INTRODUCTION

In the coming decades, the frequency and gravity of extreme weather events are expected to increase. As a consequence, transport infrastructure failures or network disruptions will be more frequent, more important, and harder to recover from. In anticipation, France launched a national climate change adaptation plan with a section focused on transportation.

This plan has four objectives:

- Adapt the way transport infrastructures are designed, built and maintained;
- Assess the impact of climate change on transport demand and then on the adaptation of transport supply;
- Design a methodology for assessing the vulnerability of transport infrastructure components;
- Diagnose the vulnerability of French transport infrastructures and propose responses.

This communication is focused on the vulnerability assessment.

In France, as in many developed countries, transport infrastructures are not all recent, and some of them were designed at a time when the evolution of the occurrence and characteristics of extreme weather events had not been anticipated. Therefore, many infrastructures will probably become increasingly more vulnerable to those events. However, it is technically and economically impossible to upgrade all the transport infrastructures at once. It is necessary to determine priorities, based on their vulnerability and on their relative importances in transport systems (RIMAROCC, 2010).

The importance of a transport infrastructure component is assessed with respect to its role in the transport system: if the disruption of a given component significantly deteriorates the system’s performance, then this
component should be protected in priority. The assessment of the impact of a disruption on the transport system depends on the function considered. In the context of a disruption caused by an extreme weather event, it is relevant to distinguish the following functions:

- Safety: it is one function of transport systems to ensure that its users can travel safely. It should be true even under extreme weather events, in the case where the presence of travellers could not be averted.
- Emergency transport needs: particularly under extreme circumstances, transport systems should offer at least basic possibilities for emergency services to reach people, and conversely;
- Daily transport needs: once an event has ended, the transport system should still provide users with the possibility to travel efficiently.

Each function calls for specific protection measures. For example, safety relies on the physical design of the infrastructures as well as on user information; emergency transport relies on the possibility of infrastructures to still operate under extreme circumstances or in the short aftermath, given that it may be possible to use specific vehicles; finally daily transport needs may still be possible with a large number of disruptions, provided the transport system is sufficiently redundant.

From the perspective of daily transport needs, the importance of a given component should be assessed from the perspective of travel demand: if that component, say a road link, were to fail, what would be the impact on the transport system’s performance? The users of that road will probably have the possibility to take another route: they do not lose the possibility to achieve their trips, but they experience a reduced level of service. Also, by taking other routes, they will probably reduce the levels of service experienced by those routes’ users, which may in turn change route, etc. While this succession of consequences may seem inextricably complex, it is in fact exactly the kind of problem transport demand models are designed to solve.

The objective of the communication is to present a methodology based on a transport assignment model to assess automatically the importance of each road section in a road network. The importance of a road segment can be assessed with the model by comparing traffic assignment with and without the road segment; this approach can be applied on each road segment in turn. After a literature review in Section 2, the method is illustrated on the cases of the A13 highway and of the city of Rouen in Section 3. Section 4 extends the
method to the analysis of the contribution of each road section to the road network’s robustness. Section 5 concludes the communication.

LITERATURE REVIEW

Risk management has been the subject of a considerable amount of literature. This is also the case of risk management applied to transport networks, and, more recently, to the specific topic of the management of risks associated to climate change. This is a complicated issue: it requires methodologies for the analysis and forecast of climate change and its consequences; the analysis of how transport network components, and particularly infrastructures, will react to (or be vulnerable to) to climate change and its consequences; the analysis of how the vulnerability of transport network components endangers the transport network’s functionalities; the design and assessment of solutions; and eventually the development and implementation of management processes, which include data collection, component inventory, risk analysis and evaluation protocols, prioritisation rules, etc. (RIMAROCC, 2010).

Analysing the consequences of disruptions is important because the failure of one or a group of infrastructure component causes a loss of performance of networks. This loss of performance can be the impossibility to reach some people and provide them with emergency services, or, on a longer term, the decrease of the quality of transport services, with an impact on the economy and on society. One important by-product of the analysis of disruptions is the ranking of infrastructure components by importance.

