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Chains of damages and failures in a metropolitan environment: some observations on the Kobe earthquake in 1995

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Abstract

The interaction and the couple effects that may occur as induced and indirect consequences of any triggering hazard in metropolitan areas is one of the most important problems to be tackled during disasters, as the Kobe earthquake in 1995 showed very clearly. The analysis of direct, secondary and indirect effects of the Kobe earthquake suggests to substitute the concept of chain of losses and failures to the simple couple hazardous event-damages which is currently used. Not only parameters related to physical weakness or strength of the built environment should be considered by scientists, experts and decision-makers. Organisational, social, and systemic factors are equally crucial to understand the magnified dimension of disasters at increasing levels of exposed systems vulnerability. Linking failures due to different kinds of vulnerability one to the other permits to reconstruct complete event scenarios, where social and organisational elements are not simply added to the 'hard' components of cities, but contribute to explain why failures and losses occurred and why it took so long to repair them. Lifeline damage assessment provides a good example to show how physical, organisational and systemic vulnerabilities are intimately connected one to the other. The point of view from which governance problems related to prevention and emergency preparedness will be looked at is that of an urban and regional planner. When planners look for design solutions suitable for a specific town or region, they must constantly bridge between hard technical matters and social and economical concerns. Furthermore, they are forced to consider in their projects spatial and geographic dimensions. Those two typical features of planners' approach to problem solving can be interesting for scholars in the field of risk assessment and mitigation research.

Keywords: Kobe earthquake; Lifelines; Systemic approach; Emergency management; Disaster scenarios

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1. Introduction

In the last years, there has been a considerable change in the way risks are perceived not only by the lay public but also by the scientific community. A different approach to calamities is progressively taking over the strictly technical perspective: the recognition that social, psychological, and economic factors are important to deal with emergencies and especially to prevent them is evident when conference programs of 10 years ago are compared to today's ones. In the latter, even when the main topic is the scientific characterisation of hazards, a much larger room is devoted to sessions where public policy and social issues are discussed. The involvement of experts with different backgrounds is increasingly called for in the attempt to improve current preventive strategies.

Studies aiming at analysing the hazard component produced limited results, or, better said, improved the understanding of natural phenomena without achieving though a satisfactory control of all the parameters at stake. In fact even if it were possible to develop a perfect alerting system — still the question of how to evacuate the exposed population from densely inhabited areas would remain unattended.

The second factor of the risk equation, vulnerability, has to be taken into account as well. How prone are exposed systems to be damaged in case a severe natural hazard strikes in a given region? Answering this question requires the co-operation of several disciplines, including those that were left aside from scientific risk studies until very recently. It is not surprising then that vulnerability assessment has been pointed at as the most promising field for future research, together with plan making and implementation [1]. Among the actions "local governments and partners in the private sector can take to foster sustainability" Burby [1] (pp. 275–276) underlines the need for "systematically assessing vulnerability and risk, establishing planning processes through information and possible use of action, and working collaboratively with stakeholders to devise land use management strategies".

In this changing arena, in fact, new opportunities have opened also for planners, traditionally considered the end-users of risk analyses, as those who should have taken the latter into account for setting conveniently urban functions and land use regulations. Planners can do more than this, providing present risk scenarios with the spatial and geographic dimension they are generally lacking. Furthermore in their everyday activity of trying to control urban development and transformation they must constantly bridge between technical factors and social needs.

It can be argued that disasters are complex events, because many factors interact often in unexpected ways giving rise to problems that were not accounted for in emergency plans. However, a disaster occurring within a metropolitan area is far more complex than in any other place, because of the concentration of people, functions, facilities, storage sites of food, water, and also of dangerous materials.

The interaction and the couple effects that may occur as induced and indirect consequences of any triggering hazard in metropolitan areas is one of the most important problems to be tackled, as the Kobe earthquake in 1995 showed very clearly. Many lessons can be learnt from that event and its aftermath, not only regarding seismic issues, but also with respect to the very demanding task of facing emergencies, recovery and reconstruction in a large and modern metropolitan area.

The attention should be focussed on some induced disasters caused by the ground motion, like the many fires ignited by gas leakage as well as on the long-lasting effects of lifelines disruption. Such an analysis enlightens the concept of chain of losses and failures, which better fits to disasters in a metropolitan environment than the simple couple hazardous event/damages that is currently used. Linking various failures one to the other and to organisational and systemic factors is crucial to understand the magnified dimension of disasters at increasing levels of exposed social and physical systems vulnerability. It permits to reconstruct a complete event scenario where social and organisational elements are not simply added to the 'hard' components of cities, but contribute to explain why given damages occurred and why it took so long to repair them.

Nevertheless, most of the lessons learnt by local and national agencies after the Kobe event refer to technical countermeasures which can be added to individual systems or components so as to make them redundant and more reliable in case of any triggering hazard. Unfortunately, it can be demonstrated on the ground of the same Kobe disaster, that solutions relying too heavily on technological fixes, no matter how sophisticated, tend to fail if they are not combined with organisational improvement of emergency and recovery operations.

2. The earthquake

2.1. The event

The 17th of January 1995, at 5.47 a.m. a violent earthquake, 7.2 on the Richter scale, hit Kobe, one of the largest cities of the Kansai area in Japan.

The epicentre was located in the Awaji Island, at only 20 km south of the town centre. The quake provoked many victims: 43,177 people were injured, 6300 died, 5500 of whom in the town of Kobe. These numbers are not exact figures of the earthquake impact, as they differ from one report to the other. They just provide an idea of the disaster magnitude. Seismic waves propagated along the coastal line, parallel to the Rokko Mountains (as it can be seen in Fig. 1), thus hitting all the urban settlements located along the SO-NE direction (like Ashiya, Takarazuka, Amakasaky). Very little damage was reported in Osaka, which lies quite close on the Osaka Bay, but in the E-O direction. 320,000 people were left homeless, as 93,775 houses collapsed, 106,000 were partially damaged, and 7000 were burnt during the fires spreading as a consequence of ignited gas leaking from damaged pipes, especially in the southern part of the city.

