization $ho_j \in V_{HO}$ uses an air infrastructure $ai_i \in V_{AI}$.
- $e \in E_{RIC} \subseteq E$ between a road infrastructure and a city such that $e = (ri_i, c_j) \in V_{RI} \times V_C$, when a road $ri_i \in V_{RI}$ allows to reach a city $c_j \in V_C$
- $e \in E_{WC} \subseteq E$ between a warehouse and a city such that $e = (w_i, c_j) \in V_W \times V_C$, when a warehouse $w_i \in V_W$ is located in a city $c_j \in V_C$
- $e \in E_{WHO} \subseteq E$ between a warehouse and a organization such that $e = (w_i, ho_j) \in V_W \times V_{HO}$, when a warehouse $w_j \in V_W$ is used by a humanitarian organization $ho_i \in V_{HO}$
- $e \in E_{DHO} \subseteq E$ between a donor and a humanitarian organization such that $e = (d_i, ho_j) \in V_D \times V_{HO}$, when a donor $d_j \in V_D$ provides funding to a humanitarian organization $ho_i \in V_{HO}$

3 Ongoing work

Information availability during humanitarian interventions is a cornerstone to make relevant decisions. Authors like [4] state that the lack of information greatly hamper humanitarian operations. Although the exchange of information during collaborative working can reduce uncertainty [5], humanitarian workers are mainly focused on sending assistance to victims, than on information sharing. For humanitarian operations to be as effective and efficient as possible, solutions for information sharing need to be developed. Databases like Reliefweb.int already exist. But the data stored are rather used for reporting and accountability than for analysis and decision making purposes [6]. To fill this gap, in [2], the dynamic network mapping and analytics system provide near real-time information on the status of the roads' infrastructure. Aid organizations can in turn take enlightened decisions to reach affected populations. In this line, we propose a support decision system based on multilayer networks. We investigate two research topics of utmost importance for humanitarian operations, relief demand and forecasting. Relief demand is the basis for decisions making, and for performing field activities. In this work, we focus on the population demand. Besides the demand, we take into account services supply and material supply availability [7], in order to match needs and available supplies. Forecasting did not trigger a lot of research in the humanitarian context so far [8]. In this work, we focus on accessibility forecasting by studying the resilience of the road network. The goal is to provide advice to improve the network resilience. Note that this can be applied not only for forecasting but also in the heart of a crisis. The aforementioned objectives raise a body of research questions: RQ1. How to assess the relief demand of a population? RQ2. How evaluate the availability of some services or supplies? RQ3. How to match a need and an offer? RQ4. How to assess the resilience of a road network? RQ5. How to reinforce the resilience of a road network?

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