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ROADAPT
Roads for today, adapted for tomorrow

Guideline - Part D
Socio-economic impacts analysis (WP3)

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CEDR Call2012: Road owners adapting to climate change

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Socio-economic impacts analysis (WP3)

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Executive summary

The present report forms the part D of the overall ROADAPT guidelines and is related to the socio-economic assessment. It contains details on how to perform a socio-economic impact assessment of the consequences of weather events. It is built on the principles that have been developed in the French GERICI project [4] completed within RIMARROC.

The impact assessment addresses traffic events caused by adverse weather conditions. Therefore the first step consists in deciding what weather phenomenon or threat caused by climate change should be selected and the likely consequences on traffic, or more generally on the mobility service offered by the road network.

The consequences of climate change will either affect the infrastructure (deterioration of the pavement, landslip…) either directly the traffic conditions (heavy rain or snow, floods…) and therefore in all cases reduce the road level of service.
For road user, the level of service is generally characterised by three main criteria: safety, efficiency and comfort. It is rather impossible to measure the degradation of safety[1] as safety is dependent on many factors, the most important been the user's behaviour…. Comfort is also more a qualitative criteria. The predominant criterion in socio-economic assessment in transport is efficiency which is measured by the costs of travelling from A to B. Cost includes energy consumption, vehicle amortization, taxes, tolls… and value of time spent, per passenger or goods that are transported. In general, other externalities need also to be considered (GHG, noise…), and monetised,

For the ROADAPT project, as there is a high level of uncertainty on the occurrence and real impact of weather event, we have considered that the travel time is the main key indicator for impact assessment. When translating the travel time in monetary value, the other indicators are anyway of second order.
Selecting the threat is based on the outputs of part B and/or C of the guidelines. It is then the choice of the NRA or road network operator to decide what threat deserves to be assessed. The first approach will be qualitative and based on the knowledge of the road operator. Generally, the more frequent ones and/or those generating the most severe impact on traffic need to be assessed. Combination of threats can be considered by developing a scenario approach, the results not being an addition of the impact of individual events, but a combination of impacts.
Once this choice made, it is necessary to characterise the potential consequences on the level of service, namely:

- Reduction of speed
- Held up traffic due to lane restrictions for example
- Access restriction with rerouting or storage of vehicles (E.G. Heavy Good Vehicles).

It is worth to mention that the degradation of level of service can be due to the event or to the measures that are taken to minimize the impact of the event (E.G. access control, vehicle storage)

For simple network and limited event, a rough estimation of the time lost by all network users can be made and translated in monetary value. The HEATCO project (Harmonised European

[1] However, the safety criteria is considered at a macro level in transport planning studies fo comparing different transports projects: comparison of modes or road with different characteristics (separeted carriageways,, level crossings, etc.)

Approaches for Transport Costing and Project Assessment) recommends harmonised values to be used in Europe.

But in general, the consequences of a major weather event will impact a large part of the network. It is then required to use a traffic model. Typology of traffic models is presented in the report and recommendations made.

Depending on the shareholder's point of view the socio-economic impact will be evaluated at different levels. The guidelines propose three levels of analysis:

- The network level: only the impact on travel time of road users network is estimated
- The territory level (territory which is irrigated by the network): impact on the travel time on the various liaisons which are ensured by the network is estimated
- A wider perimeter which we have termed: the economic system as a whole and which extends the analysis not only in terms of geography but also in terms of economic activities that can be impacted.

Examples of results illustrate the application of these models in different cases. In order to better visualise the impacts, it is recommended to use a GIS model in combination with the traffic model software.

1. Introduction:

Infrastructures are the backbone of our society. Citizens, companies and governments have come to rely on and expect uninterrupted availability of the road network. Extreme weather is an important factor for the reliability and safety of the road network. In the same time it is generally understood that the climate is changing and that this will have significant effects on the road infrastructure. Since road infrastructure is vital to society, climate change calls for timely adaptation.

