CENTRE RISQUE & PERFORMANCE – WORKING PAPER

Reflections on the Place of Human Beings in Interdependencies among Critical Infrastructures

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ABSTRACT

In recent years, work on the interdependencies among critical infrastructures deal with many issues, including those of electricity, telecommunications and oil supply. However, few works has been undertaken to understand the role humans (human resources) in these interdependencies between critical infrastructures. This article proposes a new methodology for recognition of human interdependence. This article is a reflection, discussion, for begin work to define the place of human resources in the proper functioning of our critical infrastructures.

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- Tecsult
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The contributions of all of these partners, both technical and financial, allowed us to collect the data we needed to develop concrete tools for managing risk, including those presented in this article.

INTRODUCTION

Critical infrastructures (CIs) supply a set of resources (goods and services) that are necessary for the normal functioning of our modern, industrialized society. If these resources are unavailable, even for a moment, it may have significant consequences for the health, life, safety and economic well-being of a person, a company or a community, and for the effective functioning of government and its institutions. CIs constitute "the skeleton and the nerves of our complex societies" (Lagadec & Rosenthal, 2003). Nobody today can imagine living without electricity, telecommunications, drinking water, transportation, etc. CIs, which are usually organized into systems that have become increasingly complex and interconnected, have caused new risks to emerge (Robert et al., 2007). Identifying, understanding and analyzing interdependencies constitute significant challenges in mastering these emerging risks (Rinaldi et al., 2001).

But the interconnections among these systems constitute a real medium for propagating failures from one system to another (Robert et al., 2007). Thus, the failure of a single CI could extend to others, triggering a chain of unpredicted failures. This domino effect can intensify the impacts of certain failures and their impacts on other CIs, society and the environment. In addition, it may endanger the functioning of our societies, depriving them of the resources that are essential to their functioning.

Thus, according to Lagadec and Rosenthal (2003), CIs constitute "at the same time key sources of destabilisation potentialities." Our societies have become a "target-rich environment" (Critical Infrastructure Protection Oral History Project, 2008). The importance of the risks related to CIs and their interdependencies has led to the preparation of numerous studies and the implementation of methods intended to manage these risks. However, few scientific publications consider the role of human factors in CIs, and this topic has not been addressed by studies of interdependencies among CIs. The reality of these risks suggests that certain principles should be highlighted and a method be put in place to evaluate the influence of human beings on other CIs.

The aim of this article is to launch a reflection on the role of human beings in the functioning of these systems and how to take them into consideration in studying interdependencies among CIs. We will start by explaining the role of the population among CIs. Then the relationship between the population and CIs will be considered. In conclusion, we will present a methodology that can be applied to start taking the population into consideration in studying interdependencies among CIs.

THE POPULATION AND CRITICAL INFRASTRUCTURES

Many efforts and resources have been allocated to the analysis and security of CIs (Barnes & Newbold, 2005). Since the terrorist attacks on the World Trade Center on September 11, 2001, research into interdependencies among CIs has really taken off, since such interdependencies constitute a key problem in the field of risk management (Robert & Morabito, 2008). According to Barnes and Newbold (2005), human beings are, in fact, at the core of existing interdependencies among CIs. Indeed, one could say that humans have developed interdependent relationships with other CIs.

Barnes and Newbold (2005) saw "human infrastructure," as they call it, as being society in general. They attempted to show that this human infrastructure is indeed a CI, as defined by the *USA Patriot Act* (Congress of United States of America, 2001). Other researchers, though, do not see the population as being a CI (PSC, 2008). It is not the intent of this article to get involved in this debate. It seems obvious that human beings are important actors in the proper functioning of CIs and it is from this perspective that we study the impact of humans on CIs.

The relationship between the population and CIs

Barnes and Newbold (2005) identify three relationships between human infrastructure and other CIs. Although the first one is easy to imagine—humans need infrastructures for the services they provide—the other two endeavor to demonstrate human beings' influence on CIs. One is a corollary of the above-mentioned relationship, namely that CIs need humans to ensure their functioning, but also for the innovations they contribute. Finally, the last relationship between CIs and human infrastructure that Barnes and Newbold identify is the role of humans in facilitating communications and cooperation among CIs.

To this end, it is interesting to look at the representation of interdependencies among "human infrastructure" and other CIs that Barnes and Newbold (2005) propose (figure 1). As the figure shows, these authors place humans at the heart of all interactions. This voluntary and strategic placement reflects the importance they assign to human beings in interdependency relationships. On this basis, it appears important to take human resources into consideration and study their interdependencies with CIs. They also propose a list of goods or services provided for each CI and identify relations of interdependency on that basis. It is interesting to examine those for "human infrastructure."