Many papers and reports present various kinds of approach to analyse the consequences of disruptions of transport infrastructure components. They can be categorised into two broad groups. The first type of studies calculates scores, with the objective to assess the consequences of a disruption on a qualitative scale which typically contains three, four or sometimes five levels. There are different methods to build such indicators: e.g. Pereboom et al. (2014) consider a classification of roads of the Netherlands into four categories, based both on traffic flows, on the zones they relate, and on redundancy. Rowan et al. (2013) build adaptive capacity indicators based on the importance of the components in the transport system, with the originality that they also consider the capacity of the components to recover from a failure. Oswald et al. (2013) propose an indicator to approximate network redundancy. NJTPA (2013) determines the importance of a road segment by checking if it is located on routes between two critical zones. The main advantage of this type of approach is its flexibility; it is notably able to consider
a large number of transport functions, including emergency transport and connectivity.

The second type of studies aims at quantifying the impact of a disruption on the performance of a transport network. This approach applies methods of transport modelling (see e.g. Ortúzar and Willumsen, 2011, for a general presentation). The main advantage of this approach is that network effects are taken into account; the main disadvantage is that it is relevant for medium term loss of performance from the perspective of travellers, not for the loss of performance for emergency transport etc. Examples of studies are Jelenius et al. (2006) for Sweden, Earth et al. (2006) for the Swiss road network, or Schultz (2012) for the German road network. An original example where transport modelling methods are used to forecast the impact of disruptions on the proximity to health services is Taylor et al. (2006), in Australia.

ASSESSING ROAD NETWORK’S DISRUPTION

3.1 - Analysis of the particular case on A13 highway’s Incarville section

This first paragraph will present the problem based on a simple example: the disruption of a particular highway link in the French urban area of Rouen.

Figure 1 shows the location of this section. The other sections, also figured on the map, will be presented in the next steps.

The traffic on highway A13 is 70,000 vehicles per day (vpd) on the section of Incarville. Several types of traffic are observed on this section: long distance...
transit traffic between Paris and Rouen or the English Channel’s coast, exchange traffic between Rouen and cities around and few local traffic.

In case of a disruption of this section, users generally have the possibility to opt for another itinerary. However, the closer they are from that section, the fewer other possibilities they have.

In order to assess the impact of a disruption of this section, a traffic assignment model is used. This model considers two vehicle classes; it was calibrated on a regional area including Paris and Rouen.

One of the benefits of using a traffic assignment model is that it is possible to analyse how travellers react to the disruption of a given road. Figure 2 shows the consequences of the disruption of the section of Incarville on the surrounding road segments: on the map, the segments’ widths are proportional to traffic variations: blue segments represent traffic decreases whereas red segments represent traffic increases. Quite expectedly, the traffic tends to decrease on the rest of the highway while it increases on surrounding road segments, particularly those which are close and parallel to the disrupted segment.

As a consequence of route diversions, congestion increases critically on the roads submitted to the largest traffic increases (in this case, RD6015 and RD321). This entails a substantial increase of total travel time on the study area, which reflects the significant, negative consequence on the local transport network’s performance of the road disruption. Note that not all users
suffer similarly from the disruption’s consequences: local trips are more impacted than longer trips, for which more efficient alternate routes are available (see e.g. RD6014 and RD613). Figure 3 illustrates the variations of travel time per road segment.

![Figure 3: Travel time relative variations caused by the disruption](image)

Other effects can be noticed on the road network. In particular, as noted above, the traffic on highway A13 tends to decrease: as a consequence, travel times on the remaining road segments of A13 are improved: some of the highway users whose routes did not cross the Incarville segment before the disruption may actually benefit from the disruption. Due to the complex structure of transport networks, the consequences in terms of traffic of a disruption are hard to anticipate: at least for this reason, traffic models are relevant to address these issues.

