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A Resilience Space Focusing on Municipal Critical Infrastructures' Electricity Dependence

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ABSTRACT

This article addresses the growing vulnerability of municipal critical infrastructures to their dependence on electricity, a situation exacerbated by complex interdependencies. Major power outages, considered systemic risks, are difficult to anticipate and control. Moreover, within a given territory, such outages affect a wide range of infrastructures simultaneously. Consequently, consequence management requires collaborative and adaptive governance among all relevant stakeholders to mitigate impacts on populations. In this context, the concept of a resilience space is introduced. It is defined as a structured framework bringing together municipal actors and the power grid operator to strengthen both individual and collective resilience through enhanced cooperation. The central tool is the Common Situational Picture, which maps infrastructures' response capacities and vulnerabilities, thereby supporting shared understanding and the development of adapted strategies. The implementation of the resilience space in the Montréal region has demonstrated significant benefits: improved identification of vulnerable sectors, adaptation of municipal emergency plans, and strengthened relationships among all involved stakeholders. The sustainability of this approach relies on clear governance, secure information sharing, and neutral leadership. It is becoming increasingly critical in the face of emerging challenges related to the energy transition and climate change.

Keywords: municipal critical infrastructure (MCIs), electicity dependence, collaborative governance, vulnerability assessment, energy, emergency management, adaptation strategies, climate change.

INTRODUCTION

Electricity is essential to the functioning of societies today, but it is becoming increasingly complicated to manage, given the existence of highly interrelated issues, which may be regulatory, political, climatic or consumption-related. This complexity is a source of vulnerability and may result in major, long-term service interruptions that can affect several municipalities. In urbanized territories, such interruptions can be particularly damaging for critical infrastructures (CIs), defined as "processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government" (Public Safety Canada, 2022). Some CIs provide services directly to the population, such as drinking water, wastewater treatment, safety and public transit; these are referred to as municipal critical infrastructures (MCIs). If their own services are interrupted, the consequences for public health and safety are immediate. Consequently, MCIs' dependence on electricity, which is amplified by little-known interdependencies, represents a systemic risk that is difficult to analyze without a global approach focusing on their resilience. It is therefore important to implement joint risk management strategies, based on close collaboration between MCIs and the manager of the electricity system. This requires the creation of a resilience space designed to structure such collaboration and ensure collaborative, adaptive management of electricity outages.

In this article, we first present the findings that led us to consider collaboration as essential for the management of a major electricity outage. We then develop the concept of resilience space and discuss the results of the implementation of such a space within a group of Quebec municipalities. Finally, the challenges related to the long-term maintenance of the resilience space are discussed, and avenues to ensure its long-term effectiveness are suggested.

RISK MANAGEMENT AND RESILIENCE

National and international risk management practices to handle the technical risks associated with electrical systems remain consistent with the principles and guidelines of ISO 31000:2018 on risk management (International Organization for Standardization [ISO], 2018). In general, this standard requires the application of three phases.

The first phase consists in establishing the context of the study. This involves defining the study's objectives and scope and clearly characterizing the system to be studied. A multidisciplinary analysis team with the appropriate skills to handle the complexity of the system under study should be set up. The risk analysis and acceptability criteria must be defined and approved, which is a crucial step for the rest of the process.

The next phase, which is more technical, involves risk assessment. The hazards that may affect the system under study are identified and characterized, along with how they might materialize (scenarios). In this article, risk situations based on long-lasting service interruptions in large urban areas are addressed. Consequently, major hazards must be considered, such as earthquakes, windstorms, and freezing rain that may affect generating stations, transmission lines, distribution substations, etc. It is crucial to identify existing protective measures designed to prevent the impacts of these hazards or lessen their consequences. These scenarios are then analyzed in terms of their impacts on facilities and the consequences of service interruptions, as well as their probability of occurring. The impacts are determined based on duration, sequences of events, equipment affected, etc. Frequencies of occurrence are also established using relevant historical data, analytical techniques, digital simulations and expert opinions.