The real story about those quite extensive fires is hard to tell; what can be said is that automatic gas shut off failed and that managers at the Osaka Gas (the third gas company of Japan, serving the entire conurbation of Osaka and Kobe) waited until 11.00 a.m. to cut down the service to 1.5 million customers.

The Kobe disaster has been extensively studied and analysed, mainly in Japan but also elsewhere in the world, because it was the first real case of a strong earthquake affecting a large and densely populated metropolitan area. Other seismic events of the XX century either struck large towns before the huge development they underwent after the World War II or affected smaller settlements. Kobe was, therefore, considered an important test for similar cities in developed countries.

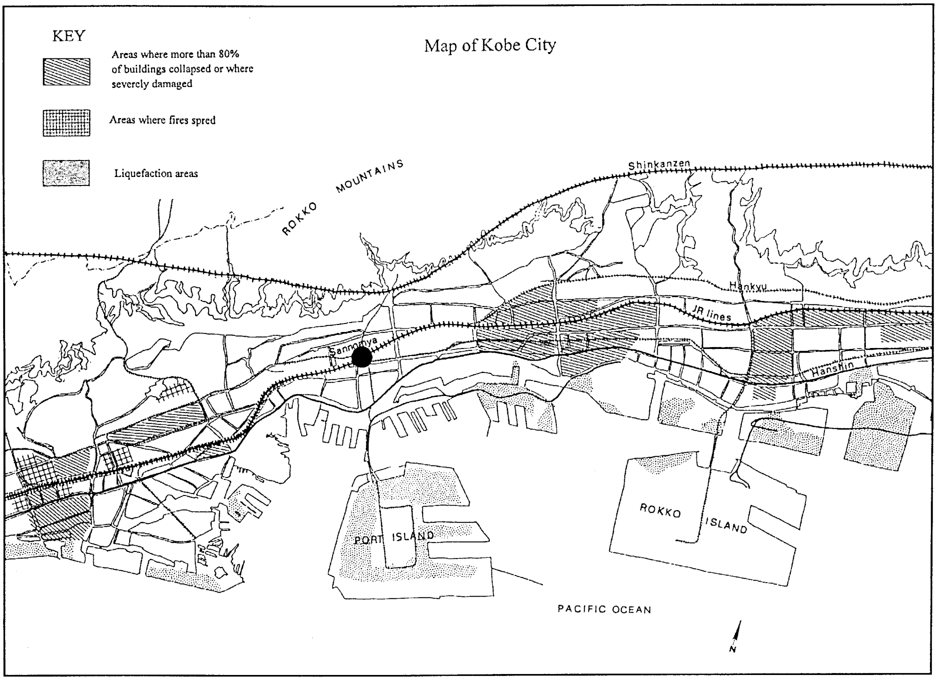


Fig. 1. Map of Kobe city.

It should be recalled that the Japanese were not expecting such a strong ground shaking in this part of the Kansai area. In foreigners' mind, whole Japan is particularly prone to earthquakes, however, the perception is quite different in the country and particularly in the South, where typhoons represent the most threatening hazard. Highest seismic intensities are expected in Tokyo, where the 'big one' is yet to come, according to many seismologists. Although some scientists had found evidence of seismic activity in the Kobe area long before 1995, authorities and local administrations had taken very little initiative for promoting earthquake emergency preparedness among the citizens and had not prepared specific plans and programs. The result was a quite chaotic response, especially in the first hours and days after the 17th January event, and it took a rather long time for central authorities to grasp the scope of the catastrophe [2]. Foreign media, but also national ones, were surprised by the lack of preparation and co-ordination of civil protection agencies in Japan — a country that many considered resilient and provided of robust antiseismic devices to face any earthquake. Clearly reality was different and the same Japanese were confronted with repeated organisational and systemic failures.

It might be objected that the Kobe earthquake had been particularly strong; nevertheless many buildings constructed according to the newest antiseismic codes (especially those passed in 1984) suffered little damage. Most collapses occurred in old wooden houses, poorly constructed with heavy roofs to protect them from typhoons. In many cases owners had taken away central columns in first floors converted into garages, small manufactories or storage rooms, thus diminishing buildings resistance.

2.2. The reconstruction phase and critical revision of the disaster

The reconstruction process developed at two speeds: very fast for infrastructures, firms, administrative and commercial districts; very slow for private citizens, who could not afford to rebuild their homes. Even today, long after the event, there are still people living in temporary shelters even though these were designed to last just for 2 years.

Market forces put pressures to reconstruct as quickly as possible transportation networks to long distances and commercial and office buildings, hampering efforts to implement lessons learnt from the disaster in the attempt to reduce pre-earthquake vulnerability. In Kobe, engineers certainly applied some technical fixes suggested by post-earthquake damage analysis, but generally pre-event patterns were followed with little change. For example, safety distances between highways, railways and buildings were not respected, so that physical mutual interactions have to be expected in the case a similar (or even smaller) earthquake occurs.