Although there are considerable uncertainties involved in both the projections of future climate change and related socio-economic developments and in estimations of the consequences of these changes in transportation needs, there is a constant need for decisions and development of the road transport system. As stated in the CEDR 2012 Climate Change DoRN: *'Road authorities need to evaluate the effect of Climate Change on the road network and take remedial action concerning design, construction and maintenance of the road network.'*

The ROADAPT project is part of this CEDR Call. ROADAPT has an integral approach following the RIMAROCC (Risk Management for Roads in a Changing Climate) framework that was developed for ERA NET ROAD in 2010. ROADAPT aims at providing methodologies and tools enabling tailored and consistent climate data information, a good communication between climate researchers and road authorities, a preliminary and fast quickscan for estimating the climate change related risks for roads, a vulnerability assessment, a socio economic impact analysis and an action plan for adaptation with specific input from possible adaptation techniques related to geotechnics and drainage, pavements and traffic management.

Outputs of the ROADAPT project are guidelines that address all these topics. In the main guidelines an overview of all topics is provided. In five following parts the specific topics are addressed in detail. These five parts are:
A. Guidelines on the use of climate data for the current and future climate
B. Guidelines on the application of a QuickScan on climate change risks for roads
C. Guidelines on how to perform a detailed vulnerability assessment
D. Guidelines on how to perform a socio economic impact assessment
E. Guidelines on how to select an adaptation strategy

The present document forms Part D of the guidelines. It is decomposed in two main parts:

- The introduction, with the presentation of the framework, the objectives of this part D of the ROADAPT guidelines, and overall vision of socio-economic impact assessment.
- The second part consists in three sections each one dealing with the methodology of evaluation for a given geographical level of analysis (among the three levels identified in the first part).

1.1 What do we want to evaluate?

In the ROADAPT framework, Road Authorities (and Road Operators) may want to evaluate three different kinds of object:

- The impact of an event on the transport system,

- The impact of adaptation measures, strategies or group of strategies to fight against climate change,
- The impact of global scenarios and policies.

This first section of this chapter describes these three types of analysis, that derive from one-another.

1.1.1 Impacts of an event

The basis of risk consequence assessment is to evaluate the direct consequences of a simple event. The event first needs to be precisely defined. In the case of climate change risk, such a basic event could be for example:

- heavy rain e.g. 50 mm of rainfall in 1 hour
- heavy snow e.g. 1m height
- landslide on a road stretch.

It could also be a resulting phenomenon from (often combined) weather event(s), for example:

- flooding of a road stretch from heavy rain + strong wind from sea + depression (storm) + sea level rise
- flooding of a road stretch from heavy rain + high level of water because of snow melt.

Considering transport networks, whatever the mode of transport, these events can have two kinds of impacts:

- **Impacts on the infrastructure asset itself, that is to say damages that will induce reparation costs**. This first kind of impact highly depends on the kind of asset (bridge, road, station, etc.) and the damaging event. *Even if it may not be the least impacts, it is not in the scope of this study. Data on cost of construction works from road authorities, operators and constructors allow to assess this kind of impacts. See [1] CEDR (2012) 'Adaptation to climate change' Good practices in annexe 3: 1.8.a, 1.8.b, 1.8c.*
- **Impacts on the transport system affecting the traffic mobility service**. The present guideline will focus on this kind of impact.

Then, in order to assess the consequence of an event on transport system considering the mobility service, what we need to define is the event from a transport perspective.

In the ROADAPT framework, the following list presents the possible events or threats on a road transport system, that we'll later call **a traffic event**, here grouped in three increasing levels of impact:

- **Reduced level of mobility service:**
    - o Loss of driving ability:
        - Reduced visibility (fog, rain or snow)
        - Reduced speed (heavy rain, snow, ice, strong winds) [recommended or mandatory speed reduction]

- Traffic management events that can be put into place by road operator as a response to a weather event (and congestion):
  - Access restriction
  - Weight limits
  - HGV Storage (stop and park heavy good vehicles)

- **Degraded level of service:**
  - Lane closure
  - Road stretch closure (rerouting)
- **No transport services:** Road network closure.

In the case of **other modes of transport** (Air, Train) and also for **any transit system on road**, since the service can simply be defined with its travel time and its frequency, the main type of events could simply be:

- Reduced level of mobility service: **small delays, few services cancelled**
- Degraded level of service: **great delays, some services cancelled**
- No transport services: **all services cancelled**

Once chosen (see section 1.2), the traffic events will then have to be defined in the traffic model (see section 2.2), whatever the detailed economic approach that is put into place. The model will translate these events in indicators: typically travel time, energy consumption, vehicle operation costs, GHG emission, noise levels, etc…

1.1.2 Time resolution of the modelled traffic event

If the scale of the event is small, typically if its duration is about few hours within one day only, then it may be worth to look at the impact on different stages of the traffic event.