The impact analysis takes account of the protective measures in place and the vulnerability of the relevant equipment. Both immediate and long-term consequences are considered. For the electrical system, consequences are generally assessed in terms of generation losses and unsupplied power, and repair and recovery costs, as a function of the duration of the interruption, its geographic extent and the duration of recovery. For major interruptions, some studies have also quantified the direct and societal costs, which are referred to as Value of Lost Load (VoLL) (Morissette et al., 2024). This indicator, which is generally expressed in $/kWh or $/MWh, reflects the economic impact and inconvenience experienced by users if the power supply is lost, giving an economic value to the quantity of power that is not supplied (Morissette et al., 2024). In addition to economic values, the consequences in a territory are related to domino and snowball effects. Domino effects correspond to cascading impacts on several CIs (an electricity outage leads to a drinking water outage, etc.). Snowball effects correspond to direct impacts without domino effects. They mainly concern MCIs and consequently affect populations directly. The analysis of these impacts is the topic of this article, as we will see below.

Risks are then calculated, assessed and ranked, applying the risk analysis and acceptability criteria defined and approved when the context was established at the outset of the project.

The final phase, risk processing and control, completes the process. The goal is to implement protective measures so that identified risks do not remain in the class of risks deemed unacceptable. In the scenarios used to assess the risks of major service interruptions, other strategic risk control measures may be envisaged over the long term, such as reinforcing equipment, adding new equipment, changing maintenance policies, reviewing design standards, etc. In addition, recovery strategies are established to allow for the fastest possible restoration of service. The residual risk that remains after all the preventive and protective measures are put in place is then documented.

In major service interruption scenarios, with the acceptance that failures are inevitable, the concept of system resilience becomes significant. The resilience of these systems is defined as their ability to limit the scope, severity and duration of the degradation of elements following an extreme event, in order to ensure acceptable functioning. It is achieved by applying a set of protective measures before, during and after extreme events (Abdul-Nour et al., 2021; Komljenovic, 2021; Logan et al., 2022; Moreno Vieyra et al., 2020; Panteli et al., 2017). Rapid recovery and adaptation, rather than merely resistance to the initial disruption, are considered, adhering to the control strategies for these risks. In this context, Hydro-Québec published its *Action Plan 2035* to guarantee a reliable electricity supply throughout Quebec, despite increasing demand, more frequent climatic hazards and aging infrastructures. The plan highlights the importance of improved collaboration with all players in a territory (Indigenous communities, municipalities, area experts, unions, environmentalists and consumers) to increase resilience (Hydro-Québec, 2024).

However, ensuring resilience requires that populations and organizations in a territory that depend on electricity, including MCIs, must also be resilient. They need to accept that service interruptions are inevitable and, most importantly, establish protective and recovery strategies that are compatible with electrical systems' resilience strategies; this process demands sustained collaboration among all the organizations involved.

In addition, electricity dependence is characterized as a so-called emerging risk because it applies in contexts that are new and unusual for managers (Florin et al., 2018). Electricity dependence is also considered to be a systemic risk (UNDRR, 2019) since numerous interconnected players depend on this resource. Moreover, the characteristics of systemic risks make it impossible to define a single acceptability criterion, in view of the many organizations involved. Thus, whether a risk is acceptable can no longer be the decision of just one organization; rather, it must be the subject of discussion and consensus building by all stakeholders (Florin & Parker, 2020).

In conclusion, the stakeholders, and especially MCIs, in a territory must accept that major electrical outages can occur and must adopt collaborative, adaptive management of such disruptions. They need to collaborate to develop and adapt coherent protective and recovery strategies to deal with such events in their territory, given that their consequences and scope cannot be known or anticipated.

A RESILIENCE SPACE

Charmont (2025) defines a system's resilience as its ability to support collaborative, adaptive management of disruptions. This resilience is based on three pillars: acceptance, planning and adaption. Since the system studied here is an urban area, we propose integrating a resilience space that can incorporate all MCIs in order to develop collaborative, adaptive management of major electricity outages. A resilience space corresponds to a structured framework that unites major players (from a territory or an organization) to work on their individual and collective resilience. It can structure and support communication, coordination and cooperation among all stakeholders.