### 3.2 - Global performance indicators

In order to analyse the overall impact of disruptions on the road network, it is necessary to produce global performance indicators. The following indicators are easily calculated by a typical traffic assignment software:

- **vehicles.hours (veh.h):** total travel time spent by the travellers on the road network;
- **vehicles.km (veh.km):** total distance covered by the travellers on the road network;
• cost of vehicle use: total vehicle operating costs borne by the travellers on the network: those include fuel consumption, maintenance and depreciation costs (0.20 €\textsubscript{2010} fixed by national guidelines);

• toll charges.

In order to assess the performance loss caused by the disruption, the approach chosen in this study is to reason on the basis of the generalised costs of travellers. A generalised cost function represents the preferences of travellers with respect to the quality of service characteristics of a transport alternative. It can be used to calculate how much a given traveller would be willing to pay for a quality of service improvement. Conversely, it can be used to measure how much money a traveller would demand to be compensated for a loss of performance. In this study, the generalised cost consists of monetary costs and of travel time, multiplied by a value of time of 14.40 €\textsubscript{2010} per hour (based on the average guidelines for the cost-benefit analysis of transport infrastructure projects in France). In order to simplify the analysis, this value was used both for cars and trucks (except in the assignment model, where those values differ).

Table 1 shows how these indicators vary with the disruption of the Incarville segment.

### Table 1: impact of the disruption on the performance indicators

<table>
<thead>
<tr>
<th>Reference</th>
<th>Disruption of the section “Incarville” (A13)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vehicles x hours</td>
</tr>
<tr>
<td>Reference</td>
<td>6 329 200</td>
</tr>
<tr>
<td>Disruption of the section “Incarville” (A13)</td>
<td>6 412 100</td>
</tr>
</tbody>
</table>

Except for the sum of toll charges, all the indicators are increased by the disruption. The total travel time increases, because of the increased length of the longer, slower routes chosen by the travellers, and because the increased congestion makes most of these road even slower. Similarly, the total travel distance also increases. We observe that the relative evolution (+0.5 %) of this indicator is lower than that of the total travel time (+1.3 %). It may be explained by the fact that some users, which were not initially going through the Incarville road segment, are nonetheless impacted by the increased congestion on their own routes.

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Due to the disruption, less travellers use the highway, thus the reduced total toll charges; however, their total vehicle operation costs increase, due to the increased distance and travel time. The sum of all these variations is that the total generalised cost increases: the performance of the road network is globally reduced by the disruption.

3.3 - Global performance indicators analysis with several scenarii

The main motivation underlying this type of analyses is the identification of the road segments of which the disruption would cause the highest performance loss. The analysis presented above is now applied to a selection of other road segments. The results are presented in Table 2.

*Table 2: variation of global performance indicators of all disruptions (per day)*