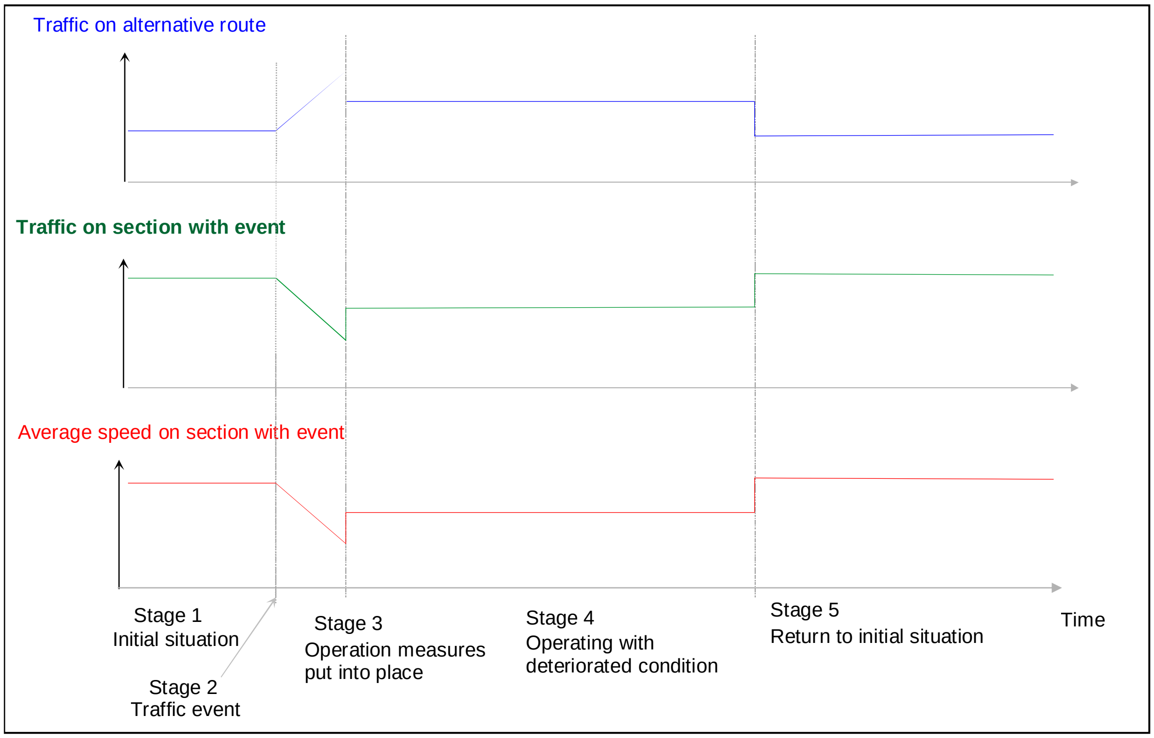
The temporal sequence of socio-economic evaluation of a "network problem" can be divided into 5 stages:

- Stage 1 - Initial situation before the event: network is operating normally before the event occurs.
- Stage 2 - Occurrence of the traffic event: network problem occurs, but no action has yet been implemented by the operating organisation. Vehicles continue to arrive on the scene of the incident:
    - Either the network incident results in a total break of the traffic and we are witnessing a "build-storage" of vehicles
    - Either the network incident is resulting in partial closure of traffic and we see both more complex traffic conditions and a "build-storage" effect.
- Stage 3 - Managing the problem. It is the situation after taking direct response measures. Emergency services and operators are involved for the return to a temporary situation with degraded conditions.
- Stage 4 - Operation in degraded conditions: take operational measures in order to return to initial stage, during which traffic conditions are deteriorated. The network is operating in a degraded mode for a certain period. Two situations are possible:
    - Stage 4a: Traffic is still possible on the road stretch affected by the incident but the level of service is degraded (e.g. traffic on one lane only instead of two lanes), alternative routes are optionally used for rerouting.
    - Stae 4b: The road stretch is closed and alternative routes are defined in order to reroute the whole traffic.
- Stage 5 - End of the incident: back to the initial situation. (Stages 1 and 5 are identical).