The development of a resilience space is based on a common situational picture (CSP), a tool to bring the stakeholders together around the problem of an electricity outage (Charmont, 2025). This tool is based mainly on Endsley's (1995) work on situational awareness. The CSP, which was first used in the military and aviation fields, allows for quick, informed decision-making on the basis of the perception and interpretation of the information held by several players, allowing for effective anticipation and decision-making. The CSP is adapted to a resilience space that is developed over time; it is similar to a dashboard presenting one or more representations of shared vulnerabilities (Charmont, 2025). In the context of electricity outages, the CSP provides a representation that incorporates MCIs' vulnerability and the consequences for the services with which they supply the population. Thus, it allows stakeholders to identify critical issues and collectively reflect on solutions. The CSP depends on the use of a certain amount of room to manoeuvre, defined as the tolerance interval available before the disruption significantly affects an MCI's functioning (Charmont, 2025). This room to manoeuvre is the result of the MCI managers' professional judgments, which incorporate knowledge of vulnerabilities, existing protective measures and the processes for implementing those measures.

Because it uses this room to manoeuvre, the CSP is able to strengthen each of the three pillars of the territory's and the MCIs' resilience. This tolerance depends on an understanding of vulnerabilities (acceptance pillar) and includes planning measures (planning pillar). Thus, the CSP enables stakeholders to consider the issues that have been raised and define joint solutions (adaptation pillar). As a result, it fosters collaboration, allowing the various players present in the territory to heighten their resilience in the face of certain disruptions. Even before the resilience pillars are strengthened, the creation of a CSP allows MCIs to develop and consolidate their communication mechanisms and their connections and clarify their roles and responsibilities, which are necessary for effective mobilization when a disruption occurs.

A resilience space has been set up in the territory of the Communauté Métropolitaine de Montréal, a community of several large and small cities, including Montreal, Longueuil, Laval and Terrebonne (Morissette et al., 2024). The implementation process started with the creation of a CSP for all the MCIs concerned. To do this, the managers of each MCI identified the key electricity-dependent elements their networks needed to function. For each one, they established the available room to manoeuvre, which involves defining the impacts on the functioning of the key elements, as shown in Table 1. The evaluation of functional status corresponds to the evaluation of each key element's vulnerability.

A colour code was also created to allow for the visualization of the various entities' room to manoeuvre in the CSP. Figure 1 presents a CSP for part of the territory. It was integrated into mapping tools that make it possible to consider the geographic areas that are most critical from the public's point of view, as well as the most vulnerable populations.

Table 1

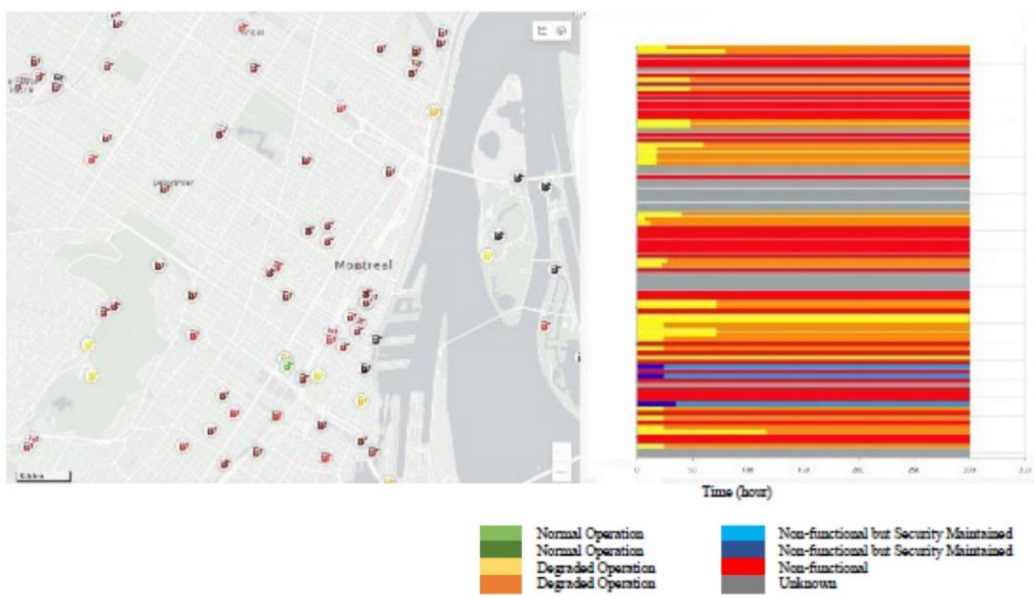
Description of the status of a key element.