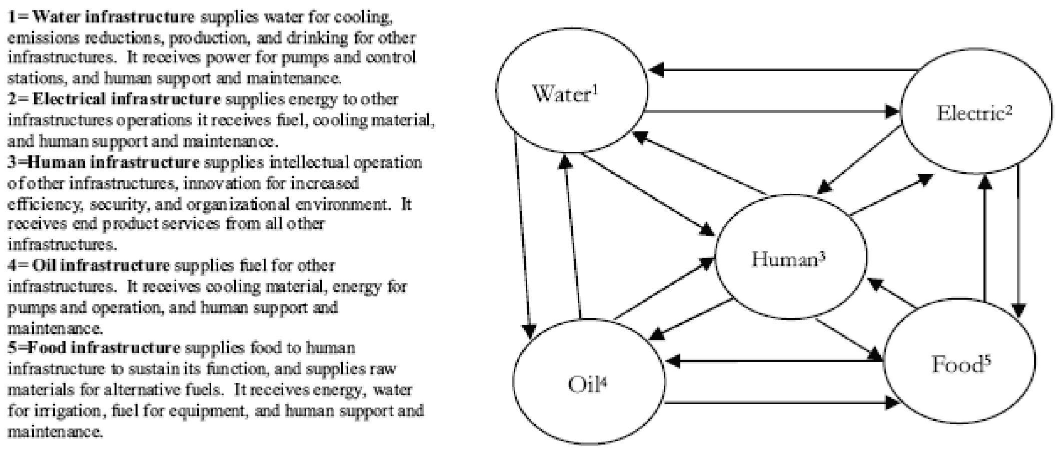

Figure 1: Human infrastructure interactions (Barnes & Newbold, 2005)

The positions held by Barnes and Newbold (2005) raise numerous questions, especially concerning the place that the population occupies in interdependencies. The authors participate in the debate concerning whether to consider the population as a full-fledged CI or not. The main thrust of their arguments in favor of human infrastructure is to ensure the safety and resilience of the population. Thus, one of the key questions that must be asked is exactly how to consider the population in the management of risks related to CIs and their interdependencies.

RELATIONS BETWEEN THE POPULATION AND CIS

An interdependency is defined as a two-directional relationship between two CIs, the status of one of which is influenced by or correlated with the status of the other (Rinaldi et al., 2001). Thus, after focusing on the one-directional relationship between human beings and CIs, we will study the correlation between the status of one system and that of the other.

By definition, CIs directly supply people with the resources needed for their activities. On the other hand, the connection between the population and CIs may be less obvious. CIs need humans to fulfill their mission. How could these systems operate or be maintained without humans? Even when we take technological progress into account, such as automation or new communication technologies, CIs need humans to be able to function normally. Another way of proving this is to analyze the impact of the loss of human beings on CIs.

Along these lines, Analytic Services Inc. of the Trust for America's Health (2006) identified the potential impacts of an influenza pandemic in California. For example, they analyzed the impact of absenteeism due to a pandemic on infrastructures in the energy and transportation sectors. In conclusion, they emphasized that the functioning of these CIs depends on a qualified workforce. In their view, a high rate of absenteeism could endanger these systems. Similarly, Brunet (2007) describes the impact on the Ontario hospital system of the 2003 SARS epidemic in Toronto. He notes that the spread of this disease to hospital workers profoundly disrupted the health care system. The decrease in the number of staff members, many of whom were sick or in quarantine, at the same time as the increase in the number of cases to be treated had direct impacts on emergency and resuscitation services, but also on other activities due to the redeployment of teams. The medical impacts were significant, as Brunet points out, due to the disorganization of the hospital system. These examples show how a failure of the population can have significant impacts on the operation of CIs.

Now that we have seen that the status of certain CIs is correlated with the status of the human factor, the corollary remains to be demonstrated, namely that the status of the population is influenced by that of CIs.

In a report prepared for Électricité de France on feedback following Hurricane Katrina in Louisiana in 2005 (Guihou et al., 2006), one point is dedicated to societal breakdown. The evacuation of 1.5 million people following the disaster decreased the number of available employees by over 930,000. This loss of labor aggravated the reconstruction difficulties. Obviously, this loss of human resources can be attributed to the severe flooding that affected the region, but the impact of the destruction of vital systems cannot be ignored. From 80% to 90% of vital systems were destroyed in less than 3 hours (Guihou et al., 2006); consequently, 1.1 million people experienced power cuts. Although the flooding was responsible for the displacement of human resources, the destruction of vital systems certainly played a role in its duration and intensity. Is it even possible to imagine living and working in an area without safe water, electricity, transportation, etc.? Although the impact on humans of the loss of a resource they use has not yet been extensively documented, one can assume that such an impact will exist.