Then, the situation in the future may be different, when adaptive measures have been made to be more climate proof.

The figure below describes this sequence of stages.

Figure 1: Main characteristics of the temporal sequence of a traffic event



The duration of stage 3 is generally short (few dozens of minutes) relatively to the whole sequence 2 to 5. Then it can be considered as the same conditions as in stage 4. It allows to work with a static model (no variation within a stage).

Thus, it is generally possible to work with only two situations for a given traffic event:

- The initial (and final) situation with the network operating normally
- The degraded situation with specific measures put into place by the road operator.

1.1.3 Impact of adaptation measures, strategies and policies

Once a threat is identified, road authorities may want to evaluate different adaptation measures as responses to these identified threats and their corresponding traffic event.
The aim of an adaptation measure can be to:

- Completely prevent the traffic event to occur: then the assessment of the technique is directly deducted from the assessment of the traffic event.
- Reduce the effect or intensity of a traffic event, e.g. its duration or the length of the impacted network. Then, a specific traffic event corresponding to the reduced event may have to be analysed in detail in order to evaluate the new situation.

Adaptation measures can thus be evaluated from the impact assessment of the corresponding traffic event, and then compared to its cost of implementation.
The resulting cost-benefits analysis and the multi-criteria analysis are the main tools for decision making (see chapter *2.1 Background on existing methodology for Cost Benefit Analysis*).

Adaptation measures can be combined to form strategies and policies.
For groups of measures (strategy or policy), it is possible to combine the corresponding events assessments. But for that purpose, the probabilities of each evaluated event have to be known, which rarely the case is.
That is why simpler methods (without detailed economic assessment) have been defined for risk assessment, using semi-quantitative methods to evaluate the probabilities and the consequences of a risk (risk represented in a two dimensional diagram).

For general analysis of risk and simpler method estimation of consequences, the reader should refer to the general framework of risk management (Rimarocc + Roadapt) [And for rough estimations of socio-economic impacts, see also section *2.2 The use of a traffic model*]

On the same principle, a climate scenario or a policy scenario (combining many policy measures) can be assessed using detailed economic approach provided the probabilities of all events can be estimated. Otherwise, as mentioned just above, more general and semi-quantitative method will be more appropriate.

1.2 *How to choose which events to evaluate?*

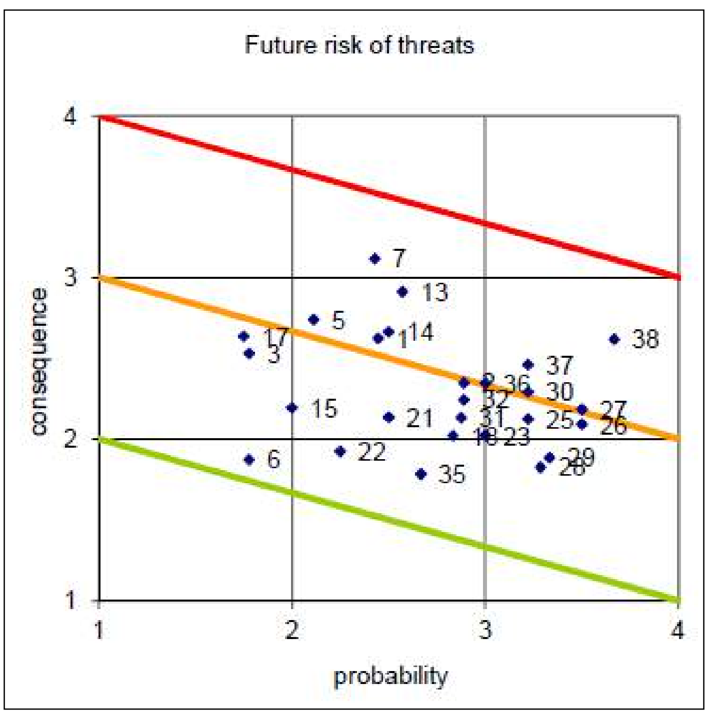
1.2.1 Selection of main risks

We have to recognize first that precise impact assessment of weather/network events is quite time consuming. Then, all events may not be precisely evaluated: choices may have to be made.
Logically, we recommend evaluating those which have a high level of risk, that is to say a high level of probabilities, or high level of consequences, or even both in priority. We could also choose to evaluate events that have high level of uncertainty in terms of consequences in order to reduce this uncertainty.