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Reference (absolute values)</td>
<td>--</td>
<td>6 329 200</td>
<td>225 815 600</td>
<td>45 163 100</td>
<td>3 551 200</td>
<td>48 714 300</td>
<td>139 854 700</td>
</tr>
<tr>
<td>1</td>
<td>Disruption of RD6015 - Mesnil-Panneville</td>
<td>14 600</td>
<td>+25 500</td>
<td>+414 000</td>
<td>+82 800</td>
<td>+54 500</td>
<td>+137 500</td>
<td>+504 600</td>
</tr>
<tr>
<td>2</td>
<td>Disruption of RD6014 - Les Thilliers-en-Vexin</td>
<td>10 300</td>
<td>-11 400</td>
<td>+427 400</td>
<td>+85 500</td>
<td>+61 000</td>
<td>+146 500</td>
<td>-17 200</td>
</tr>
<tr>
<td>3</td>
<td>Disruption of A13 - Vernon-Gaillon</td>
<td>47 100</td>
<td>+9 600</td>
<td>+768 100</td>
<td>+153 600</td>
<td>-44 800</td>
<td>+108 800</td>
<td>+247 100</td>
</tr>
<tr>
<td>4</td>
<td>Disruption of A13 - Incarville</td>
<td>70 500</td>
<td>+82 900</td>
<td>+1 098 800</td>
<td>+219 800</td>
<td>-81 200</td>
<td>+138 600</td>
<td>+1 332 900</td>
</tr>
<tr>
<td>5</td>
<td>Disruption of A13 - Rougemontiers</td>
<td>38 200</td>
<td>+38 000</td>
<td>+352 900</td>
<td>+70 600</td>
<td>+10 500</td>
<td>+81 143</td>
<td>+628 300</td>
</tr>
<tr>
<td>6</td>
<td>Disruption of A13 - Buchelay</td>
<td>61 200</td>
<td>+69 200</td>
<td>+1 046 800</td>
<td>+209 400</td>
<td>-150 400</td>
<td>+58 900</td>
<td>+1 054 900</td>
</tr>
<tr>
<td>7</td>
<td>Disruption of A13 - Tourville-Criquebeuf</td>
<td>80 000</td>
<td>+112 300</td>
<td>+1 165 000</td>
<td>+233 000</td>
<td>-79 800</td>
<td>+153 200</td>
<td>+1 770 500</td>
</tr>
<tr>
<td>8</td>
<td>Disruption of A13 - Moulineaux</td>
<td>56 800</td>
<td>+62 100</td>
<td>+821 700</td>
<td>+164 400</td>
<td>+11 800</td>
<td>+176 100</td>
<td>+1 070 000</td>
</tr>
<tr>
<td>9</td>
<td>Disruption of Tancarville Bridge</td>
<td>20 900</td>
<td>+49 800</td>
<td>+261 900</td>
<td>+52 400</td>
<td>+49 200</td>
<td>+101 600</td>
<td>+815 700</td>
</tr>
</tbody>
</table>

In cases where the disrupted road is parallel to a highway, there is a small increase in veh.h index (or slight decrease) (Scenario n°1 or 2), while the increase in total cost is more consistent. Conversely, the disruption of a
highway segment leads to a strong increase in total traffic while the total cost, in turn, remains virtually unchanged. This phenomenon occurs when there is a competition between a fast but tolled route and a slower but free route (e.g. A13 vs RD6014).

Table 2 shows that when there was a lot of traffic on the disrupted road segment, the consequences of the disruption in terms of total travel time and cost tend to be large. However, this is not always the case: the comparison of the consequences of the disruptions of segments “Rougemontiers” and “Vernon-Gaillon” of highway A13 shows that while they both have similar traffic volumes, the disruption of the former has a higher impact on total travel time than the other. It depends also a lot on the alternatives available to the users.

In so far as they anticipate the traffic diversion, and impacts on travel time and costs due to road disruptions, static traffic assignment models are adequate tools to perform an analysis of the consequences of road disruptions on the performance of transport system. However, using a traffic assignment model implies that the users still have the possibility to achieve their trips, and that they have had the time to reorganise their trips. It is relevant for medium to long term network disruptions, leaving travellers enough time to adapt to their new travelling conditions. Despite these limitations, another main strength of static traffic assignment models is that they can be used in an automatised way.

SYSTEMATIC AND AUTOMATIC ANALYSIS

4.1 - General principle of the automatic methodology

An important objective of risk analysis is to identify the components of transport networks which should be protected in priority, with respect to the consequences of their disruption. One approach to do so is to use a traffic assignment model to simulate systematically the consequences on travel demand of the disruption of each and every link of a given road network (or a subset of those links).

In this section, this method is applied to the road network of the urban area of the French city of Rouen. The transport model used in this analysis is a multi-class assignment model (with several classes of vehicles and values of time) of "user equilibrium" type, working on five time periods (two peak periods, two off-peak days and off-peak night). In order to keep the computation time minimal, only “cars” are taken into account in this analysis.
This model, runs in about 6 minutes. The road network considered in this analysis consists of ~4 400 road segments. Furthermore, the value of time of the travellers is assumed to be 10,00 €\textsubscript{2010}, lower than in the previous case. This value of time is more representative of the preferences of travellers in urban areas.

