Bayesian networks: an original approach towards the quantification of the resilience of a society after a large-scale event

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Resilience is probably the most famous of the unknown concepts: everyone – from psychology to engineering – uses the term but no one reaches a consensus on its definition in the domain of large scale catastrophes. Experts agree on the set of factors that favor a "good resilience". Nevertheless, a real benefit for decision making would be to know how much each of these factors contributes to resilience independently of the others. This in turn would enable the decision maker to take risk-informed decisions regarding the a priori improvement of those factors that most contribute to resilience.

This paper proposes an original method, based on the collection of twenty experts' view on the resilience of a society after a large-scale catastrophe. To enrich the qualitative knowledge of these interviews, a Bayesian Network approach permits to quantify the effect of each parameter on the resilience of a society.

The results show that there is no lever that permits to improve dramatically the resilience of a society. Implication of both government services and civil society and their collaboration is necessary to achieve a sustainable resilience. Nevertheless, neither government services nor society implication can be significantly favored by one of their "parents" in the Bayesian model, due to an important inertia.

From the decision making perspective, the main conclusions are that resilience after a large scale catastrophe would benefit from a strong local support from decentralized state resources. Whenever possible, decision should be taken locally to ensure the best fit to the needs of the population and ultimately, to lead to a better "rebound". The use of Bayesian networks brings an interesting and innovative method that permits a better comprehension of the functioning of the post-disaster rebound complex phenomenon.
For future research, we could improve the Bayesian network including spatial and temporal dimensions.

I. INTRODUCTION

There is a wide literature on resilience since many domains deal with this concept. Engineers, biologists, psychiatrists respectively apply the concept to materials and technical systems, to organism and living systems and to human being and social systems (Ref.1). In all these domains, the common point is the capacity to resist to important chocks: how can we afford extreme cold events and hurricanes? How a population of preys can survive to the invasion of a predators 'population? How to live again after the sudden or violent death of a close relative?

In the context of our topic, societal resilience is the ability of a social system (in a city or a nation for instance) to actively adapt and recover from unexpected disturbs. Behind this consensual but too large definition, there are a lot of debates on the question of the delimitation of the concept. The discussions deal with:

- the domains concerned by resilience: for instance a society can achieve a social resilience in the sense that all the social relations are recovered but no economic resilience. In that case, can we talk about the resilience of the global society?

- the duration of the recover : in the case of the Kobe seism in 1995, the port reconstruction was quite quick (so that the economic system recovered quite rapidly) whereas the living places reconstruction took more time (Ref.5). In the case of a long-term recovery, can we talk about a resilient process?
- the social groups concerned by resilience: should a recovery of the previous inequalities be considered as resilience?

As a consequence, defining resilience and, a fortiori, determining what can explain it seems to be a complex task since this concept has several realities and that it is complicated to get a global vision of this phenomenon.

Nevertheless, the literature permits to enlighten some key concepts playing a role in the resilience achievement.

The leadership seems to have an essential role: it must have a strong political force enabling it to inspire a vision (Ref.2, 7,8)). It has to be a model which inspires confidence (Ref.3). Another key aspect in the literature is the preparedness of all the society (leaders, firms, civilians, victims, media) and its ability to take initiatives, even in the long-run. Finally, the importance of the concept of collaboration between all the members of the society (between the different decisional levels, between the civilians and the experts (Ref.6) for instance, is also mentioned

The ambition of this paper is to propose a new intent to determine, which of these elements plays a major role and what are the mechanisms that rule the resilience process. To do that, we propose a new approach mixing both a qualitative and a quantitative approach to gain more information.

The following part is dedicated to the presentation of the presentation of the qualitative concepts and of the quantitative model. The third part will present the results. Finally, we will conclude and discuss the main limit and the main perspectives of this exploratory study.

II. AN ORIGINAL APPROACH OF BAYESIAN NETWORKS APPLIED TO QUALITATIVE DATA

Three main motivations drove the choice of the implementation of a Bayesian network of concepts: first of all, it gives a structure to semi-directive interviews. Moreover it permits to give a visual structure of resilience which can be helpful for the person to be interviewed. Last but not least, it will maybe permit to quantify the effect of both elements on resilience.

II.A. The construction of the model

A literature review on the concept of resilience permitted to determine the key elements which had a direct or indirect effect on resilience and the way each of them are related. The main conclusions of this work is that it is necessary to have 1) an efficient leadership (meaning that it has a strong political will and it is able to build trust), 2) have a prepared society that is able to accept to abandon the plans in favor of improvisation, to have a long-term vision. Moreover, the collaboration of all the actors (experts, leader, civil society, media, firms, international actors …) is essential, 3) develop an answer using the information and communication technologies to make the information quickly available.