To select which events to evaluate, some previous risk analysis is therefore needed, at least in a semi-quantitative way. The reader is here referred to the Part B of ROADAPT Guideline on how to perform a Quickscan. Though, the consequences on territory and on the economic system scale will surely not be accounted for in the risk assessment from the Quickscan.

As an example, the risk matrix below is extracted from the Quickscan exercise in the Rotterdam-Ruhr corridor.

Figure 2: The risk matrix from the Quickscan in the Rotterdam-Ruhr corridor



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In this example, the main identified risks (whatever their locations), from which we could choose the events for detailed impacts assessment, are the threats number 7, 13, 14, 37 and 38.

Once a risk is chosen, the locations (road stretch) with the highest level of risk should be selected for detailed impacts assessment. The next section (§ *1.2.2 How to choose which location for the traffic events)* gives guidelines on how to process in more details.

A comprehensive approach is possible if all risks have been mapped with their respective levels.
It requires then to select the locations where there are the more risks combined (with the highest level of risk).
Risk level, defined as the product of consequences with probabilities, can be sum up at each location in order to find the location with the higher level of risk.
The impact assessment of a traffic event (e.g. road closure) at this location will allow evaluating the impacts of each risk that generates the same traffic event.

1.2.2 How to choose which location for the traffic events

First of all, the choice of traffic event, their location and their precise definition should involve a transport analyst (or transport engineer, economist, modeller, etc.).

From a traffic point of view, a section of road is defined by a stretch of roads between two intersections or interchange (the traffic volumes are the same all along). Whatever the precise location of the risk within a traffic section, the traffic event is the same.

The main criteria to be used for the location selection of the events (whatever the detailed economic approach that will then be implemented) are the following (in decreasing order of importance):

- Selection of stretches with high risk potential and:
- Estimation of total lost time (= Flows x Individual average time loss)
- Traffic volumes, as the main component of total time loss
- The absence or existence and characteristics of alternative routes, as the main component of average time loss and additional distance travelled
- The importance of the road (approach more territory oriented), to determine locations that are most sensitive: close to economic poles, health care, tourist areas, etc. (see chapter 3 for more details).

For rough estimations of socio-economic impacts (three first bullets), the reader should refer to section *2.2 The use of a traffic model*.
Of course multiple locations can be selected, but it is worth saying that close locations on the same road (at least where traffics are homogenous) will lead to close result (because level of traffic is similar, and alternatives routes are identical). This will not work typically with two sections of road lying on two different sides of an important motorway interchange or entry/exit.
One must also care to the fact that traffic scenarios can’t be summed:

- The effect of closing two adjacent sections may be exactly the same as closing only one of the two sections,
- On the contrary, closing two parallel sections of roads will lead in far worse consequences than the sum of each two, because in that case, users will have to find a 3rd alternative road that may be much longer than the two closed routes.

That is the reason why traffic precise analysis is needed, and the use of a traffic model recommended.

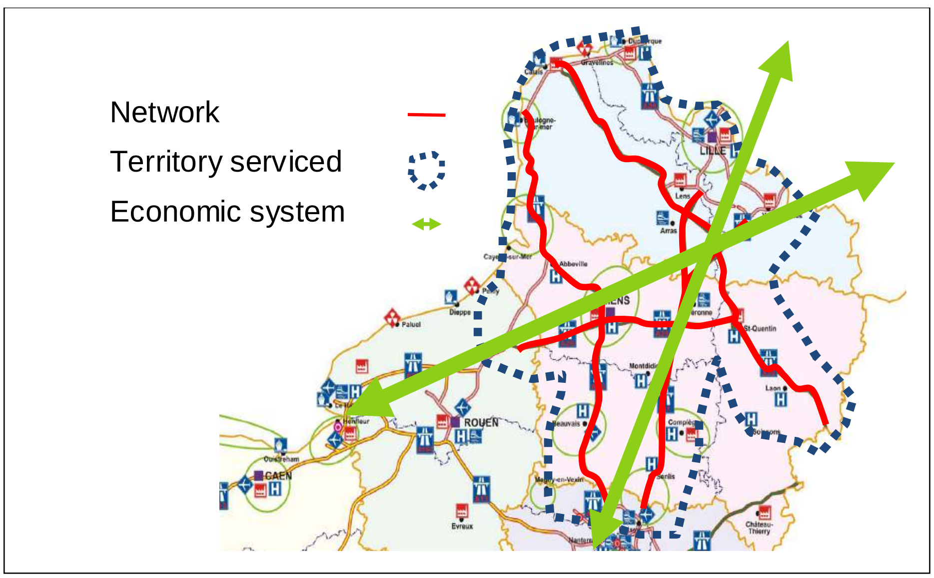
1.3 Three main approaches for detailed economic analysis