This method does not need to perform the assignment for all closures: a selection of significant edges can be established.

More than 18 days of computation time would have been necessary to perform the analysis on the whole network. So, the problem has been split into several parts to perform calculations on three of four computers at the same time.

Data slicing, traffic assignment and concatenation results have been launched by several algorithms.

4.2 - Automatic method’s results

The results are presented by Figure 4:

Figure 4: results with automated analysis – urban model of Rouen

The results show that the most important impacts are:

- for large transit infrastructures (A13);
• for large urban penetrating high traffic roads (A150, N138, and to a lesser extent, A28, N338, and RD18E);

• for road junctions supporting heterogeneous traffic patterns (eg RN31 junction / A28 junction RD6014 / RD6015).

As before, we notice that the traffic flow is not high enough to characterize the consequence of the disruption of a given section. For example, the disruption of A150, with a traffic level between 50 000 and 60 000 vpd, would have more consequences than that of Mathilde bridge, which supports more than 80 000 vpd. This is due to the quantity and quality of existing substitution routes, which are much lower for A150 than for Mathilde bridge.

This example shows the potential of using a traffic assignment model for the analysis of the consequences of road disruptions on travellers. The automated approach yields a global view of which parts of the networks are vital to maintaining the network’s performance. Practically, this methodology is limited by calculation time considerations: it is even recommended to use a model as simple as possible, and to simplify it if necessary.

4.3 - Manual issues analysis

There are cases where a traffic assignment model will not be available. The aim of this part is to develop a simplified methodology for the analysis of disruptions in such cases.

Beforehand, it is important to understand that the people who will apply this simplified approach must have an excellent knowledge of the studied transport network as well as of the travel demand. Ideally, this work should be an approach in partnership with several stakeholders, including network managers and operators, in order to have a complete sight of the transport system.

The methodology presented here derives from the results presented above. It should begin with selecting the road segments which will be analysed (it is practically impossible to analyse each and every road segment of a typical transport network). Then, each road segment should be described in terms of: traffic type (for interurban: short and/or average, and/or long distance, and for urban: intern and/or exchange and/or transit), traffic flow, alternate routes (possibly distinguishing the types of traffic), and the capacity of these alternate routes to accommodate additional traffic. For instance, in the case of Rouen urban area, this exercise would provide the results presented in Table 3. An intuitive rule can then be designed to estimate the impact of
disruptions on travellers, based on a combination of the information obtained in the analysis. For example, the following rule was used in Table 3: based on the number of alternate routes and their residual capacity, the consequences of a disruption are categorised as:

- 2 or 3 « weak capacities » → unacceptable
- 1 « weak capacity » and 1 (or 2) « average capacity » → significant
- 0 « weak capacity » and 2 (or 3) « average capacity » → acceptable
- 0 or 1 « average capacity » (and the remainder: « high capacity ») → little to no consequence

