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A proposition for a classification of the catastrophe systems based on complexity criteria

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Abstract. A classification system of catastrophic events is a methodology assembling all the catastrophes groups. It is possible to identify several catastrophes classifications. The most widely known are classified into: nature, consequences of the event, duration, affected territories and areas of the destroyed zone, and at last into the needed intervention measures. But these criteria of classification allow with difficulty to apprehend the complexity of the catastrophe. Thus we propose a classification based on the complex characteristics of the risks and catastrophes. Within the scope of this paper, we focus first on the complexity of the organization and the emergence of the phenomenon which result from it, and then, on the complexities resulting to the spatial and temporal scales of the catastrophe. The organization is considered as a central concept of the complexity. In the field of the catastrophe, the complexity of organization results essentially from the self-organization of the systems (the system develops its internal constitution and its behaviour thanks to the interactions between its various components and not thanks to an external strength). Phenomena as different as mantels of snow, seismic hazards, behaviours of people and population have characteristics of self-organization allowing the emergence of new events: snowslides, earthquakes, collective panic. A particular attention will be given to the emergence of this kind of panic in situation of disaster. There is indeed a double-way within two levels, a double action of the crowd on the individual and the individual on the crowd, without leader. It means that we need to take into account the multi-scales aspect in order to be able to study the behaviours. The complex systems of catastrophe have characteristics able to emerge at higher or lower levels of scales. It allows us to apprehend the complexity of the disasters through the scales. The disasters belong to the multifarious temporal- and space scales. First, the disasters can not be classified in one single category of spatial scale. Some of them appear on the scale of a territory, a region, a country or the planet. If we speak about a natural or technological disaster, none of them

will be automatically associated with a spatial scale. Furthermore, a local disaster can have large-scale impacts. Various events (attacks of September 11th, 2001 in New-York, the tsunami which ravaged the South of Asia in December 2004, the hurricane Katrina who destroys New-Orleans in 2005) remind us that the catastrophe is not always an event restricted at the affected area but can have consequences outside this area. The increase of the complexity of the disaster can result from the movement between different spatial levels and from systemic relations between these levels. The complexity also results from various temporal scales of the risks and the disasters. Three temporal phases can be found. The first one is relative to the temporality of the potential risk I mean what takes place before the disaster. The second phase refers to the temporality of the disaster I mean all what happens during the catastrophe. We show that during the disaster, the temporalities of the hazard, the vulnerability and the domino effects rarely happen together. The third and last phase refers to the time after the disaster and to the experience feedback for the risk management. These three temporal phases are based on two scales of time: a short time, I mean a time - action, inherent to the functioning of any dynamic system (Ch.-P. Péguy, 2001) and a long time. Thus, the catastrophe must be approached in various scales. And the study in each of the scales gives several information of the disaster in its whole, or about some of its components (hazard, vulnerability and domino effects).

1 Introduction

In the expression, "systems of catastrophe", the word "system" represents a set of elements in interaction, "an entity not reducible in its parts. (...) It [a system] implies the appearance of emergent qualities which didn't possess the parts" [1]. The word "catastrophe", in the sense of social and spatial disorganization of the territorial system affected by a disturbing event, implies that these interactions concern the various components of the catastrophe, namely the hazard, the vulnerabilities, and the domino effects I mean a chain of events, activated by hazard or vulnerability. Thus the catastrophe is at the interface of the nature-society relations, at the interface between the space of danger and the vulnerable space. In this article, we set up basis for a classification of the catastrophes established on complexity criteria. We focus first on the complexity of the organization and the emergence of the phenomenon which result from it, and then, on the complexities resulting to the spatial and temporal scales of the catastrophe. But first, we set up a panorama concerning the systems of existing classifications.