Along with the reconstruction effort, the academic and scientists community carried out a very large and detailed damage survey, and analysed the reasons of failures in confronting the calamity. Engineers, architects, geologists, seismologists, sociologists, psychologists, talked each about the disaster from his/her partial point of view, without forming an overall picture that might be used by decision-makers and public administrations to test alternative options of intervention. An exception is provided by the report issued by a group of researchers at Kyoto University in May 1995 [3]. In the latter technical analyses of damage conducted by engineers, were completed by descriptions concerning social and psychological effects on the hit population. The main limitations of this work are due to the fact that it is closer to a description of what happened in Kobe than to a multifaceted explanatory model. This hindered perhaps its continuation in developing the initial multidisciplinary effort. The group of researchers at Kyoto University is nevertheless trying to promote the construction of a comprehensive seismic scenario, including economic and social parameters, despite of difficulties that can be easily imagined in a country where hyper-specialised investigations are preferred in the academy and a rigid division of labour is the rule in public administrations as in private companies.

In their opinion, the efforts to prepare to future emergencies undertaken by public officials in Kobe should be further evaluated. For instance, the information systems recently installed in control rooms by the Hyogo Prefecture and the Kobe city seem to them too rigid. Real time information regarding hazardous events that may occur in any part of Japan can be gathered in those rooms through seismometers and meteorological stations. Other data, like maps and population statistics are stored in the system, which is quite similar to others installed in various countries to enhance current practices of information exchange among civil protection agencies.

3. The systemic approach

Several scholars state that disasters are complex events, as many factors often interact in unexpected ways giving rise to problems that were not accounted for in emergency plans. However, a disaster occurring within a metropolitan area is far more complex than in any other place, because of the concentration of people, functions, facilities, storage sites of food, water, and also of dangerous materials, used in hospitals or processed at risky plants inside inhabited quarters.

The interaction among systems can potentially lead to induced and indirect effects, as the Kobe earthquake in 1995 showed quite dramatically. Complexity is not just a question of quantities, in terms of number of people and artefacts at stake, it also derives from qualitative aspects, like social and economic factors as well as from the relations that developed historically between settled populations and their environment. Besides physical parameters, like building typologies, materials, age of construction of houses and infrastructures, equally important are indicators related to how this environment is used, how resources and settlements are accessed, what are the rules regulating the function of services. In other words 'soft' parameters are as important as physical to grasp the complexity of different kinds of settlements, but especially of metropolitan areas.

Apparently the picture after an earthquake is always the same, in whatever country and circumstances: destroyed lifelines and buildings, rubbles everywhere, difficulties in communicating and in finding a first temporary shelter for those left homeless. Only apparently, however, as the concept of vulnerability is there to distinguish different degrees of weakness and strength of one country with respect to the other, of one region compared to the other [4,5]. Sociologists and geographers have been studying for long time those local elements, linked to income, public facilities, organisational capacity, ability to control the compliance with building codes. The condition of all those variables may explain why the same severity of ground motion can result in a catastrophe in one place or be easily overcome in others [6]. More efforts should be devoted to the bridging between those studies and research carried out by engineers, geotechnical experts, seismologists, etc. The aim is to obtain more complete and satisfactory interpretations of natural calamities, in order to design better mitigation and prevention strategies. There have been attempts in this direction, producing interesting results, as the Kyoto University report mentioned above. It is felt, however, that the integration of tools and analyses provided by various disciplines should be further enhanced to become part of a unique model, instead of simply putting together different models which can hardly be integrated and made part of a comprehensive explanation.

Shortcomings deriving from the lack of a coherent and complete picture of hazardous events become evident both in emergency programs and in reconstruction plans.

In a study carried out at the Tokyo University [7], researchers found that public officers in charge of emergency operations were unable to imagine a scene of destruction similar to that after the Kobe earthquake and were unaware of the possible consequences on their capacity to perform as expected. Clearly exercises and drills they do on a routine basis do not correspond at all to the complexity they should face in a real event and furthermore, they are too restricted to the specific task everyone must perform. Nobody has control, neither intellectually, over the entire sequence of emergency procedures. Nobody can take responsibilities beyond those he has been explicitly charged with. As a consequence, in case a link of the organisational chain fails, the overall system of civil protection collapses. There is a quite large literature regarding social and organisational patterns that develop in the disaster aftermath [8,9]. Beyond cultural features specific to Japan, remarks made by social scientists fit perfectly the Kobe event [10,11]. Perhaps more surprising for foreign observers was the clear notion of a gap between 'bureaucratic and emergent norms' as defined by Schneider [12] (p. 55), that is between people's expectations and governmental agencies response capabilities. Among the three variables that she recognises as affecting the size of this gap, "the magnitude of the event, the degree of governmental preparedness, and the prevailing orientation of the affected population", the first two played a relevant role in the Kobe disaster aftermath, along with the rigidity of organisations that must conform to very strict rules and codes. A good example of the rigidity of the Japanese system is provided by the complicated formal procedure that had to be followed to call for troops help in case of a severe disaster: without a written request of the governor troops could not be sent in. In his request, he should have detailed how many men, ships, and planes were needed as well as what kinds of activities were required. Furthermore to be granted the necessary help, he should have also provided his superiors with an exact picture of the situation and of most heavily stricken area. Given the widespread destruction and confusion, it was not reasonable to expect the governor in Hyogo Prefecture to be able to produce such a detailed request.

3.1. Models of emergency management

In a study comparing civil protection systems in the European Union to face industrial accidents, the results showed that officials value most preparation and training conducted using simulations and scenarios [13]. Even though nobody expects everything to go as in the training — the latter seems nevertheless a necessary condition for performing well in real situations. There is no reason why this should not be applied to emergencies provoked by natural hazards as well.

Preparedness, training, exercises: they all bring the attention to the human factor. Technical devices are essential in modern societies, but they can hardly substitute humans, especially under extreme conditions or in case of unexpected events. The human factor plays a prominent role not only in the man–machine interface, but also in the behaviour of ordinary people. The attempt made by the Kobe city Government to call for closer co-operation between people and the city council seems very positive in this regard. Not only consciousness about existing risks is enhanced, but also the sense of responsibility for what Huber [14] correctly defined 'collective risks' (those transcending the individual ability to cope) as opposed to 'private risks' (like driving a car).