**Table 3: qualitative analysis of some disruptions around Rouen**

<table>
<thead>
<tr>
<th>Section</th>
<th>Traffic</th>
<th>Traffic structure</th>
<th>Substitute routes</th>
<th>Ability of those substitutes routes to assimilate the estimated delaying traffic</th>
<th>Results: section issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>A13 Tourville - Oissel</td>
<td>Very important (90 000)</td>
<td>Internal, exchange, and transit</td>
<td>Internal: Oissel bridge, Arche bridge Exchange: Arche bridge - D6015 Transit: none!</td>
<td>Weak Weak --</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>RD18E Roundabout of Cows – Mathilde bridge</td>
<td>Average (30 000)</td>
<td>Internal, exchange, and transit</td>
<td>Internal: N338 ou RD6015 Exchange: N338 ou RD6015 Transit: A29-A150-N338</td>
<td>Average Average Average</td>
<td>Acceptable</td>
</tr>
<tr>
<td>A150 Flaubert bridge– La Vaupalière</td>
<td>Important (60 000)</td>
<td>Internal and exchange</td>
<td>Internal: valley of Cailly Échange: valley of Cailly, A28</td>
<td>Weak Weak Weak</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>Guillaume le conquérant bridge</td>
<td>Average (45 000)</td>
<td>Internal and exchange</td>
<td>Internal: other bridges of Rouen Exchange: Flaubert bridge, Mathilde bridge</td>
<td>Average Average</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Mathilde Bridge</td>
<td>Very important (80 000)</td>
<td>Internal, exchange, and transit</td>
<td>Internal: other bridges of Rouen Exchange: other bridges of Rouen Transit: Flaubert bridge</td>
<td>Average Weak Average</td>
<td>Significant</td>
</tr>
<tr>
<td>Jeanne d’Arc bridge</td>
<td>Weak (10 000)</td>
<td>Internal</td>
<td>Internal: other bridges of Rouen</td>
<td>Important</td>
<td>Little to none</td>
</tr>
</tbody>
</table>
The proposed method is built so as to give results similar to those obtained with a model. However, it demands a very deep and detailed understanding of the transport network. It is also, by construction, limited in its accuracy. However, it has the advantage over a methodology based on a model to be combined to the analysis of other types of consequences of disruptions (particularly those related to connectivity loss, or to emergency transport).

4.4 - Choice of method: synthesis

Based on the discussion above, we present a scheme that may help stakeholders selecting the methodology best fitted to their needs and means. The two main criteria are: the availability of a traffic model, and the possibility to ensure that the model’s running time makes an automated method practical.

Figure 5: global scheme of the propose method

We must keep in mind that this analysis, whether manual or automatic, will always be limited by the fact that only one section is considered for the disruption.

NETWORK ROBUSTNESS ANALYSIS

The main limitation of the automated method presented above is that it is only relevant for isolated disruptions. The consequences of the disruptions of road
segments do not add: they can combine in non-linear ways, which make it necessary to have at least some knowledge of what will happen if several segments fail simultaneously.

Obviously, it is practically impossible to test all combinations of disruptions with a traffic model: the calculation time would be exponentially more than that of analysing isolated disruptions. There are two types of solutions:

- get a better knowledge of the sources of disruptions, so as to analyse only realistic scenarios, limited in numbered;
- derive information on the interaction between road segments in the network.

The second type of solution is explored here. More precisely, the idea is to identify which links help the network not losing too much performance in the case of a disruption. Symmetrically, this means that those links should be protected, because if they fail and other links fail simultaneously, the consequences in terms of performance will be dramatic. In other words, the idea is to identify the links which make the network robust.

For example, there are several road segments in the network supporting a small traffic flow under the network’s normal condition, but which are frequently used as alternative routes when there are disruptions elsewhere. Those links contribute to the network’s robustness: if they were absent, the consequences of the disruption of other road segments would often be much worse.

5.1 – Methodology

To identify those segments, a specific method has been developed. It relies, again, on a traffic assignment model. For each disruption simulated with the model, the traffic flow is registered for all the other road segments. As a consequence, the distribution of traffic flows over all possible isolated disruptions is calculated for each segment.

Indeed, consider segment $i$, and simulate the disruption of segment $j$. It is then possible to calculate the variation of traffic flow on $i$, as follows (where negative variations are set to zero):

$$
\Delta \text{Traffic}_{i,j\text{disrupted}} = \begin{cases} 
0 & \text{if } (\text{Traffic}_{i,j\text{disrupted}} - \text{Traffic}_{i\text{calibration}}) < 0 \\
\text{Traffic}_{i,j\text{disrupted}} - \text{Traffic}_{i\text{calibration}} & \text{otherwise}
\end{cases}
$$
Then, a robustness index can be calculated. Here, the following index is chosen:

\[ CR_i = \sum_j \Delta \text{Traffic}_{i,j,\text{disrupted}} \cdot L_{j,\text{disrupted}} \]

with:

- \( i \): studied segment
- \( j \): other network segment
- \( L_{j,\text{disrupted}} \): length of the disrupted link \( j \)

This indicator increases when segment \( i \) is often on an alternative route, taken by users diverted from their original routes by a disruption. Traffic variations are weighted by the length of the disrupted link, in order to give the same importance in this index to all network components.