The status of a system is reflected in its capacity to provide a resource (Robert et al., 2007). An interdependency, by definition, presents a correlation or an influence between the status of two interdependent systems. The examples described above show that the status of certain CIs is influenced by the status of the population, just as the status of the population is influenced by the status of some CIs. This is reflected in a one-directional link between the population and the CIs, through the exchange of resources. In addition, the two previous paragraphs have made it clear that the status of either humans or CIs is correlated with or influenced by the status of the other. The connections between humans and CIs therefore clearly correspond to the model presented by the definition of interdependency, that is, a two-directional link.

To be fully qualified as interdependencies, these relationships would need to exist between two CIs. As we have seen, there is a real debate concerning whether to consider the population as a true CI or not, and this article is not intended as a contribution to that debate. Rather, it is meant to show the impact that the population can have on other user CIs by providing avenues for exploration and highlighting certain concepts related to the consideration of the population in existing interdependency management models. Thus, by proving that the relations between the population and CIs fit into the same schemas as interdependency, we can show that it is possible to apply the same models we apply to interdependencies among CIs to these relations between the population and CIs, using the existing methods formulated by the *Centre risque & performance* (CRP) at the École Polytechnique de Montréal (Robert & Morabito, 2008; Robert et al., 2007; Robert et al., 2008).

RESULTS

In this section, we will present the results of the preliminary work done by the CRP concerning how to account for the population when studying interdependencies among CIs. These findings will feed into our reflections on the subject.

Characterization of the resource used by the population

According to the CRP's methodology, the first step in characterizing the population consists in defining the resources it uses (resources used, or RUs). These RUs are necessary or useful for accomplishing the population's mission, which is to supply a resource: the resource supplied (RS), which will be discussed in the next section. RUs include electricity, drinking water, natural gas, health care, etc. These resources, grouped by CI, are presented in the first and second columns of table 1.

Then, based on the Public Safety Canada (PSC) (2008) definition, it is possible to determine the vital functions for the population. These functions are public health, public safety and economic well-being (table 1, columns 3, 4 and 5). They enable us to find out how the loss of an RU will affect population. Grouped under two potential impacts, they allow one to determine what effects the unavailability of an RU will have on the population. With these two impacts, availability and mobility (table 1, columns 6 and 7), we can consider both CIs that affect humans directly (e.g., health, energy and safety) and those that affect human mobility (e.g., transportation). To better illustrate these remarks, table 1 presents some examples of RUs with their corresponding functions and impacts.

Sector	Resources used	Functions			Impacts	
		Public health	Public safety	Economic well-being	Availability	Mobility
Energy	Electricity		X	X	X	
	Natural gas		X	X	X	
	Petroleum		X	X	X	
Transport	Air			X		X
	Rail			X		X
	Water			X		X
	Land		X	X		X
Safety	Police		X		X	
	Fire department		X		X	
	Ambulances		X		X	
Manu-facturing	Waste	X		X	X	

Table 1: Extract from a table listing resources used and their impacts

In this table, the resources contributing to the performance of one or more functions are listed; they all have an impact on the availability of human resources, which can only be available in the long term if these basic functions are met. For example, a lack of electricity will affect the public safety (alarm systems) and economic well-being (inability to work) functions. These two functions will generate a problem with the availability of the population. The same is true of a problem with transport (land), which will create a problem with resource mobility, for example, public transit. On the other hand, a power outage would not directly affect the population's mobility; however, it could affect the transportation system (e.g., metro), which would in turn affect people's mobility.

Characterization of the resource supplied

The question may seem to be a simple one: what resources does the population supply to the other CIs? Nevertheless, the answer is not obvious. One could consider several approaches to qualifying the resource supplied by the population. From a general perspective, is this resource not simply the men and women who work or might work within the CIs? Their functions could be in maintenance, production, management or support; differentiating them does not add value to the preliminary study of interdependencies—it merely makes it more complex. This leads us to define the resource provided by the population as the "human resource." This human resource cannot be restricted to only those people who work for the CIs themselves. In fact, economic realities mean that a person carrying out his or her functions within a CI can be replaced by another, and that means it is necessary to take this resource into account in its entirety.