Colour		Status of a key element
Light green		Normal operation
Dark green		Normal operation with redeployment of activities to a backup site
Yellow		Degraded operation with standby equipment
Orange		Degraded operation with standby equipment that needs recharging or refuelling
Light blue		Non-functional but security is maintained by standby equipment
Dark blue		Non-functional but security is maintained by standby equipment that needs recharging or refuelling
Red		Non-functional
Grey		Unknown

Source: Morissette et al. (2024)

Figure 1:

Example of a CSP related to electricity dependence in the Montreal area.



Source: Morissette et al. (2024).

The CSP revealed was confirmed to have played a direct role in increasing the collective and individual resilience of the MCIs involved in the resilience space. This finding is based on the three pillars of resilience. The managers gained a better understanding of their vulnerabilities and mobilized to deal with their joint vulnerabilities (acceptance). The municipal managers took actions to reduce some of the vulnerabilities, and individual action plans related to major electricity outages were updated (planning). Finally, discussions were rapidly initiated between the electricity system and certain MCIs to adapt their joint recovery strategies in order to enhance public safety (adaptation).

To set up resilience spaces in the territories covered by this study, the MCIs were contacted through their emergency measures and operational continuity departments, which directly piloted the dependence analyses within the municipal departments. Data confidentiality agreements were established, including with the managers of the electricity system. One player was made responsible for the interface between the MCIs and the electricity system. This person worked directly with the municipalities to collate the dependence of the MCIs' key elements on electricity and then map the results, which were then transmitted to the electricity system's geomatics department. Inside the municipalities, the resilience spaces enabled all municipal departments to understand their vulnerability in the face of electricity. The most vulnerable areas were highlighted and individual action plans could be adapted. Protective measures could also be planned, together with the electricity system's managers. For each municipality, the work the head of each municipal department had to do was minimal, but the pooling of their results led to shared awareness of their vulnerability and adaptation of the protective measures for all the key elements under consideration. These results clearly showed how effective the CSP was in the collaboration process, since it stimulated numerous discussions among all the stakeholders.

CONCLUSION AND DISCUSSION

Overall, this work has shown the importance of collaboration within a territory and the value of a resilience space for the MCIs in that territory. The study carried out in Montreal clarified the MCIs' vulnerabilities, raised their awareness and opened the door to expanded collaboration in order to enhance the entire territory's resilience. Today, the major issue is ensuring that this space is maintained, which will depend on the continued commitment of the managers involved, each of which has its own operating constraints. A clear governance structure needs to be installed and sustained in order to:

- Define common objectives and manage information sharing, bearing in mind confidentiality, transparency and the MCIs' roles.
- Ensure that the actions resulting from the analysis of the CSP are followed through on, in accordance with the municipalities' policies and operational realities. Preparatory exercises can be done to support these actions.
- Manage documentation, to track changes in vulnerabilities and allow all players to access the CSP.
- Maintain managers' commitment through regular communications about the actions taken and periodic updating of the CSP.

These actions must be supported by a leader (Morabito & Robert, 2023). In addition to building and maintaining ties between the members of the resilience space, the leader's role is to create real consistency throughout the territory and effective coordination of all the players, including the electricity system's managers, since short- and medium-term changes in municipal departments' electricity dependence must always be in phase with the issues facing the electricity system and its generation and distribution strategies. The leader must be neutral so they can ensure transparent coordination without any conflicts of interest. However, the manager of the electricity system must ensure the long-term survival of the resilience space so it can continuously update its protective measures and plans, particularly its priority restoration list, and adapt it to the realities on the ground. This is especially true in the current context of the fight against greenhouse gas emissions and adaptation to climate change. In fact, the energy transition undertaken by the vast majority of players in the territory is making it more complicated to manage sources of energy and the system as a whole, and thereby significantly changing vulnerabilities throughout the territory. This situation makes collaboration among all the players involved more necessary than ever before.

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