Finally, 9 elements were organized in a network: they are the nodes of the Bayesian network presented in figure 1. The arrows represent a causal link between nodes and they indicate the sense of this influence.

The concept of resilience was defined to the respondents as “the capacity of a society to recover after a large scale catastrophe”. We voluntarily used an imprecise definition to let the respondents tell their own perception of the key concept of the study. Indeed, as long as there is no consensus on this definition, it could have been difficult to impose a definition some respondents would not agree with. We so defined 3 levels of resilience: “Good”, “Mean” and ”Bad”. The number of levels a node can take is written between brackets in figure 1.

In this conceptual network, resilience has two direct parents: the mobilization of civil society (victims of the event, firms but also the whole population) and the mobilization of public services (all the local executive organs of the state).

The civil society

The mobilization of the civil society is considered as good if it collaborates with the public services, if it is active in the information and rebound process. To the opposite, a civil society which would wait for the help of the society without being active in the rebound process would be considered as non-mobilized. 4 gradual levels compose this node. The network makes the hypothesis that this node has 4 parents: the preparation of minds, the availability of operational information, the media context and the mobilization of public services.

The public services

The public services are defined by 3 levels: they can be well mobilized if they are committed in their actions and have a long-term vision that enables them to take initiatives. To the contrary, they are considered as non-mobilized if they are not strongly committed and do not have any long-term vision. This node is expected here to depend on 4 factors of influence: the efficiency of the leadership, the availability of operational information and the media context.

The availability of information

This node has two levels: "the useful information is easily available" and "the useful information is not easily available". The idea is that even if the useful information exists it can be that it is not easily available (by the public, by the services…) because it is hidden by a stream of other information on the internet and on social networks for instance. In this network, this node depends on the level of the leadership.

The media context

Here again, two levels are defined. The media context can be either positive (if no rumors on the victims or wrong information generally circulate) or negative. This node also depends only on the level of the Leadership.

The efficiency of the leadership

We consider that the leadership is efficient if it manages the strategy, the mobilization and the information. To the contrary, it is considered as inefficient if he manages neither the strategy neither the information. Between those two extreme levels, two other describe a progressive loss of efficiency.

In this network, three elements are the parents of the efficiency of the leadership: the comprehension of the stakes, the adaptability of structures and the preparation of minds.

The stakes' comprehension

This node reflects the level of comprehension and consensus that exists between the experts about the stakes of the catastrophe. For instance, in the case of the economic consequences of a nuclear accident, one of the stakes to be clearly understood by the experts is that the radiological consequences are much lower that the economic consequences non directly linked to radiation. This node is composed of 3 levels, from the best level which describes a state where the experts understood the stakes and agree on this point, to the worst level where they do not understand what is really at stake and do not come to a consensus on the priorities.

The adaptability of structures

The best level of this node describes the fact that institutions (state institutions like the parliament for instance) are able to adapt their "normal" procedures to face the challenge and allow for exceptional measures. To the contrary, the worst level is described as a situation where the structures behave as usual, with long and non-exceptional procedures.

The mind's preparation

The preparation of the society means that everyone has a risk culture, has some radiologic knowledge (in the case of the nuclear accident) and is able to play its role. This node has two level: the minds are either "prepared" or "not prepared".

The institutions' preparation

This node has two levels: we consider that the institutions are "prepared" if they are even prepared to face unexpected situations. Otherwise, they are considered as "unprepared".

These four last nodes have no parents. We will call them "control variable".