The human resource is considered in general terms throughout the methodology. Differentiating among all of the activities performed by humans within the various CIs would be a long, tedious and complicated task and it is not clear what one would gain by doing it. Consequently, the human resource is considered as a whole, without differentiating between its use in the CIs' various missions. Each CI that uses the human resource can itself identify how it uses this resource. In fact, who is better placed than the CIs themselves to determine how they use the human resource in their systems? It is up to them to identify what tasks or missions within their systems require this resource. If necessary, the CIs can differentiate the various uses they make of the human resource. They themselves are able to establish the impacts they would undergo in case of a failure of the human resource. Nevertheless, although we do not intend to examine the various uses of the human resource, it is important to determine how this resource can fail, to ensure that everyone is speaking the same language.

Characterization of the failure of the resource supplied

In order to be used by CIs, human resources must not simply be able to perform a socio-economic activity. They must also be able to be used immediately and to be on the site where they are needed. This property of the resource leads to two important criteria: availability and mobility. To be used by CIs, human resources must be able to become functional without delay—that is, available—and able to get to the location where they will be used—in other words, mobile.

The first criterion, availability, means that the human resource is completely available to perform a socio-economic activity, immediately and in a non-degraded manner. Unavailability may be temporary (e.g., illness) or permanent (e.g., death). The second criterion, mobility, is necessary for the human resource to get to the location where it will be used by the CI, which may differ from the location where it now is. Thus, mobility depends exclusively on the "transportation" CI and will not be examined in detail here. The CRP's ongoing research is examining the problem of transporting human resources.

These components of the resource can be represented in the form of a bar chart, as figure 2 shows. To adequately illustrate the behavior of the human resource, it will be studied as a function of time. At time T_0, the first bar shows that some quantity of the resource is available and some is unavailable. As long as a failure does not occur, it can be assumed that this status will not change. However, when an RU crucial to the population fails, there will be a change in the quantity of the human resource available for CIs. This change is represented by the second bar in figure 2.

The duration of the failure will also have an impact on the quantity of the human resource available to the CIs. The longer the failure lasts, the less of the resource will be available, as shown in figure 2. One can see that at time T_2, the percentage of the human resource available is different than at time T_1.

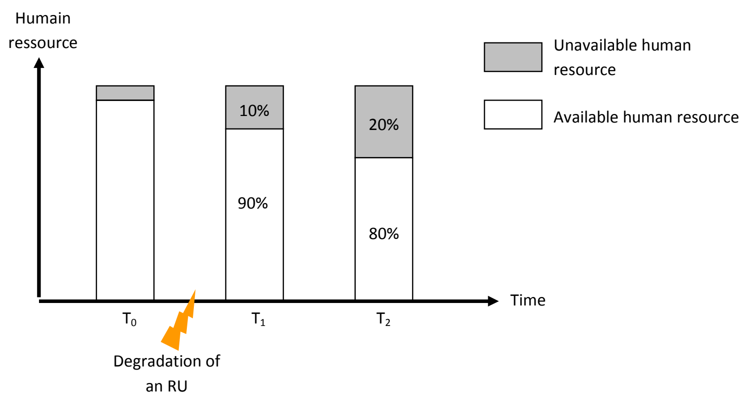

Figure 2: Representation of the effects of the degradation of an RU on the availability of the human resource

These changes in the availability of the human resource lead one to think that there may be a correlation between the duration of the degradation and the quantity of the human resource available in relation to the population. This correlation can be represented by a reduction factor, called F_{pr} (Population Reduction Factor), between the population on one hand and the available human resource on the other. In the event an RU needed by the population fails, the available human resource would decrease in accordance with this factor. This factor will be applied in the methodology presented in the following section.

Method to determine the quantity of human resources available

As shown above, a failure of a resource used by the population will have an impact on the quantity of human resources available. This impact is represented in the form of the population reduction factor explained above. To determine the F_{pr}, one must construct a matrix for every RU and every study zone. A study zone typically corresponds to the territory of a municipality or an urban region. It will supply this factor as a function of the duration of the RU's failure and the percentage of the population affected.

Table 2 presents a sample matrix. The duration of the failure can be adapted depending on the RU being studied and the zone. What is important to understand, though, is that if, say, a power outage affects 10% of the population of a given zone, the F_{pr} will give one some idea of the impacts that could affect the CI that is using the matrix. Of course, the population's reaction to the failure of an RU in a given zone cannot be exactly determined. For example, if the CI knows that most of its employees come from a particular zone, then if a power outage affects that zone, the F_{pr} will be greater than if it had affected a different zone. The F_{pr} provided by these matrices makes it possible to determine, based on the population, the human resources still available after the failure of an RU the population needs. It is up to the various CIs using the human resource to identify the impacts of its failure on their systems' operations.