Collective risks require the sharing of responsibilities among citizens and among various levels of government. Although apparently similar structures of civil emergency agencies and approaches to crisis management can be found in different countries, a large variety of models can be recognised at a deeper analysis. Formally everywhere personnel and agencies involved in emergency management will gather in a place (a room, an office or a tent), while technical groups will try control strategic locations within the disaster core area to be able to act efficiently and in the meantime provide the control room with the latest news from the field.

A first model guarantees that for any operation to be performed there is an available procedure already tested in previous cases and in past exercises. This is very different from what happens in other contexts, like Italy for example, which can be considered as a second model at the opposite end of a virtual organisational scale. In the Italian case, though the flow of decisions and the people to be contacted are written in a plan, it is hard to talk about real procedures, unless in a quite limited sense. Actions develop in a very flexible way, having as a background some experience gained in the past. Flexibility and being able to take quick decisions is a very important quality in emergency situations when creative solutions have to be found for unexpected problems or problems which were not included in the available procedures. Sometimes very good decisions are taken like this; nevertheless too often the lack of actual procedures, already tested and verified, becomes a hard obstacle.

The Japanese system seemed somehow in the middle: written procedures had been set, but they proved to be too rigid and did not contemplate situations that can easily occur under emergency stressful conditions. This is the reason why those procedures have been deeply revised after the Kobe earthquake, trying to widen the range of events covered by rules of correct behaviour. However, designed procedures and preparation should not rely too much on back analysis, as the next disaster will never pose exactly the same problems encountered in the last one.

3.2. Descriptive and outcome-oriented scenarios

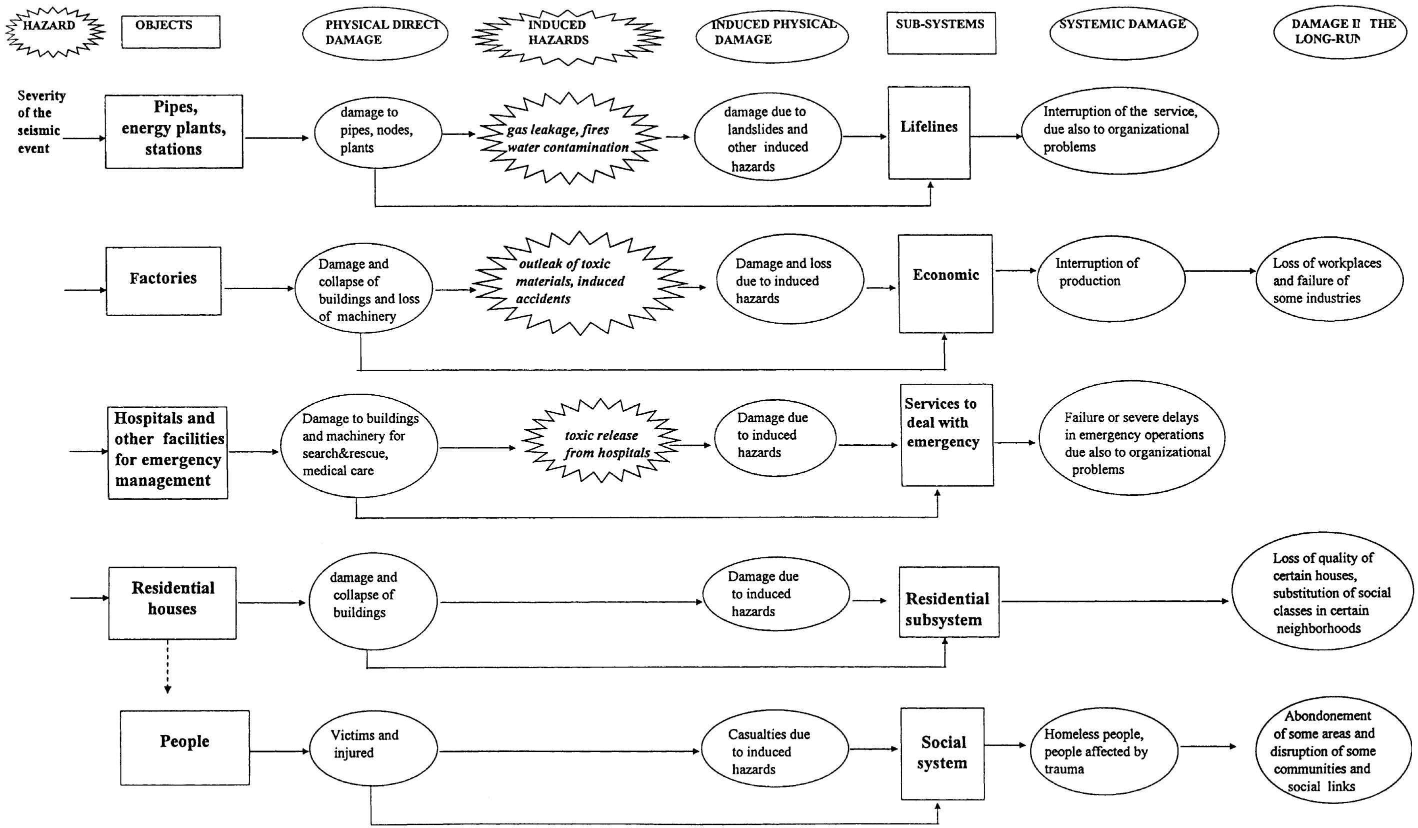
It will never be possible to fully comprehend all the interactions and disastrous chains originating in a metropolitan environment: the more complex and rich in functions the settlement the more difficult to detect the potential causes of a major failure. A step forward, however, can be made following the systemic approach, which at the very least permits overcoming the traditional way of estimating direct, secondary, indirect losses, as if they were separate chapters of an economic report in favour of the notion of chains of damages and failures.