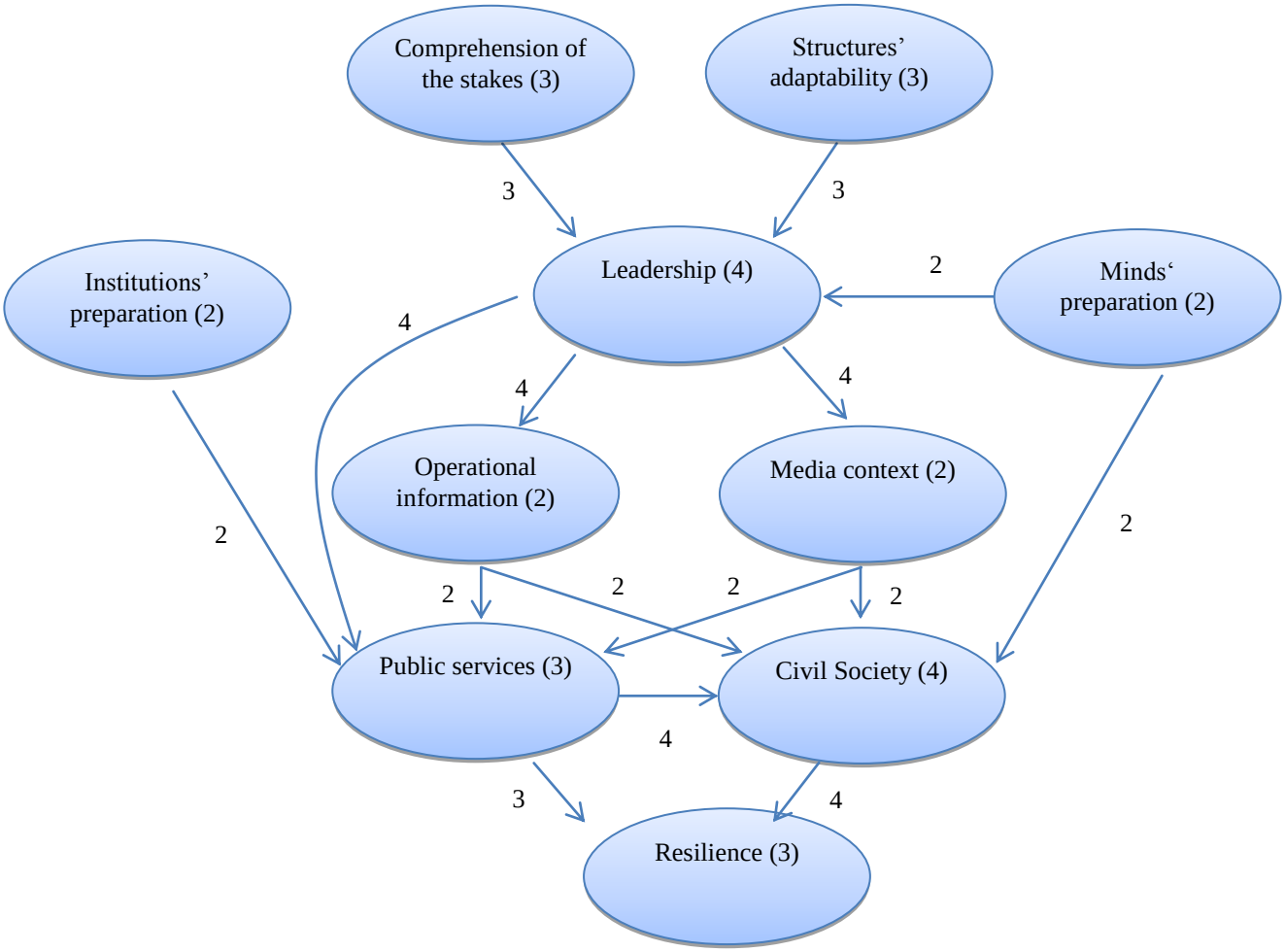

Fig. 1. Structure of the Bayesian network used for the purpose of this study

II.B. The elicitation format

In a classical Bayesian network with quantitative nodes, the causal link between two nodes is materialized by a node conjoint probability table. This table gives the probability of occurrence for each level of a node, given the level of its parents, for each possible combination of the parent's levels. For instance, for the node "Resilience" in Figure 1, the node probability table must inform the probability of the Node Resilience to be at its level 0, at its level 1 and at its level 2 when :

1. Public services is fixed at level 0 and civil society is fixed at level 0,
2. Public services is fixed at level 0 and civil society is fixed at level 1,
3. Public services is fixed at level 0 and civil society is fixed at level 2,
4. Public services is fixed at level 0 and civil society is fixed at level 3,
5. Public services is fixed at level 1 and civil society is fixed at level 0,
6. Public services is fixed at level 1 and civil society is fixed at level 1,
7. Public services is fixed at level 1 and civil society is fixed at level 2,
8. Public services is fixed at level 1 and civil society is fixed at level 3,
9. Public services is fixed at level 2 and civil society is fixed at level 0,
10. Public services is fixed at level 2 and civil society is fixed at level 1,

11. Public services is fixed at level 2 and civil society is fixed at level 2,
12. Public services is fixed at level 2 and civil society is fixed at level 3,

In the case of this article, as long as the nodes are qualitative and that we intend to measure the perception of a panel of experts, we ask to the informants to determine these tables. To simplify the elicitation we only asked the respondents for the marginal relations between nodes (and not the conjoint ones). It permits to get the probability of occurrence for each level of a node, given the level of one of its parents (independently of the others), for all the potential levels of the parent and for all the "parent" nodes. For instance, in the case of the node "Resilience", it implies that we asked the respondent to determine the probability of resilience to be at level 0, level 1 and level 2 given that:

1'. Public services is fixed at level 0
2'. Public services is fixed at level 1
3'. Public services is fixed at level 2
4'. Public services is fixed at level 3
5'. Civil society is fixed at level 0
6'. Civil society is fixed at level 1
7'. Civil society is fixed at level 2
8'. Civil society is fixed at level 3

We then develop a model to infer the conjoint probability table thanks to this information (see part II.C).