1.3.1 Three geographic levels of analysis

We propose to consider 3 main approaches, corresponding to 3 geographical levels in the socio economic analysis:

- Network level: considering potential impact on traffic; delays, risk of accident, GHG emissions, etc.
- Local territory level: the territories that are served by the road network and other transport infrastructure (in particular railways) with impact on economic activity, including as a result of any temporary modal shifts (either to or from road, depending on whether other transport modes are also disrupted by the weather event)
- Economic system as a whole: at a wider scale the potential impact on long distance corridor and at inter-regional, national or cross-border level and the consequences on economic activity.

Figure 3: The three geographical perimeters



1.3.2 Proposed methodologies according to the 3 geographic perimeters

The three proposed methodologies for detailed economic assessment, according to the three geographic perimeters seen above, are the following (see following chapter for more details):

- **Chapter 2 - Network level**: classical method of Cost-benefit analysis for transport project assessment (see in particular [2] European Project Heatco Deliverable 5)

- **Chapter 3 - Local territory level**: analysis of facilities and their accessibility (accessibility maps)
- **Chapter 4 - Economic system as a whole**: analysis of the structure of flows, organisation of the logistics and calculation of PIB according to spatial analysis.

The three proposed methodologies above are independent and complementary. They can be done independently and simultaneously.
However, their implementation can be time consuming, and we may want to choose only one of them. In this case, their deployment will mainly depend on:

- the objectives and needs of the Road Authority (or Road Operator)
- the existence of a traffic model (see § 2.2)
- the time, budget and work force available (especially transport economists).

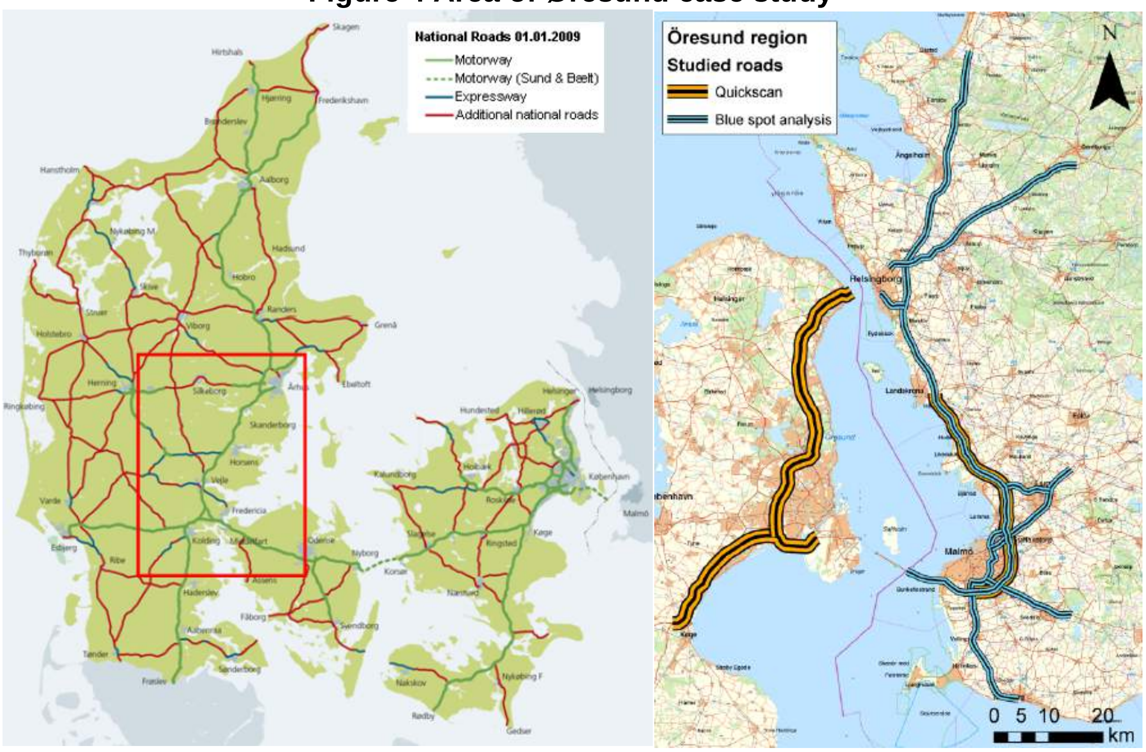
Concerning the objectives, if we want to focus **on short term impacts**, we should stick to classic CBA analysis, since the two others are more related to long term impacts.
It has to be noted that the analysis on network level, in particular CBA analysis, is well adapted for both short and long term analysis.