In some analyses carried out in the realm of technological risks [15–17], human, organisational and physical aspects have been already integrated in a unique framework. There are no reasons why similar applications should not be attempted also for natural risks. In most cases, in fact, damage is not the result of natural forces only, but rather of the interaction of the latter with vulnerable social and economic systems and with poorly constructed built environments. As stated by Hewitt [18], vulnerability is already there just waiting for an event to become evident to everyone.

The enchained effects of an earthquake in interconnected urban systems are shown in Table 1: the physical event is just the triggering factor, which provokes physical damage (to vulnerable structures), but which also reveals organisational failures and the elements that make systems prone to systemic damage.

Factors and links included in the framework should be all taken into account while constructing scenarios supporting prevention strategies and emergency plans. Good information systems are not enough: equally important is the process of constructing scenarios, as an exercise of imagination resulting from a multidisciplinary effort. Descriptive scenarios as intended here constitute an analytical framework for assessing weaknesses and strength of involved systems and result from the combination of hazard and vulnerability. Until now scientists took into serious consideration the hazard factor only for obtaining different scenarios, as if systems' response were just depending on varying levels of seismic intensity and acceleration. It is time to carefully examine also vulnerability factors, exploring potential chains of damage in a real geographical, urban and spatial context.

Table 1
Framework showing major systems interacting in a metropolitan environment



Without a careful evaluation of scenarios it becomes rather difficult to set priorities during the emergency, as well as to design reconstruction plans that will reduce instead of increase pre-event vulnerabilities. Scenarios in fact are not only descriptive: they can also represent the result of the variation of one or more parameters that have been recognised as crucial in the descriptive-analytical phase and which can be changed by human beings. Planners are quite accustomed to work with those two types of scenarios. The first extrapolate from models and context-based data what may happen in case a given natural hazard strikes. Outcome-oriented scenarios correspond instead to the expected result of mitigation and preventive measures, designed to diminish risk levels that have been previously determined in descriptive scenarios.

The question cannot be considered merely technical, as the 'philosophy' of prevention and effective emergency procedures are at stake here. A choice has to be made with respect to what information is really strategic and to how data already stored in control systems must be used. Beck [19] makes some comments regarding the misuse of computer systems that perfectly suit here: "the increasing dependence on the computer had a number of unfortunate consequences in relation to the role and effectiveness of planning (. . .). The emphasis shifted from conceptual thinking to data generation, with the planner's role increasingly confined to administrative aspects of collecting and disseminating information (. . .). The quality of the information in the computer can vary considerably, but the people providing it are rendered invisible — with the result that the element of fallibility behind the computers' answer is equally obscured".

Strategic information concerns whatever leads to correct action and sound decisions in the field. It should specify which are the mostly damaged areas, the condition of roads to access them, as well as alternative routes to be used by search and rescue teams to reach the victims and carry them out to the closest care facilities. It seems almost impossible to reconstruct an overall satisfactory picture just collecting piecemeal information in the field, even in the ideal condition where physical means for transmitting messages are still working. Such a picture, for different levels of seismic intensity and acceleration, can be constructed before the event in the form of scenarios. It would be enough to store damage scenarios in an archive so as to select the appropriate one on the basis of the recorded ground motion — the only kind of data which is presently provided in real time with good accuracy. Once the most probable scenario selected, it would be enough to verify the validity of damage forecasts in the field.

Perhaps in the future it will be fairly easy to run damage scenarios in a few seconds; however, what is more important is to assess previously the most vulnerable residential parts of the city, the location of dangerous plants, and the features of networks and infrastructures. Information regarding the latter does not need to be collected by the hour: it can be updated whenever new plans and new interventions imply changes in urban patterns, in the road system, in lifelines. Very few administrations meet this information standard, as knowledge — not always complete — is often fragmented among a variety of offices, agencies, organisations, and very rarely easily accessible to anyone needing it. In fact, it may be suggested that the process of constructing scenarios has to be valued more than the resulting products. The latter may be unusable during crisis because of a variety of reasons: lack of electrical power or other physical conditions that impede running the system, not updated data, incomplete data. However, the process needed to design the skeleton of scenarios is a continuing learning experience, which may reveal to all the participants, including emergency managers, the perspective of all the others (engineers, geologists, sociologists, etc.).

Furthermore, having all data stored in one place does not guarantee that effective information exchange among persons and agencies will take place. Although it seems a rather simple solution to have a central room acting as a reference point for anyone needing information, this happens in reality only if a certain degree of co-ordination has been previously established among agencies and organisations involved in emergency management. In other terms to provide real exchange of information, the various agencies and organisations must be already used to work together on a routine basis, as co-operation cannot be improvised under stressful conditions.

4. The case of lifelines

Some observations regarding lifelines damage and disruption due to he Kobe earthquake will clarify the points above, showing that even dealing with a quite technical subject, systemic factors and governance aspects emerge at a deeper analysis considering any urban function in a broader perspective.

4.1. Lifelines in the Kobe earthquake

Lifeline systems were heavily disrupted during the Kobe earthquake, as it can be seen in Table 2. Almost all types of bridges and elevated parts of highways, national roads and railroads suffered some kind of damage: the 1 km long piece of the Hanshin expressway completely reversed on the road running beneath, is one of the most dramatic images of the disaster. A station of the urban underground, the Daikai, completely collapsed: it was pure luck that nobody was there thanks to the early hour. Even the famous bullet Shinkansen line suffered severe damage in several points, something that should have never happened according to the high construction standard that has been set for this line.