Good resilience
Mean resilience
Weak resilience

Fig. 2. Example of an elicitation card presented to the respondents

For each node, the elicitation process is the following;

- **General introducing step**: First people are introduced with the sense of the node and of its different levels. The interviewer gives them definitions and examples. Then, they are introduced with a card (like the one presented in figure 2) which represents the different potential level of the "child" node.

- **Step 1'**: We then define and present the first level of the first parent of the node to be evaluated (here level 0 of public services for instance). They receive 12 tokens to allocate to the different levels of the child node depending on their perceived probability that this level happens given the level of the "parent" node.

- **Step 2'** : We present the second level of the first parent node and ask the respondent to define a new allocation of the tokens.

- …

- **Step n'** : We present the last level of the last parent node to the respondent and ask him to determine the corresponding allocation of tokens.

At each step, the elicitation with tokens permits to determine the probability table (part II.C) but also to encourage an open discussion between the respondents and the interviewer. Indeed, this structured interview is a basis for a semi-directed interview. The comments (qualitative) are in this exploratory project as important as the probability determination (quantitative). The results of a wording analysis and a quantitative analysis are presented in part III.

II.C. The node probability table determination

To be able to use the Bayesian network, we have to translate our marginal causality relations into conjoint probability tables. The stake is so to determine the occurrence probability of a level's node given a combination of its parents' levels when we know the occurrence probability of this level's node given all the levels of its parents, independently of the others.
Adding and multiplying the marginal effect seem intuitive methods to recover a conjoint effect. We so made a series of tests to determine the optimal way of proceeding.

Simple additive and multiplicative models

Let us consider a simplified model composed of three nodes and presented in figure 2.

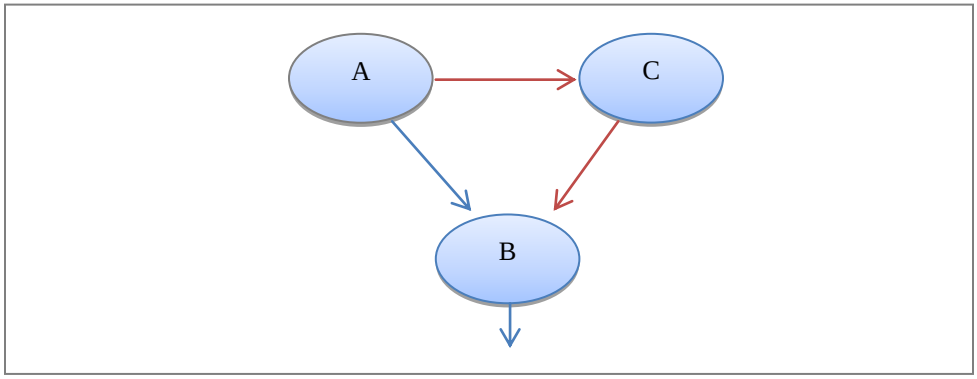

Fig. 2. Simplified Bayesian network with three nodes

The additive model consists in considering that a conjoint relation can be defined by the sum of the marginal relations which compose it.

As an example, the occurrence probability of "child" B when all its parents A and C are fixed at their 0 level is:

$$P_{add}(B_j) = \frac{A_0 + C_0 + D_0}{\sum_{j=0}^{p}(A_j + C_j + D_j)} \qquad (1)$$

with p the highest level of the "child" node

Numerator corresponds to the sum of the tokens the respondent stated for the level 0 of the parents in the marginal elicitation context. Denominator permits to normalize the result to 1 and ensuring that, for a given combination of parents' levels, the sum of probabilities for each child level is equal to 1.

The multiplicative model considers that a conjoint relation can be defined by the product of the marginal relations which compose it.

As an example, the occurrence probability of "child" B when all its parents A and C are fixed at their 0 level is:

$$P_{mult}(B_j) = \frac{A_0 \times C_0 \times D_0}{\sum_{j=0}^{p}(A_j + C_j + D_j)} \qquad (2)$$

with p the highest level of the "child" node

Note that this model necessitates that the null probabilities (when the respondents allocate the tokens it can be that they chose to allocate 0 token to one level) are replaced by a value ε which tends to 0.

Tables I and II illustrate this method. Table I presents the way the respondent allocated the tokens and table II presents the probability tables that both the additive (1) and the multiplicative (2) model can permit to obtain.