2 Classifications of the catastrophes based on a sector-related approach

A classification system of catastrophes is a methodology assembling all the disaster groups. It is possible to identify several catastrophe classifications based on a sector-related approach. The most widely known are classified into nature, it means the hazard being at the origin of the event. Therefore the catastrophes are either: -natural, technological or technical and can be as well the result of a social behaviour. Each of the groups will be again changed into subgroups. The natural catastrophes can be the result of an action of the earth, for example in case of earthquakes, volcanic eruptions, landslides, avalanches. It can be the result of an action of the water, for example in case of floods, tsunamis or drought, an action of the air and wind in case of storms and hurricanes, an action of the fire during fires caused by the lightning or the volcanic eruptions [2]. The technological risks have always anthropic origins. They include industrial, nuclear and technical risks or accidents of transport. These events can be again decomposed into subcategories. For example, the accidents of transport can happen: in the air, on the sea, on the road or by rail. Concerning the sociological catastrophes we can find 2 groups: the accidental ones and the ones which have been intentionally caused [3]. In the first case, they appear during crowd events, the crowd creating a disaster of appear with an external event: for instance the collapse of a building, of tier of seats. In the second case, the disasters are related to warfare or terrorism attacks. A second kind of classification is set up regarding the consequences of the event. These consequences are estimated mostly in term of losses, more rarely in terms of gains. They can be either material or human. The material consequences concern the deteriorations and the destructions of various infrastructures (houses, public establishment, industries, roads etc.). The categories of catastrophe also vary according to the number of victims. According to the amount of victims, the disaster will be considered as moderate, average or major. These data are mostly mixed with the nature of the disaster, in order to obtain the amount of injured and dead people for every type of catastrophe. The Emergency Disaster Data Base gives this type of information. The third classification can be realized with the needed intervention measures: local, regional, national or even international management measures to apprehend the disaster. Finally, scales of classification exist in the field of seismic or nuclear disasters. The Richter magnitude scale assigns a single number (from - 2 to + 9) to quantify the amount of seismic energy released by an earthquake and the earthquake effects. On the same way, the International Nuclear Event Scale gives 8 levels of severity: from the major accident to the most simple anomaly.

These classifications have an operational aim. They must allow the risk manager to anticipate the situations, to manage them during the catastrophic event, to increase the means of intervention and to ask for more support (international assistance for example during the tsunami in Asia in December, 2004), to identify the priority zones of intervention, and to realize rescue plans.

If these classifications have an operational aim, however, they present some limits. First, there are no common methodologies of disaster classification on a national or international scale. Furthermore, these classifications, based on a sector-related approach, are multifarious and rarely required in their variety to categorize a catastrophic event. It's thus difficult to realize comparisons between catastrophes of diverse previous history, if not in terms of human and material losses. Furthermore these classifications exist for a single type of risk. There is no multi-risks classification. Now, the urban societies, which are the most concerned by the disaster, are multi-risks societies. Finally, these criteria of classification allow us to apprehend the complexity of the catastrophe with difficulty. Thus we propose another way of reading of the catastrophes by setting up basis for a classification established on the complex characteristics of the catastrophes.

The complexity of a system of catastrophes is based on at least 4 criteria: those inherent to the organization of the system, those coming from the spatial and temporal scales, those resulting from geometrical forms of the risk and the disaster, and finally those resulting from the non-linearity and the unpredictable dynamics of the systems. These various types of complexity don't exclude each other but can be observe together during a disaster [4]. Within the scope of this paper, we focus first on the complexity of the organization and the emergence of the phenomenon which result from it, and then, on the complexities resulting to the spatial and temporal scales of the catastrophe.

3 Organization and emergence of phenomenon

The organization is a key concept of the complexity. We can differentiate two types of organizations: the structural organization (that is an organization in sub-systems or in modules) and the organization in levels. In the first case, the complex system of the disaster is constituted from sub-systems in interaction. These sub-systems are from now on well identified: it is about hazard, about vulnerabilities (human, building, network) and domino effects [5]. We will not mention it in details here. In the second case, the organization in levels interacting together creates new phenomena: some activate, strengthen or weaken the catastrophe. In the field of the catastrophes, the complexity of organization results essentially from the self-organization of the systems (*i.e.* the system develops its internal constitution and its behaviour thanks to the interactions between its various components and not thanks to an external strength [6]). Phenomena as different as mantels of snow, seismic hazards, population behaviours have characteristics of self-organization allowing the emergence of new events: snowslides, earthquakes, collective panic [6 op.cit.] [7, 8, 9]. The emergence is a polysemous notion. We shall use here the term of emergence in the sense of S. Kauffman [10]: the emergence implies that collective phenomena can't be explained by the properties of their constituents. In this paper, we propose a simulation of the emergence of the collective panic

from individual panic. The study of panic enables to put human vulnerability in the foreground of our analysis of disasters.

3.1 A model of panic

For the American school of thought, the mechanisms of panic propagation are based on behaviour of imitation, contagion or suggestion [9 op. cit.][11]. The crowd is then the support of phenomenon of contagion [12]. In the same way, the collective panic is characterized by an absence of coordination and dialogue between the individuals. The collective panic would thus appear from the diffusion of individual panic, without the attendance, the domination of a leader who would call to the panic.