Underground networks did not perform any better: distribution pipes suffered the heaviest damage, as it usually happens in such circumstances, as a consequence of falling houses and bridges. In the hierarchically higher components less severe losses were reported, with some exceptions. The water service situation remained critical for a long time: more than four reservoirs in the Kobe city were damaged and widespread ruptures in conducts were detected. Repair was hampered by the lack of precise maps permitting to locate correctly the various parts of the water system, as they went lost in the collapse of the floor of the municipality building where they were stored. There was no computer extra-version of the drawings.

The gas system was severely hit as well; even though high-pressure components were not damaged, several ruptures occurred to middle pressure and especially distribution conducts, which were in many cases invaded by water leaking from nearby pipes.

Electrical and telecommunication systems were hit less severely and it was possible to restore service in about one or 2 weeks; however, 280,000 of the 1,443,000 telephone lines were cut and those still functioning were quickly overloaded. From the Hyogo Prefecture control room only a public telephone could be used for emergency communications [20,21].

Table 2
Framework to assess lifelines vulnerability in the emergency phase

Inter- and intra-dependent systems	Functional vulnerability factors	Organizational vulnerability factors	Physical vulnerability factors
Systemic links			
Lifelines vulnerability induced by other systems	Dependence from other systems	Interagency co-operation	Physical vulnerability of systems which lifelines are physically connected to
Inter-systemic lifelines dependence	Dependence from other lifelines	Cooperation among lifelines companies	Physical vulnerability of lifelines essential for the function of other lifelines
Vulnerability factors due to lifelines components	Specific lifeline features	Organization within each company Number of companies managing each lifeline	vulnerability of each lifeline component
Siting factors			
Accessibility	Direct access to broken parts of lifelines	Coordination between civil protection and agencies in charge of roads management; information regarding alternative access; availabe personnel, materials and means for urgent repair	Physical vulnerability of roads
Vulnerability due to the physical contact among lifelines	Function depending from physical contact with other vulnerable lifelines	Coordination among lifelines service suppliers	Physical vulnerability of single components in contact points (joints)
Regional vulnerability			
Urban and regional systems for emergency operations	How much do emergency systems depend on lifelines	Coordination among hospitals, civil protection, police and other agencies; communication skills to the public	Physical vulnerability of systems other than lifelines necessary during emergencies
Other urban systems	How much do other urban systems depend on lifelines	Coordination among lifelines suppliers and managers of other systems	Physical vulnerability of systems other than lifelines

Lifelines managing companies were harshly criticised by media and by the affected population for the many organisational and functional failures they encountered in the aftermath of the event. People were complaining for the lack of water, for the inefficiency of automatic gas shut off valves which indirectly provoked several fires in the city. The agencies that received the most criticism — such as the Water Bureau — did invest more time and resources trying to figure out what had gone wrong and trying to do something to avoid a recurrence. For example, the Water Bureau designed a completely new aqueduct bringing water from the Rokko Mountains to the city, doubling the original one. Furthermore, a new emergency plan was prepared, so as to be able to provide people with water directly from medium size pipes distributing water at a quarter level [22].

The Osaka Gas Company installed a far denser network of accelerograms to detect strong ground motions as soon as possible. A global review of antiseismic rules for joints and optimal pipes siting in the ground was carried out and many parts of the old system replaced. It was an enormous endeavour, requiring the work of 10,000 technicians, many sent to Kobe from other regions of the country.

4.2. A systemic approach to lifelines

Although a lot can be done to improve lifelines resistance to earthquake, damage cannot be completely avoided. Spatial diffusion and the extension of areas they serve make it virtually impossible to control and reinforce each single unit. Furthermore, the geographical and spatial context where they are laid may considerably change lifelines response: border lines between different types of soils or unstable slopes are among the most common cause of breaks.

Lifelines system is, therefore, a quite good arena for testing scenarios including various kinds of vulnerability. Even earthquake engineers had to recognise lifelines complexity, due not so much to individual nodes or parts (with few exceptions) as to their being highly intra-dependent and inter-dependent systems [23–26]. The concept of systemic vulnerability perfectly suits here, as it refers to how prone a system is to be damaged or to fail not as a consequence of some kind of physical rupture occurring to one of its components, but rather as the indirect effect of some physical, organisational or functional failure suffered by other systems.

The framework in Table 2 shows this point. Functional, organisational and physical vulnerabilities are grouped, respectively, in the first, second, and third columns. Functional factors explain lifelines malfunctioning due to a variety of reasons, many of which are not physical. Each lifeline is a hierarchical system: if crucial nodes fail, the service they provide in normal time will inevitably cut many customers off. Those nodes are, for instance, stations transforming high into medium or into low gas pressures, energy power stations, water reservoirs, etc.

Furthermore, lifelines are dependent one from the other. Electrical power is vital for communication networks, for remote control devices, for water pumping stations. Although electrical systems can be easily and fast repaired — especially if compared to water or gas facilities — a light shaking is sometimes enough to put out of service relays in electrical generators or transformation centres, thus interrupting the power for several hours, even when no severe has damage occurred in other parts of the system. The hours so lost can be crucial for emergency operations.

Organisational factors that are considered in the present framework may consistently hamper search and rescue activities. Communication systems provide an enlightening example in this regard: the most frequent problem encountered in the first hours following the impact of a disaster is lines overloading. To a certain extent this is an organisational problem, as telephone companies have the technical capability of providing emergency services, like hospitals or firemen, with a priority-access to telephone lines (a system that has been experimented in California). However, this possibility is not always taken into account in emergency plans (for example, not in Italy). Another important organisational parameter to assess co-ordination among those involved in emergency management is the number of companies managing lifelines or even the same lifeline in a given area.