TABLE I. Example of a token allocation

« Parents » nodes values

« Child» node values

B_1	0	1	2
0	8	4	3
1	4	4	3
2	0	4	3
3	0	0	3

B_2	0	1	2
0	8	0	0
1	4	5	0
2	0	7	5
3	0	0	7

B_3	0	1
0	4	0
1	4	0
2	4	0
3	0	12

TABLE II. Node probability tables obtained by the additive model (1) and the multiplicative model (2)

1	0	1	2	3
0-0-0	0,56	0,33	0,11	0,00
0-0-1	0,44	0,22	0,00	0,33
0-1-0	0,33	0,36	0,31	0,00
0-1-1	0,22	0,25	0,19	0,33
0-2-0	0,33	0,22	0,25	0,19
0-2-1	0,22	0,11	0,14	0,53
1-0-0	0,44	0,33	0,22	0,00
1-0-1	0,33	0,22	0,11	0,33
1-1-0	0,22	0,36	0,42	0,00
1-1-1	0,11	0,25	0,31	0,33
1-2-0	0,22	0,22	0,36	0,19
1-2-1	0,11	0,11	0,25	0,53
2-0-0	0,42	0,31	0,19	0,08
2-0-1	0,31	0,19	0,08	0,42
2-1-0	0,19	0,33	0,39	0,08
2-1-1	0,08	0,22	0,28	0,42
2-2-0	0,19	0,19	0,33	0,28
2-2-1	0,08	0,08	0,22	0,61

2	0	1	2	3
0-0-0	0,80	0,20	0,00	0,00
0-0-1	0,80	0,20	0,00	0,00
0-1-0	0,00	0,99	0,00	0,00
0-1-1	0,00	0,99	0,00	0,01
0-2-0	0,47	0,24	0,29	0,00
0-2-1	0,00	0,00	0,00	1,00
1-0-0	0,67	0,33	0,00	0,00
1-0-1	0,66	0,33	0,00	0,00
1-1-0	0,00	0,42	0,58	0,00
1-1-1	0,00	0,42	0,58	0,00
1-2-0	0,00	0,00	1,00	0,00
1-2-1	0,00	0,00	0,19	0,81
2-0-0	0,67	0,33	0,00	0,00
2-0-1	0,33	0,17	0,00	0,50
2-1-0	0,00	0,42	0,58	0,00
2-1-1	0,00	0,21	0,29	0,50
2-2-0	0,00	0,00	0,99	0,00
2-2-1	0,00	0,00	0,00	1,00

The two models lead to small differences in terms of node probability tables and conduct to similar results when we globally analyze the network.

Adjusted models

We observed during the interviews that respondents tend to flee from the extreme answers: when we ask them the probability of the child when one of the parents is fixed at minimum (respectively maximum), they currently give a larger probability to the child's minimal (respectively maximal) level than when we set all the parents at their minimum (resp. maximum) level. As a result, one could observe in some cases a non-monotony of preferences which did not reflect the respondent's preferences.

To correct for this behavioral bias, we adjusted the responses to the range of responses given by the respondents for this node. For the extreme levels, the adjustment follows the following steps:

- Adjustment by lines: the multiplicative model (where the zeros are replaced by a value ε which tends to 0) implies some explosive values. We normalize to 1 the results. (This step is circled in blue in formulas 3 and 4).
- Adjustment by columns: if the respondent has never allocated more than 9 tokens to the best outcome of the child node, we ensure that the probability of the highest level never exceeds 0.75 (this step is circled in red in formulas 3 and 4).

$$P_{adjusted}(B_0) = ValMin(B_o) + (ValMax(B_o) - ValMin(B_o)) \times \frac{P_{mult}(B_{oc}) - Min_{\forall c}(P_{mult}(B_{oc})}{Max_{\forall c}(P_{mult}(B_{oc})) - Min_{\forall c}(P_{mult}(B_{oc}))} \quad (3)$$

With:

p the highest level of the "child" node,
Pmult (B0c), the probability determined for level 0 of the "child" node, by the multiplicative model for a combination c of parents' levels,
Min∀c (Pmult (B0c)), le minimum probability determined for level 0 of the "child" node by the multiplicative model, for all combination c possible,
Max∀c (Pmult (B0c)), le maximum probability determined for level 0 of the "child" node by the multiplicative model, for all combination c possible,
ValMin(B_0) the minimum number of token allocated by the respondent to the lower level of the "child" node,
ValMax(B_0) the maximum number of token allocated by the respondent to the lower level of the "child" node,

$$P_{adjusted}(B_p) = ValMin(B_p) + (ValMax(B_p) - ValMin(B_p)) \times \frac{P_{mult}(B_{pc}) - Min_{\forall c}(P_{mult}(B_{pc})}{Max_{\forall c}(P_{mult}(B_{pc})) - Min_{\forall c}(P_{mult}(B_{pc}))} \quad (4)$$

With:

p the highest level of the "child" node,
Pmult (Bpc), the probability determined for level p of the "child" node, by the multiplicative model for a combination c of parents' levels,
Min∀c (Pmult (Bpc)), le minimum probability determined for level p of the "child" node by the multiplicative model, for all combination c possible,
Max∀c (Pmult (B0c)), le maximum probability determined for level 0 of the "child" node by the multiplicative model, for all combination c possible,
ValMin(B_0) the minimum number of token allocated by the respondent to the lower level of the "child" node,
ValMax(B_0) the maximum number of token allocated by the respondent to the lower level of the "child" node,

The intermediary levels are then deduced from the extreme values (knowing that the sum of probabilities should equal 1), taking into account their relative weights in the simple multiplicative (or additive) NPT.