In this article, we have chosen the system dynamics modelling and the Stella Research software to simulate the behaviour of panic during a catastrophe [13]. The mathematical formalism of this modelling is based on differential equations; the graphical formalism on stocks, flows, converters and connectors. System dynamics is a methodology used to understand how systems change over time. A dynamic system is therefore a system in which the variables interact to simulate changes over time. And, it is in the interaction that we have the source, the origin of the emergent phenomenon.

The proposed model represents the dynamics of transmission of the individual panic to the collective panic in a crowd. This model is based on the epidemiological models of W. Kermack and A. McKendrick. It is based on three simple hypotheses.

Hypothesis 1: we imagine a situation with a crowd constituted by three types of populations: the Population Susceptible to Panic (Psp), the Panicking Population (Pp), and the "Non-Panicking Population" (Npp). In a crowd, we can observe interactions between these three populations.

Hypothesis 2: Panic is a phenomenon of contagion, of collective imitation [14]. We use transmission rate to apprehend the contagion of the panic between both human populations in contact. Indeed interactions between human populations do not necessarily lead to contagion. This transmission rate is a coefficient which varies from 0 to 1, *i.e.* a low to a high contamination.

Hypothesis 3: After a certain period of time, people will stop panicking and resume normal behaviour. In the model, there is an outflow which "empties" the stock of the panicking persons. This outflow is proportional to the numbers of individuals in panic and the return time to normal behaviour (Rtn).

These hypotheses simplify sometimes the real situations. For example, we ignore any subdivisions of the population by age, social structure [15], or others factors, although such distinctions are obviously of importance.

Figure 1 shows a Stella version of a situation of panic behaviour. This model includes three stocks of population: the population susceptible to panic (Psp), the panicking population (Pp) and the "non-panicking population" (Npp), *i.e.* people will stop panicking and resume normal behaviour; inter-

actions between these three types of population, transmission rate of panic (Tr), return time to a normal behaviour (Rtn).

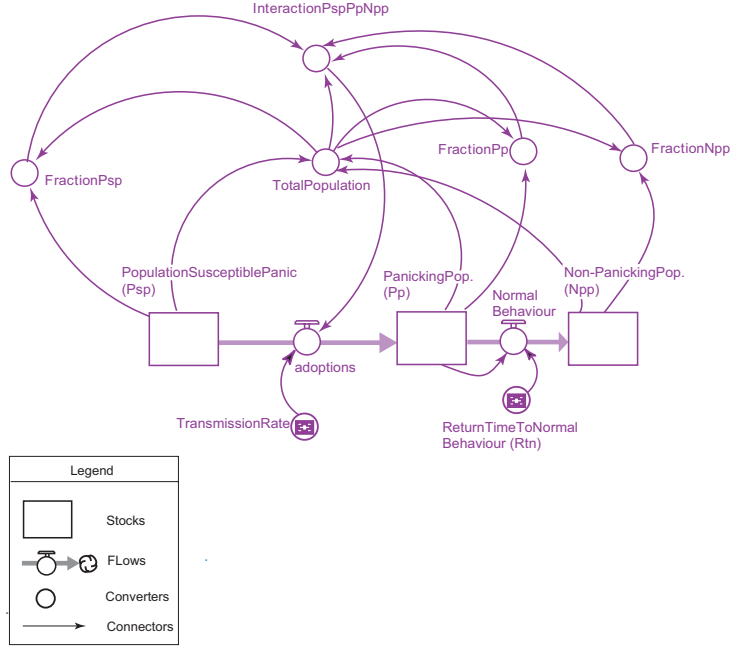


Fig. 1. A model of panic

The corresponding equations are:

$$Psp(t) = Psp(t - dt) - (adoptions) * dt \quad (1)$$

$$Adoptions = InteractionPspPpNpp * TransmissionRate \quad (2)$$

$$Pp(t) = Pp(t - dt) + (adoptions - Normalbehaviour) * dt \quad (3)$$

$$Normalbehaviour = Pp/Rtn \quad (4)$$

$$Npp(t) = Npp(t - dt) + (NormalBehaviour) * dt \quad (5)$$

The focus of this paper is a formal modelling, but not the prediction results of the panic behaviour.