Also with respect to physical vulnerability, lifelines are highly intra- and inter- dependent systems: conducts and lines can be damaged by collapsing houses or bridges or by landslides and riverbanks, the movement of which can be triggered by earthquakes.

The rows in Table 2 are grouped in three main blocks: in the first, factors related to lifelines performance are considered, in the second siting situations are examined. For example sewers can pollute water when conducts are broken and leaks or infiltration become more probable.

The last group of rows indicates how vulnerable urban and regional systems (other than lifelines) are to the interruption of services like electricity, water, gas, and communication. Without those facilities hospitals cannot treat earthquake victims, even in the best conditions, when structures or machinery have not suffer any damage. Those responsible for managing the technical apparatus of hospitals tend to be overconfident of autonomous plants; actually their capacity to store water, gas and even to maintain efficient generators is generally limited and the period of time they can resist without external supply is not long enough if compared to the time needed for repairs. In Kobe, many electrical generators did not work properly (in some case the refrigerating liquid was lacking), and in a few cases it became necessary to fill manually water thanks on the roof of hospitals, because such a problem had not been forecasted and prepared for in emergency procedures.

Advancements in technology make people overconfident about the capability of technical devices to solve many (if not all) problems: this belief shapes the way prevention and mitigation are conceived. The major lesson learnt in Japan regarding the need for inserting back-up devices and by adding redundancy to lifelines illustrates this point quite well. Failure occurring in one part of lifeline systems will be 'covered' by interconnected and reliable substituting devices.

A different perspective has been developed by some scholars analysing technological risks [15,27]. According to them, a degree of risk always remains and at some time — even though rarely — a very serious accident will inevitably occur in complex systems. The idea here is that metropolitan settlements are as complex, if not more, than technological plants, therefore, when an exceptional event makes things go wrong, an unexpected chain of failures may paralyse back-up devices and technical emergency countermeasures. Functional, organisational and physical factors cannot be separated: organisational faults may worsen physical damage; on the contrary the latter can be limited by a good organisation.

Lifelines vulnerability analysis cannot be carried out without referring to geographical and spatial information; the latter are essential in preparing emergency plans and more generally any mitigation and damage reduction program.

In urban contexts, geographical and spatial factors become even more important. This proved particularly true in Kobe, where there was a heavy traffic congestion hampering for weeks search and rescue efforts, debris removal, and restoration of lifelines. This was due to a variety of reasons, among which planners would certainly include the ‘linear’ shape of the town as opposed to a ‘grid-like’ one, which provides more alternatives to reach any single place. In Kobe, when major connections to the Northern city of Osaka and to the southern epicentre area were cut, there were no other possibilities for getting in or out, if not by sea [28]. The tremendous traffic congestion was certainly worsened by the collapse of highways, bridges and railways, but it cannot be explained only on the basis of the physical damage. While highways and railways provide a rational design at a macro-scale, if one looks at the detail of urban blocks, at a micro-scale, the pattern is much more chaotic, with narrow lanes and densely built up lots. Even under normal conditions, it is extremely difficult to reach the larger roads and highways form those quarters of the city, where bottlenecks are the rule rather than the exception. The situation was worsened by the lack of electrical power, putting traffic lights out of service. Information regarding those critical points becomes certainly crucial for civil protection agencies, so as to devise how to reach the most likely damaged areas and how to access facilities such as hospitals and fire departments.

In the recovery process, the construction of a new highway running parallel to the port in the direction of Osaka has been proposed to improve town accessibility; on the ground of what has just been said, such an intervention would be useless at least for the purpose of increasing the efficacy of emergency procedures.

4.3. Governance aspects associated with lifelines management

Priorities, both during the emergency and the recovery phases, cannot be set only upon criteria set by each lifeline system company. It is quite hard to define reliable and acceptable criteria without widening the scope of assessed needs and demands which involve many urban systems other than lifelines such as residential or industrial areas, public facilities, etc. Without a deeper understanding of what happens during disasters, it will be almost impossible to set priorities.

However, even if urban systems were considered in a more holistic way, the problem would not be completely solved and social and cultural values should also enter in the criteria for setting priorities. In exceptionally stressful conditions, as psychologists working with Kobe earthquake’s victims showed [29], decision makers and people in charge of emergency operations fail to understand that changes may occur in normally shared values and habits, resulting in a gap between people’s expectations and bureaucratic norms adopted for facing the disaster [12]. This conflict is worsened by the many uncertainties involved in any decision to be taken under emergency conditions. Those uncertainties are not only technical or scientific; rather they involve subjective judgement, liability and institutional factors that are not easy to decide at all, and that should be carefully investigated before disasters strike [30], and, why not, be included in event scenarios.

Even the management of lifelines has to be looked at from a larger perspective: there is a question of governance also in lifelines. Decisions in emergency situations imply much more than just good technical solutions as it will be shown in this paragraph.