Table III presents the probability tables that both adjusted additive (3) and multiplicative (4) model can permit to obtain.

TABLE III. Conditional probability table computed with the adjusted additive (3) and multiplicative (4) models

3	0	1	2	3
0-0-0	1,00	0,00	0,00	0,00
0-0-1	0,44	0,22	0,00	0,33
0-1-0	0,53	0,25	0,22	0,00
0-1-1	0,29	0,09	0,07	0,55
0-2-0	0,53	0,07	0,08	0,32
0-2-1	0,22	0,11	0,14	0,53
1-0-0	0,76	0,14	0,09	0,00
1-0-1	0,33	0,22	0,11	0,33
1-1-0	0,29	0,33	0,38	0,00
1-1-1	0,06	0,18	0,22	0,55
1-2-0	0,29	0,15	0,24	0,32
1-2-1	0,06	0,02	0,05	0,86
2-0-0	0,71	0,10	0,06	0,14
2-0-1	0,31	0,19	0,08	0,42
2-1-0	0,24	0,29	0,34	0,14
2-1-1	0,00	0,14	0,18	0,68
2-2-0	0,24	0,11	0,20	0,45
2-2-1	0,00	0,00	0,00	1,00

4	0	1	2	3
0-0-0	1,00	0,00	0,00	0,00
0-0-1	1,00	0,00	0,00	0,00
0-1-0	0,00	0,99	0,00	0,00
0-1-1	0,00	0,99	0,00	0,01
0-2-0	0,59	0,18	0,23	0,00
0-2-1	0,00	0,00	0,00	1,00
1-0-0	0,83	0,17	0,00	0,00
1-0-1	0,83	0,17	0,00	0,00
1-1-0	0,00	0,42	0,58	0,00
1-1-1	0,00	0,42	0,58	0,00
1-2-0	0,00	0,00	1,00	0,00
1-2-1	0,00	0,00	0,19	0,81
2-0-0	0,83	0,17	0,00	0,00
2-0-1	0,42	0,08	0,00	0,50
2-1-0	0,00	0,42	0,58	0,00
2-1-1	0,00	0,21	0,29	0,50
2-2-0	0,00	0,00	0,99	0,00
2-2-1	0,00	0,00	0,00	1,00

III. THE RESULTS

The Bayesian network structure permits to have a basis of discussion with the respondents. One of the purposes of the study is to quantify the general network but also to have a qualitative discussion which gives necessary more information that a quantitative model.

Here, are presented the results of the qualitative analysis of the respondent's wordings. This analysis permits, for all nodes to determine how its parents influence it and which parent is the most important one. We then present the quantitative analysis which permit to have a broader vision of the resilience process, no more focusing on particular nodes.

III.A. Qualitative wording analysis

III.A.1. Leadership Efficiency

Half of the respondents agree on the fact that the three explicative factors of the leadership efficiency (comprehension of the stakes, structures' adaptability, and spirit preparedness) are complementary. According to them, there is no dominant parent; they are all necessary but not sufficient. The second half of respondents consider that the "preparation of minds" is slightly dominant positively (a good preparedness ensures to obtain a good level of leadership efficiency) whereas the "stake comprehension" node is negatively dominant (if there are no comprehension and consensus between experts, the leadership cannot be able to propose an efficient strategy).

III.A.2. Public services efficiency

The respondents who considered a complementarity of the "leadership's efficiency" node parents also perceive a complementarity of the 4 parents of the "public services" node (Leadership, institution preparation, media context and availability of operational information). Nevertheless, the leadership efficiency and the availability of operational information seem to be two dominant factors. The other major point is that for the respondents, the public services will necessary commit (so they are necessary quite good) but they cannot have a long-term vision and take initiatives if they have no leader or no information.

Note that there is no consensus among respondents on the fact that the media context has an influence on the services. To the contrary, for half of the respondents, the relation would be the reverse; for them, the actions of the public services may have an impact on the media context (an efficient intervention of the services would send a positive message to the media which would deliver more positive information).

III.A.3. Civil society efficiency

For this node, there is no complementarity of the parents: for the great majority of respondents, there is a positive or negative dominance of one of the parents (the public services, the availability of the operational information, the media context and the minds' preparedness).

A general idea is that the civil society cannot be efficient alone in the resilience process in the long-run (for some it is because civil society is unable to commit in the long-run and for others because it is not its role): it needs to collaborate strongly with the services and the state to commit itself in the long-run.