3.2 Simulation results

We present results of simulation for different values of initial conditions of panicking population and of parameters related to the model. We will focus more particularly our attention on the spread and the emergence of panic. The population susceptible to panic is always equal to 500 individuals. Three cases are presented. The cases 1 and 2 present simulation results for initial different conditions of panicking population. In these two cases, the transmission rate of the panic is equal to 1 and the return time to normal behaviour to 24 units of time. The case 3 shows the evolution of the model when the transmission rate and the return time to normal behaviour vary. The representation of variables on a phase plan (Figures 2 to 6) allows us to show the various trajectories of the system.

Case 1 :

- $Psp = 500$
- $Pp = 13, Pp = 50, Pp = 100, Pp = 200, Pp = 300, Pp = 500, Pp = 600$
- $Npp = 0$ (at the beginning of the simulation, this stock is equal to 0 because the panicking persons have not found yet their normal behaviour)
- Transmission rate (Tr) = 1
- Return time to a normal behaviour (Rtn) = 24 units of time

Figure 2 shows that for the values of the panicking population ≥ 12 , and for $Psp > Pp$ or $Psp < Pp$, all the trajectories of evolution aim to the equilibrium point where Psp and Pp are zero. The panicking population and the population susceptible to panic tend to disappear. For different values of Pp , we do not observe qualitative modification of the model. Trajectories have the same shape. They spread on various points on the Y axis (as soon as the curve reaches the axis Y (Pp), then the values of Psp are zero for various values of panicking population), before converging all to the same equilibrium point. All these trajectories show that for a high transmission rate of panic ($Tr = 1$) and a return time to a normal behaviour equals to 24 units of time, there is emergence of the panic (upward slope), before reaching a equilibrium point. The emergence of the panic is particularly visible for low initial values of panicking population (13, 50 and 100). Beyond these values, the slope of the curve is smoother. This equilibrium point with coordinates (0,0) can be explained by the flow "normal behaviour" which tends to empty the stock "panicking population" and to feed that entitled "non-panicking population". Figure 3 shows the phase plan for "panicking population" and "non-panicking population". For every trajectory, in the similar profile, we can identify two breaking points: a first point of break indicates the transition from the decrease to the emergence of the panicking population; and a second breaking point where the trajectory of the system tends to the increase of the "non-panicking population". As soon as the curve reaches the axis Y (Pnp), then

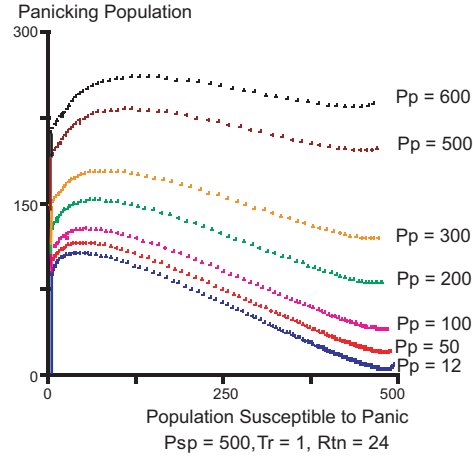


Fig. 2. Phase plan of population susceptible to panic and panicking population

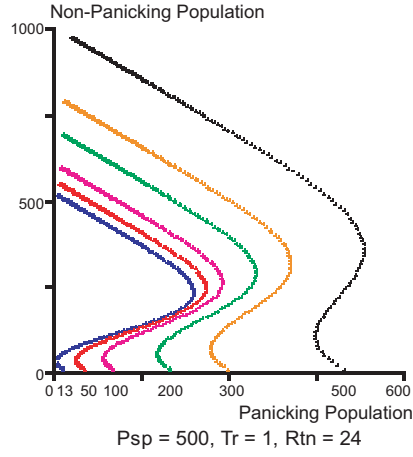


Fig. 3. Phase plan of panicking population and non-panicking population

Pp is zero. All the equilibrium points spread to the axis Y .

Case 2 :

- $Psp = 500$
- $Pp = 11$
- $Npp = 0$
- $Tr = 1$
- $Rtn = 24$ units of time

On the other hand, for values of $Pp < 12$, we observe a qualitative modification of trajectories (Fig. 4). The phase plan is completely different from the

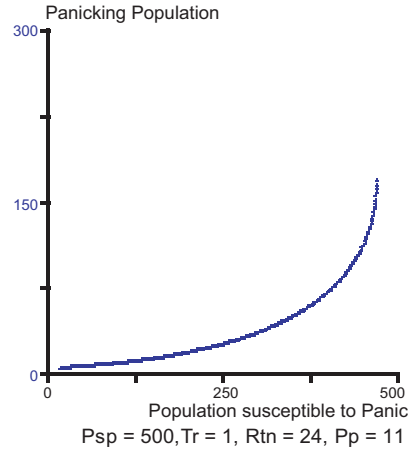


Fig. 4. Phase plan of population susceptible to panic and panicking population - An effect of threshold