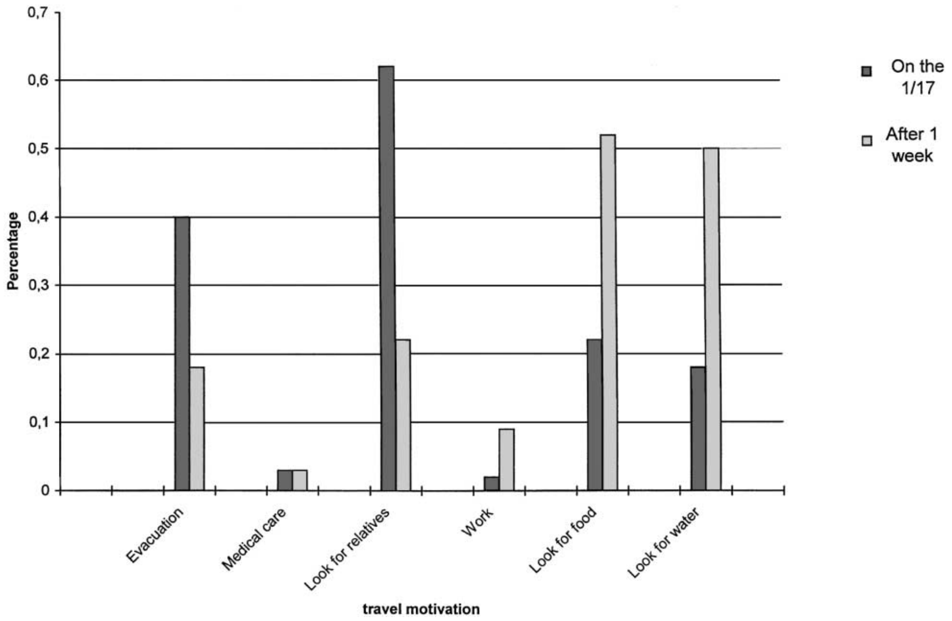


Fig. 2. Travel motivation in Kobe city after the earthquake.

In order to fully analyse the traffic congestion in the city in the first months after the disaster, social parameters must be considered. This will allow to grasp the motivation for taking the car in such a situation. The reasons a group of researchers [31] at the Kobe University were given by a sample of respondents can be summarised as follows: wish to know about relatives and friends, rescue of some personal belongings, search for food and water (see Fig. 2). All those needs might have been addressed in a more satisfactory way by local authorities, who were not only unable to maintain certain strategic lanes free, but remained trapped in traffic jams themselves. In the chain of connected factors the behaviour of people should be granted more attention, as to a certain extent it can be imagined on the ground of past experience. Emergency plans would benefit from advancement in the understanding of people's reactions which will allow to reduce organisational vulnerability. Decision-makers often address the following request to social scientists: "As you know people's reactions, improve them" [32]. The answer is that people act according to their own rationality, which is not necessarily wrong, though it may not coincide with the perspective of the civil protection officers. The key solution in this case is to understand people's needs and to adjust emergency programs accordingly. For example, if people rush to the disaster area to get news about relatives and friends, the solution would not be in prohibiting them to go, but rather in responding to their need through more appropriate strategies of collection and diffusion of information.

Another example refers to thresholds to be fixed for the intervention of automatic gas shut off in case of ground motions. Although apparently technical, the matter is also (if not mainly) political. One may ask indeed why it took more than five hours to the managers of the company to decide disconnecting the gas service. May be because this operation is not at zero cost: rerunning gas into the pipe system after a complete shut down takes a lot of time, and many careful and expensive controls because of the associated risks. A simulation that has been carried out in Japan showed that "if an earthquake triggers the venting system, it will take about 1 month to restore service, even if there is no seismic damage" [33]. Therefore, some authors [34] suggest to weight the need for shutting down the gas system and to link automatic devices to a predetermined earthquake magnitude. A decision regarding an acceptable level of risk is implicitly called for, so as to make the cost-benefit balance profitable if compared to expected induced damages. Should not the latter be decided on the basis of the vulnerability of the exposed systems and not automatically set according to a given seismic acceleration? Scenarios would provide a valuable tool to decide in which cases to disconnect the gas service, after evaluating the potential for induced fires and intoxication in the particular situation. Complete event scenarios representing the consequences of gas leakage in a specific urban context are easier to interpret than probability values, the aim being to improve the technical content of political decisions, refining the number and the range of alternative options of intervention.

5. Conclusion

In the article the need for bridging between social and engineering factors has been discussed, showing that the two are intimately connected in real life situations. Examples from the Kobe earthquake in 1995 illustrate this point clearly, as they are referred to a metropolitan environment, where this connection is more evident than in any other type of settlement.

Complete disaster scenarios, either prepared before the event as part of prevention efforts, or during its occurrence in real time, should contemplate social, systemic, and organisational vulnerabilities, besides the hazard severity and the physical weaknesses of exposed systems.

Civil protection agencies would greatly benefit from scenarios as part of their plans, as they would be forced to drop abstract procedures into real spatial and geographical contexts. Such scenarios could address also reconstruction programs, in the attempt to reduce existing levels of vulnerability.

A framework has been proposed to assess the vulnerabilities of lifelines according to this approach. Such framework accounts for parameters related to how many companies distribute the same service, or the possibility to reach any broken part or node with means and materials for quick restoration. Often this type of information is more useful for emergency preparation than that regarding the quality of joints or pipes materials. The latter in fact can be hard to survey or to control over large areas. Providing the basis for good co-operation and co-ordination among various companies managing lifelines and between the latter and the civil protection and firemen services may sometimes result in much better performance than starting to substitute all the old pipes in the system. The latter is certainly a beneficial measure, but it takes a long time and some degree of risk will still remain.

So, why so little attention has been paid up to now to organisational and systemic factors? Perhaps for their being rather 'invisible' if compared to 'high-tech' devices. Even presently softer approaches gain little credit, no matter if they often represent prevention close to 'zero' cost: modern societies tend to judge the quality of measures on the basis of money spent for them, regardless their actual efficacy. The call for better civil protection performance seems satisfied through more sophisticated technical tools, while very little is done to revise present procedures. On the contrary, it is often maintained that old, no matter how inefficient, procedures can be left unchanged under new technical facilities.

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