III.A.4. Resilience

Half of the respondents consider that the civil society has a dominant role whereas the other half thinks that the services have a dominant influence on resilience. Nevertheless, there is a general consensus on the necessary complementarity of the public services and the civil society to achieve a good level of resilience: they must collaborate.

III.B. Quantitative Bayesian network analysis

There are two interests in quantifying such a network of concepts explaining the resilience process:

- Translating into a concrete and understandable language the intuitions of "domination" of "importance" stated orally by the respondents. For instance, we know that the leadership efficiency seems to be dominant for the respondents in terms of influence on the public services efficiency. Quantification can permit to determine the weight of this domination and to compare different strategies to improve the public services efficiency. For instance, we can compare the increase of probability of the best level of the public services when the leadership efficiency is

improved and when the institution's preparedness is improved. Of course, we should observe that the improvement of leadership efficiency is more efficient in increasing the public services efficiency, since the respondents told that. Nevertheless, the interest of quantification is to know that the improvement of leadership efficiency is, for instance, two or three times more efficient that an improvement of institutions preparedness.

- Evaluating in a global way (and not only focusing on separate nodes) the resilience process. Here again, we know from the qualitative analysis that if we have a good leadership and a good availability of operational information, we end up with a good level of public services? We also know from the qualitative analysis that a good level of both civil society and public services commitment will induce a good level of resilience. Nevertheless, it does not permit to conclude that having a good level of leadership and operational information will necessary lead to a good level of resilience. The network can help us to understand how the forces circulate in the global system explaining resilience.

The quantitative analysis by nodes permits to give results in line with the qualitative results:

- If all its parents are fixed at their maximum level, the leadership node could reach a very good level. For simplification, we translated the *a posteriori* probabilities (the probabilities of the child to be at each of the possible levels knowing the levels of its parents) into a grade out of 20[1]. In that case the grade reached is 17/20.
- A good level of leadership leads to a good level of operational information (14/20) and a rather good level of public services (11/20 if another parent is fixed at maximum and the two other parents are at their lower level)
- Good levels of minds' preparedness and of operational information availability permit to reach a rather good level of civil society commitment (12/20 with the other parents at their minimal level)
- The services and the civil society nodes cannot reach excellent levels, even if their parents are all fixed at maximum. On the other hand, they cannot reach too bad levels even if their parents are all at the minimum level. It reflects the same results as the qualitative: for the respondents, these two actors are characterized by "inertia".

The second interest of the network is the analysis of its global behavior: can we achieve a good level of resilience by implementing a good level of the "control variables" (Comprehension of the stakes, structures' adaptability, and minds' preparedness and institutions' preparation)?

Figure 3 permits to answer this question. The figure represents the variation of the grade of each node when all the control variables are set at their maximum and minimum level. The main observation is that resilience does not vary a lot between these two situations: it suggests that these variables have a very small influence on the resilience. The control variables have a stronger influence on the leadership, which is efficient in transferring this positive force to the nodes "operational information" and "media context". Nevertheless, this effect is much lower on the direct parents of resilience: "Public services" and "Civil society" cannot reach the very high level which could permit to induce a good level of resilience.

[1] When the "child" has a probability 1 of being at its lower level, the grade is 0/20 and when the a posteriori probability tells that the child will be at its best level with certainty, the grade is equal to 20/20.