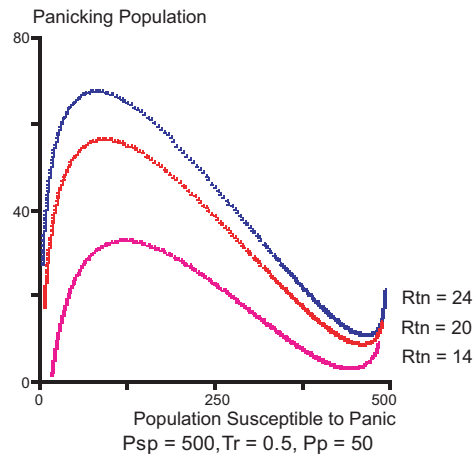


Fig. 5. Phase plan of the variables Psp and Pp for $Rtn > 13$

previous case. The trajectory converges to an equilibrium point (coordinated 0,0), but contrary to the previous case, there is no emergence phase of panic. The transition from 12 to 13 panicking persons with 500 persons susceptible to panic modifies qualitatively the dynamics of the system. There is a bifurcation, an effect of threshold, with $Pp = 12$, the "value threshold" beyond which there is effectively emergence of the panic.

Case 3 :

Finally, we study the system evolution by making vary the transmission rate of the panic ($Tr = 0.5$) and the return time to normal behaviour. Six tests

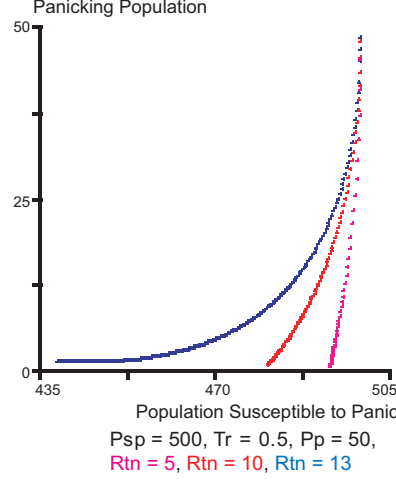


Fig. 6. Phase plan of the variables P_{sp} and P_p for $R_{tn} \leq 13$

are realized with values of R_{tn} equal to 14, 20 or 24 (Fig. 5) or equal to 5, 10 or 13 (Fig. 6). The population susceptible to panic is equal to 500, the panicking population is equal to 50. For a "return time to normal behaviour" (R_{tn}) equal to 14, 20 or 24 units of time, the phase plan is identical to the case 1 (Fig. 2). There is a first phase corresponding to the decrease of the population susceptible to panic and the panicking population, a bifurcation then the emergence of the panic before reaching a bifurcation bringing the system to a new state of equilibrium where P_{sp} and P_p are zero. On the other hand, trajectories are different for return time to normal behaviour, equivalent to 5, 10 or 13 units of time. The modification of R_{tn} influences the proportion of persons susceptible to panic and panicking people. The panic can't spread over.

The emergence of the panic does not appear in every situation. This emergence depends on the transmission rate, the return time to the normal behaviour, but also on the number of panicking population at the beginning of the simulation. The complex systems of catastrophe have characteristics able to emerge at upper levels of scales. It allows us to apprehend the complexity of the disasters through the scales.

4 The spatial and temporal scales of the disasters

The scale notion has a main place in the study of the catastrophes. Indeed, the disasters belong to the multifarious temporal- and space scales. First, the disasters can not be classified in one single category of spatial scale. Some of them appear on the scale of a territory, a region, a country or the planet. It allows

