“Home Health Care vulnerability assessment using graph theory and matrix methods”

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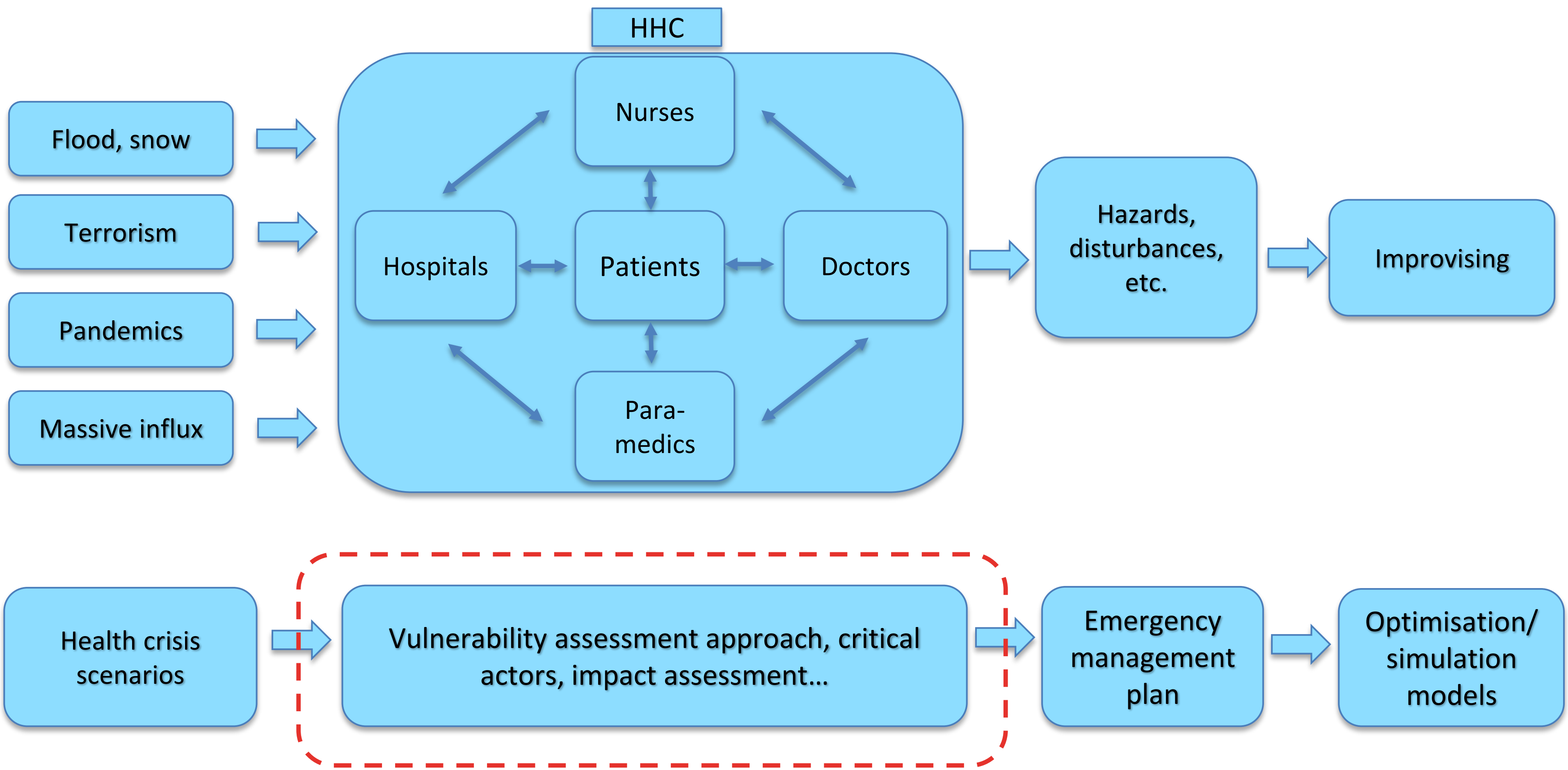
Agenda

- Context
- State of the art
- Vulnerability assessment approach
- Prospects

Context


HHC
Flood, snow
Terrorism
Pandemics
Massive influx
Nurses
Hospitals
Patients
Doctors
Para-
medics
Hazards,
disturbances,
etc.
Improvising
Health crisis
scenarios
Vulnerability assessment approach, critical
actors, impact assessment…
Emergency
management
plan
Optimisation/
simulation
models

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State of the art

Supply chain vulnerability assessment

Static

- Supply chain vulnerability (Faisal et al., 2006,Soni et al. 2014)
- Critical infrastructure vulnerability (Kamissoko et al.2013; Yazdani et Jeffrey, 2012)

- Use of graph modeling
- Definition of global vulnerability index

Dynamic

- Cascading events in chemical and process plants (Khakzad and reniers, 2015; Khakzad et al. 2016).