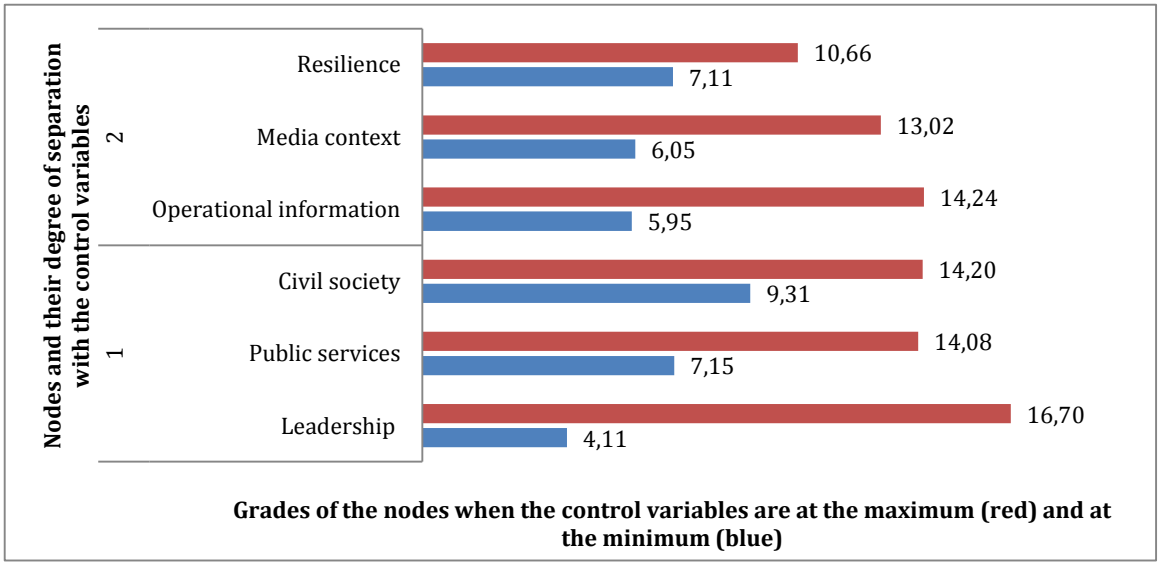

Fig. 2. Effect of the control variables on the different nodes of the model.

III. CONCLUSIONS AND PERSPECTIVES

The main conclusion of this exploratory work is that the architecture of resilience presented in this network of concept does not permit to achieve an excellent level of resilience. The main weakness of this organization is the fact that the direct explicative factors of this concept (the efficiency of the public services and the efficiency of the civil society) cannot induce a good level of resilience for two reasons:

- They cannot achieve a good level themselves because they are characterized by a sort of inertia. For the respondents the services and the society are "what they always are" and we cannot easily change themselves. As a consequence, they won't reach the worst outcome (they cannot be completely inefficient) but they won't nether be excellent.
- They are not sufficient to create an excellent resilience: according to the respondents resilience will be achieve thanks to the strong collaboration of these actors. The services need to act taking into account the needs and the knowledge of the civil society which can commit efficiently and in the long run only if it knows the implication of the services and of the state.

As a general conclusion one could say that to promote resilience, the decisional power should be given to local powers and services to promote a dynamic of collaboration between all the local actors (firms, victims, civilians, local power).

From the form perspective, this study proposes a new way of considering resilience after a large scale catastrophe. Considering the fact that no consensus is reached on the way resilience works, the purpose was to have discussion with several experts, starting from the same framework. This basis, which can be discussed concerning its construction and on the definition used, is a network of concepts. It gave a physical representation of the problem to be discussed. We also intend to complete this qualitative analysis by a quantitative analysis by quantifying this network thanks to the Bayesian network method.

The main conclusions of the quantitative analysis are consistent with the qualitative analysis so that we can be confident in the results given.

This exploratory project permitted to raise questions on some methodological points concerning the construction of such a network to be quantified. It appears that, for simplifying the elicitation, one should rather multiply the concepts (which are, here, sometimes too complex) and create two-levels concepts, more easy to understand. For instance, the efficiency of leadership was a complex node taking into account the ability of the leader to give the appropriate monetary resources, to implement a strategy, to pilot the information, to create a mobilization. We could imagine to split this node into several nodes taking only two levels "yes" or "no": " the leader implements a strategy", "the leader gives the appropriate resources", " the leader pilots the information", "the leader creates a mobilization" Moreover, some concepts such as collaboration between the services and the civil society should be added to the network.

REFERENCES

1. M. DE BRUIJNE, A. BOIN, M. VAN EETEN, "Resilience: exploring the concept and its meanings", *Designing Resilience*, Chapter 2, pp.13-32, Comfort, L.K.,Boin, A.,Demchak, C.C., Eds, Pittsburgh, University of Pittsbugh Press,(2010).
2. G. DJAMENT-TRAN, A. LE BLANC, S. LHOMME, S.RUFAT, S. REGHEZZA-ZITT, "Ce que la resilience n'est pas, ce qu'on veut lui faire dire", HAL Archives ouvertes (2012).
3. X. GUILHOU, P. LAGADEC, E. LAGADEC, "Les crises hors cadre et les grands réseaux vitaux- Katrina: Faits marquants, pistes de réflexion, Mission de retour d'expérience", EDF, (2006).
4. J.-C. MALLET, "Défence et sécurité nationale : le livre blanc", Présidence de la République, Ministère de la défense, La documentation Française (2008).
5. S. MENONI, "Chains of damages and failures in a metropolitan environment: some observations on the Kobe earthquake in 1995 ", *Journal Hazardous Materials*, pp.101-119 (2001).
6. J. TOURNON " Concentration: sur quoi ? avec qui ? ", Risques infos
7. M. USEEM, H. KUNREUTHER and E. MICHEL-KERJAN, "Leadership Dispatches Chile's Extraordinary Comeback from Disaster", Standfort University Press, (2015).
8. H.Harter, "Chicago et l'incendie de 1871 : entre mythes et réalité", *Mythologies urbaines, les villes entre histoire et imaginaire*, A.CABANTOU (dir.), Presses universitaires de Rennes, (2004).