us to distinct the disasters which are considered as localized from the more diffuse ones. But, if we speak about a natural, a technological, a social or a sanitary disaster, none of them will be automatically associated with a spatial scale. For example, terrorism, present on a world scale, can affect a confined territory, and have something of an impact on vast territories. Furthermore, we can note that metropolis play a role of "spatial switch" which enables the disturbance to spread outside the initial impact zone and on multiple scales (agglomeration, region, country, planet) [16]. Thus, a local disaster can have multiple scales impacts. We can proceed from the same assumption for more diffuse risks. Various events (the tsunami which ravaged the South of Asia in December 2004, the hurricane Katrina which destroys New-Orleans in 2005, the climatic risk) remind us that the disaster is not always an event restricted at the affected area but can have consequences outside this area. Regarding this various spatial scales of disaster, we have to consider the interaction of the scales of intervention (not only the local and regional one, but also sometimes the international one). The increase of the complexity of the disaster can result from the articulation between different spatial levels and from systemic relations between these levels. The question of the interaction of various spatial scales is certainly a theoretical and methodological challenge for the researchers in science of the risk. Indeed, studies of risk are mostly limited to a single spatial scale. The multi-agent formalism or cellular automata give certainly possibilities to study the various scales of a catastrophe.

The complexity results from various temporal scales of the cycle of the disasters. Three temporal phases are identified [17]. The first one is relative to the temporality of the risk as well at the level of the physical or social processes as at the level of the regional planning and prevention policies I mean what takes place before the release of the hazard. Generally these events work on a long temporality. The second phase refers to the temporality of the disaster I mean all what happens during the catastrophe. Mostly the temporality of the catastrophe is of short duration. But we showed that during the disaster, the temporalities of the hazard, the vulnerability, the domino effects and the rescue operations rarely happen together. Models of simulation showed the existence of temporal gaps between these three constituents [18]. The third and last phase refers to the time after the disaster and to the resilience of the system. It is possible to classify the systems affected by a disaster according to their resilience that is to say according to the time needed to return to the initial situation after a disturbance, for example after an environmental disorder [19]. Resilience gives us the possibility to study the catastrophe not any more from the point of view of the event but rather from the angle of the crisis. This concept of resilience requires us to apprehend the system of the disaster in its whole. This return time to equilibrium depends on the extent of the disaster and the damage, on the adaptability of the society and on the type of properties [20]. These three temporal phases are based on two scales of time: a short time, I mean a time - action, inherent to the functioning of any dynamic system [21] and a long time. The short

time square with the rapidly developing disasters (some exceptions do exist: famine, drought are slowly developing disasters). It is also the time of the alert and of the management of the event. On the other hand the long time is the time of the prevention, the anticipation of the consequences resulting from these phenomena, the experience feedback. It can also be the time of the processes. For example, during an earthquake, the energy accumulates slowly in the fault networks (long time), before being brutally released (short time). Long phases of stability are juxtaposed to intense and brief fluctuations [22]. Furthermore, there are temporal relations not only between the various phases of the catastrophe cycle but also between the entities which constitute every phases of the cycle. Some events depend on the occurrence of other events (for example, vulnerability of the population, buildings etc. depend on the occurrence of the hazard, prevention measures are being often established after the disaster etc.), on some states of the system (the alarm system mobilize the evacuation forces).

It is thus necessary to study the cycle of the disaster in its various phases: the long time of the processes, the effects of threshold at the origin of the release of the hazard, the time of the catastrophic event and that of "after disaster". And the study in each of the scales gives several information of the disaster in its whole, or about some of its components (hazard, vulnerability and domino effects). Let us take an example: the floods of the Seine and the risk of inundation of Paris. The hazard can be studied on the scale of drainage basin (study of the precipitations on the whole basin and determination of the stream flow of the river, *i.e.* hazard), the catastrophe on the scale of the city (flooded surface and vulnerability of the population = vulnerability) and of the country (impact of the flood on the economy = domino effects) and the resilience on the city, national and world scale. Each of these scales is interesting. They offer different information on the catastrophe. Thus it's necessary in a modelling approach of phenomena to clarify the levels of observation and modelling [23].

5 Conclusion

In this article, two types of complexities were more particularly studied: the first one concerned the concept of organization and the emergence of phenomena; the second one is relative to the multi-scales character of the catastrophe. This proposal to classify the disasters according to criteria of complexity is certainly imperfect and must be further refined. However this classification leads to the conclusion that you have to apprehend the disaster on a different way, that is to say to exceed the disciplinary approaches and to establish comparisons between the various categories of disaster. The natural, technological or social disasters have similarities which can be identifies with the help of the sciences of the complexity. It leads us to compare disasters of different origins, different impacts (in terms of human and financial losses), different

duration, different required measures and different territories. It would not be in conflict with the already existing classifications, but so we can apprehend the catastrophes in another way, taking into account all the complex aspects. It enables us answering following question: is one system of catastrophe more complex than the other? It gives the possibility of more differentiated answers for the spatial and temporal management of the catastrophe.

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