- Use of BN modeling dedicated to acyclic graphs

State of the art

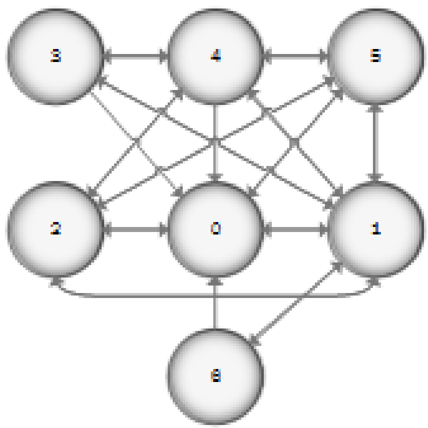
- Define a set of criteria for vulnerability assessment of each actor and flow facing different types of crisis.

- Provide indexes to assess the vulnerability of actors and flows based on actor resilience and flow robustness, using matrix operations that do not necessitate a big computational effort.

- Propose a method to calculate the dynamic vulnerability that takes into account the cascading events in a cyclic graph.

Vulnerability assessment approach

- 1- Digraph modelling:



$$F = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

N°	**Acteur**
0	Patients
1	Call centre
2	Nurses
3	Deliverers
4	Doctors
5	Hospitals
6	Collectors

Vulnerability assessment approach

2- Influence matrix:

Rule: « The more the flow is important for the actor (flow consumer), the more its degradation/breakdown has more probability to disrupt the functioning of this actor and the higher the associated value is. »

Verbal judgment	Assigned value (a_{ij})
No importance	0
Very weak	1
Weak	2
Medium	3
Strong	4
Very strong	5

Actors	0	1	2	3	4	5	6
0	0	4	4	0	0	3	0
1	3	2	3	4	4	3	3
2	5	4	2	0	3	2	0
3	4	3	0	1	0	0	0
4	3	4	4	0	2	2	0
5	3	3	2	0	3	1	0
6	1	3	0	0	0	0	1
Total	19	23	15	5	12	11	4

$$wf_{ij} = \frac{a_{ij}}{\sum_{l=0}^{6} a_{ij}} ; i, j = 0 \ldots 6$$

$$WF = \begin{pmatrix} 0 & 0.173 & 0.266 & 0 & 0 & 0.272 & 0 \\ 0.157 & 0.086 & 0.200 & 0.800 & 0.333 & 0.272 & 0.75 \\ 0.263 & 0.173 & 0.133 & 0 & 0.250 & 0.181 & 0 \\ 0.210 & 0.130 & 0 & 0.200 & 0 & 0 & 0 \\ 0.157 & 0.173 & 0.266 & 0 & 0.166 & 0.181 & 0 \\ 0.157 & 0.130 & 0.133 & 0 & 0.250 & 0.090 & 0 \\ 0.052 & 0.130 & 0 & 0 & 0 & 0 & 0.25 \end{pmatrix}$$

Vulnerability assessment approach

3- Actors resilience

- Resilience: the capacity to adapt existing resources and skills to new situations and operating Conditions (comfort 1999, Kamissoko, 2013).

➢ Criteria: Insufficiency of Capacity (IC), Lack of preparedness (P), Responsability (R).