The matrix presented in table 2 makes it possible to determine the F_{pr} as a function of two criteria:

1. The population affected (as a percentage) by the failure of the RU ("electricity" in the example);
2. The duration of the failure of the RU ("electricity" in the example).

Proportion of the population affected by the failure of the RU (as a %)	**Duration of the failure of the resource "electricity"**			
	1 to 2 days	**3 to 4 days**	**5 to 6 days**	**+ than a week**
0–10	$\mathbf{F_{pr}}$			
11–20				
21–30				
31–40				
41–50				
…				
90–100				

Table 2: Sample matrix to determine the F_{pr} for the RU "electricity"

Supplementary matrices can also be created to take into account certain factors specific to the RU. For the resource "electricity," it might be appropriate to take climatic conditions into account and create one matrix for this resource in summer and one in winter. In fact, the impacts on the human resource of the failure of an RU can vary as a function of certain parameters, such as climatic conditions for the resource "electricity." These various criteria can be evaluated by the user CIs, which can adapt them to meet their specific needs. Some studies can help one to better define F_{pr}, such as the work of Guihou et al. (2006).

Example of the use of a matrix

The example presented in this section will help readers to understand the use that can be made of a matrix. Table 3 presents a fictitious matrix for the resource "electricity."

Proportion of the population affected by the failure of the RU (as a %)	**Duration of the failure of the resource "electricity"**			
	1 to 2 days	**3 to 4 days**	**5 to 6 days**	**+ than a week**
0–10	0.8	0.7	0.65	0.6
11–20	0.76	0.68	0.61	0.58
21–30	0.74	**0.65**	0.59	0.55
31–40	0.7	0.62	0.56	0.53
41–50	0.68	0.6	0.53	0.49
…	…	…	…	…
90–100	0.35	0.28	0.25	0.2

Table 3: Sample matrix for the RU "electricity"

If a failure of the RU "electricity" occurs in a sector and affects 25% of the population for 3 to 4 days, this matrix allows one to estimate the amount of human resources that will be available. Out of a population of 100, the available human resources will then be 65 people. If we apply this F_{pr} to the quantity of human resources used by a CI, we can see that approximately 35% of them could potentially be absent. Consequently, it is possible for the CI to put measures in place to prevent vital functions from being affected by this decline.

LIMITATIONS AND FUTURE DEVELOPMENTS

As yet, in the course of the CRP's studies, no research has been done to determine the various real-life reduction factors that must be inserted into these matrices. Nevertheless, we can assume that a concerted effort by the various CIs would be able to produce complete matrices. It would be difficult to create general matrices that could apply to different locations. As mentioned above, each CI has its own specific relationship with the population. Moreover, the population will not react in the same way in all circumstances and all places.

It seems obvious that these matrices must be established in a climate of cooperation among the various CI managers. The CRP has worked to create such a climate of cooperation by setting up a cooperative space (Robert et al., 2007). In the next few years, the CRP will also work to include the population within the study of interdependencies among CIs. The introduction of this problem set will allow us to enhance the scope of our work and provide an opportunity to face the reality of the concepts sketched out in this article.

The results of this initiative will enable CI managers to grasp the problems related to the availability of the human resource. When an RU needed by the population is degraded (e.g., electricity), managers can use the F_{pr} to anticipate the likelihood of a decline in human resources. They will then be able to react accordingly to ensure that their mission is not affected by this lack of human resources. It is important for managers to be aware that this factor does not constitute a certainty. In fact, it is very difficult to accurately assess the impact that the failure of an RU may have on the population.

CONCLUSION

Taking the population into account in the study of interdependencies among critical infrastructures represents a complex problem. The failure of the population is inherently uncertain. If CI managers act as described in this article, we think a solution can be found. By applying the logic of user/supplier (RU/RS) and characterizing the population as supplying human resources to the other CIs, it is possible to focus on the CI using this human resource.

Choosing an overall approach and characterizing the failure has allowed us to focus on the decrease in the human resource available for CIs. This factor, which must be investigated in more depth, allows one to quickly envisage the estimated scope of the decrease in the available human resources. This information will help CI managers in their decision-making and planning for a possible failure of their own infrastructures following such a decrease.

As with Barnes and Newbold (2005), the goal of this article is to fuel our thought process on this topic. What is proposed is not an end in itself and makes no claim to be the only possible way of doing things. Researchers and practitioners in the field of interdependency management must continue to feed into these reflections. If they do, it may eventually be possible to take the population into account in this context, despite the complexity of the problem.

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