We have to note several breaks, as those on the same itinerary of the studied arc, can cause a drop in the indicator that artificially reduce the overall importance of this arc\(^2\).

This method works better if all the possible disruptions are tested. This implies potentially very long calculation times, as well as the possibility to store large amount of data.

**5.2 – Results**

The methodology has been applied on the city of Rouen and its surrounding area. Figure 6 shows the results. Each road segment’s width is proportional to traffic flow, while the colour indicates the contribution of the segment to the network’s robustness. In particular, red and deep red segments have a high probability to experience traffic flow increase if there is a disruption somewhere else on the network.
This analysis shows that most of the segments which were identified before as important also contribute substantially to the network’s robustness. But there are other segments of which the disruption would have less consequences, but which are often used as alternative routes when there are disruptions at other places. Consider, for example, the case of the “Avenue des Canadiens”, which is one of the ways to access the south of the town centre. This avenue supports up to 18,000 vpd on the busiest section. Its disruption would not have unacceptable consequences. However, it assumes the role of natural alternative route when larger and parallel roads (for example RD18E or RN338) are closed. In this case, the urban boulevard (2x2 lanes) can support up to 25 or 30,000 vpd.

In general, the observation of Figure 4 and Figure 6 show that the network considered as “structuring” by local road managers is indeed the one which is identified as important in our approach. It is constituted by segments which should be maintained active in priority, and protected if necessary.

CONCLUSION

Risk analysis has become increasingly popular, in particular with respect to the adaptation of infrastructures to climate change. One consequence of climate change is the potential increase of frequency and gravity of extreme weather events, to which existing transport infrastructures are probably vulnerable. It is not physically and financially feasible to adapt instantaneously all infrastructures to the new environmental conditions. Therefore, priorities
should be established. Some elements on which these priorities are based are the consequences, including in terms of transport performance, of disruptions.

A proper analysis of the consequences of disruptions on transport performance requires to take into account network effects. Traffic assignment models are able to take such effects into account, and are therefore relevant tools to analyse the consequences of disruptions. This communication illustrates this type of approach.

Traffic assignment models are rare and expensive: they are not always available to proceed to an analysis of the consequences of disruptions. This communication presents an alternate, qualitative method which can be applied by stakeholders in a practical contexts. It relies on the identification of the main segments, as well as on their alternate routes and the possibility those have to accommodate additional traffic.

The analysis of isolated disruptions is not enough for a proper understanding of the risk caused by extreme weather events on transport networks: it is also necessary to consider multiple disruptions. This is a much more complicated task. One option to do so is to analyse the network’s robustness, by the identification of the interactions between arcs. The communication illustrates this approach.

Directions for improvement of this work are: to better take into account multiple disruptions through explicit scenarios; to set this type of analysis in a multimodal context (the difficulty being that when a rail-road segment is broken, this has non-local consequences on the services the rail operators are able to provide); and to provide elements of socio-economic assessment of the various solutions which can be imagined to reinforce the transport network’s resistance, robustness and/or resilience.

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NJTPA (2013). Climate change vulnerability and risk assessment of New Jersey’s transportation infrastructure. Study report.


NOTES

¹ CEREMA: Centre for Studies and Expertise on Risks, Environment, Mobility, and Urban and Country planning

² It should be noted that some edge effects can occur when closing links on the periphery of the network and whose failure causes the artificial suppression of an injector.