- Example: measure of IC (quantitative)

- Lack of Resources (LR)
- Acceptable Lack of Resources (ALR)

⟶ $$R_{IC} = 1 + \frac{LR}{ALR}$$

Value of R_{IC}	Value of IC	Activity
$1 \leq R_{IC} \leq 2$	R_{IC}	Maintained
$R_{IC} > 2$	3	Degraded

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Vulnerability assessment approach

3- Actors' resilience

- Example: measure of P (qualitative)

  - **P = 1:** nominal state, without crisis.
  - **1<P<2:** the actor is more or less prepared to manage the disturbance (the value 2 can be seen as a threshold).
  - **P =3:** the actor is not prepared at all to manage the disturbance, he/she will improvise.

$$LRS(i,i) = IC(i) * P(i) * R(i)$$

$$LRS = \begin{pmatrix} LRS(1,1) & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & LRS(6,6) \end{pmatrix}$$

Vulnerability assessment approach

4- Flows' robustness

- Robustness: the robustness is the ability to maintain the operations intact while undergoing disruptions (Kamissoko et al. 2013).

  - Criteria: Lack of quality (Q), Cost (C), Delay (D).

Exemple: Measure of « D »

-D_0: Standard duration of flow delivery, without delay;
-D_1: Duration of flow delivery in times of crisis;
-DL= D1 – D0: Delay
-ADL= $(D1-D0)_{acceptable}$: Acceptable delay (threshold),

$$\longrightarrow \quad R_D = 1 + \frac{DL}{ADL}$$

$$D = \begin{cases} 1, \text{ if } R_D < 1; \\ R_D, \text{ if } 1 \le R_D \le 2\text{: acceptable delay;} \\ 3, \text{ if } R_D > 2\text{: above the acceptable threshold;} \end{cases}$$

$$D = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 3 & 3 & 3 & 3 & 3 & 3 & 3 \\ 3 & 3 & 3 & 0 & 3 & 3 & 0 \\ 3 & 1 & 0 & 3 & 0 & 0 & 0 \\ 2 & 3 & 3 & 0 & 3 & 3 & 0 \\ 3 & 3 & 3 & 0 & 3 & 3 & 0 \\ 2 & 1 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

;

Vulnerability assessment approach

5- Vulnerability assessment

- Vulnerability : vulnerability is the incapacity of a stake to resist to the occurrence of a feared event and to recover efficiently its nominal function during a given period of time (Kamissoko et al. 2013).

❖ Flows vulnerability:

$$FVI(i,j) = LRS(i,i) * LRB(i,j) \; ; i,j = 0 \ldots 6$$

$$FVI = \begin{pmatrix} LRS(1,1) & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & LRS(6,6) \end{pmatrix} * \begin{pmatrix} LRB(1,1) & \cdots & LRB(1,6) \\ \vdots & \ddots & \vdots \\ LRB(6,1) & \cdots & LRB(6,6) \end{pmatrix}$$

❖ Actors vulnerability

$$AVI(j) = \sum_{i=0}^{6} wf_{ij} * FVI(i,j); \; j = 0 \ldots 6$$

Vulnerability assessment approach

6- Dynamic vulnerability assessment

❖ A period (p) is the laps of time required for all flows to circulate once in the network.

- Initialization

$$DFVI(i, j, 1) = FVI(i, j); i, j = 0...6;$$

$$DAVI(i, 1) = AVI(i); i = 0...6;$$

- Dynamic Flow Vulnerability Index

$$DFVI(i, j, p+1) = DAVI(i, p) * FVI(i, j); i, j = 0...6;$$

- Dynamic Actor Vulnerability Index

$$DAVI(i, p+1) = \sum_{j=0}^{j=6} wf_{ji} * DAVI(j, p) * FVI(j, i); i, j = 0...6;$$

Vulnerability assessment approach

7- Actors classification

- Vulnerability Priority Index (VPI)

$$VPI(i,p)=\frac{DAVI(i,p)}{\sum_{j=0}^{j=6}DAVI(j,p)};i=0\dots6;$$

Période	**P=1**			**P=2**		
Indice	DAVI	VPI	Rang	DAVI	VPI	Rang
0	31.181	0.155	3	834.004	0.177	2
1	19.286	0.096	7	504.878	0.107	7
2	23.084	0.115	6	569.553	0.121	4
3	37.440	0.187	1	840.908	0.178	1
4	34.935	0.174	2	803.306	0.170	3
5	23.860	0.119	5	556.528	0.118	5
6	30.182	0.150	4	595.349	0.126	6

Prospects

- Establish a criteria Weighting (AHP),
- Define classes of actors (critical, influential, dependent, neutral),
- Define mitigation strategies according the actors’ classes,
- Define a “redesign” of the HHC supply chain aiming at minimizing the overall vulnerability of the structure.

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Thank you!

Do you have any questions?

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