If we want to look at the allocation of impacts on the different actors (users, operators, society), or type of cost/advantage (time, cost, externalities), the only appropriate methodology is the CBA (Network level). The two other approaches are global and do not give any allocation of impacts per actors (to summarise, they give only one figure).

1.4 Presentation of Øresund Case study that illustrates the methodology

The Quickscan-method has been performed and assessed in the Öresund region, on both the Danish and the Swedish side of the strait. Studied roads include road E55 between Helsingør and Copenhagen and road E20 from Amager to Køge in Denmark and road E20/E6 in Sweden between the Öresund bridge and Landskrona (see Oresund case study report)**Error! Reference source not found.**.

Figure 4 Area of Øresund case study



The Quickscan method has been conducted in the Öresund region (thick stretch of roads on right side) and the Blue spot analysis has been conducted on an extended stretch of National roads in Jutland, Denmark (left) and in Sweden, roughly between Ängelholm and Trelleborg.

However, there was no analysis of traffic flows on this stretches of roads (see case study report for more details).

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2 Socio-economic analysis on the network level

2.1 Background on existing methodology for Cost Benefit Analysis

The main idea to evaluate the impacts of a traffic event is to use a traffic model and do a cost benefit analysis. Indeed, event assessment is equivalent to a new project assessment, but instead of evaluating the impact of a new infrastructure, we evaluate the consequences of closing or reducing the capacity of a road (negative impacts).

Basically, we recommend using a traffic model which can give at least:

- The total travel time spent over the network (veh.h)
- The total distance travelled (veh.km).

The impacts are calculated from the difference of these indicators between two situations:

- the current normal situation, as the referenced situation
- the exceptional situation with the network event (modelled scenario)

The analysis includes all effects on the network:

- Users: Time loss for users, operating vehicle cost depending on travelled distance
- Operators: cost of operation, diminution of revenue from toll
- Society: safety, externalities (GHG, air pollution, noise)

The following table, extracted from the WebTAG (Transport Analysis Guidance from UK Department for Transport), lists all the impacts included in the Appraisal Summary Table (AST), categorised by impacts that:

- are typically monetised and reported in the Transport Economic Efficiency (TEE), Public Accounts (PA) and Analysis of Monetised Costs and Benefits (AMCB) tables;
- can be monetised but their monetary values are not reported in the AST as the underlying evidence base is considered less robust; and
- it is currently not feasible to monetise, therefore qualitative or quantitative analysis should be reported in the AST.

Table 1: Appraisal Summary Table Impacts

Category of impact	Impacts that are typically monetised	Impacts that can be monetised but are not reported in the AMCB table	Impacts that it is currently not feasible or practical to monetise
Economy	Business users and private sector providers (including revenues)	Reliability impact on business users Regeneration Wider Impacts	
Environment	Noise Air quality Greenhouse gases	Landscape	Townscape Historic Environment Biodiversity Water environment
Social	Commuting and other users Accidents Physical activity Journey quality	Reliability impact on commuting and other users Option and non-use values	Security Access to services Affordability Severance
Public Accounts	Cost to broad transport budget Indirect tax revenues		

This table offers the elements for performing a multicriteria analysis. For assessing a traffic event linked to climate change at the network level, we recommend focusing on impacts of the first category only: impacts that are typically monetised. It is not worthy to study the other impacts at the network level, given that there are of second order, and given their level of uncertainty (plus the time needed for other impacts estimation). Moreover, they are more qualitative and linked to the territory level.

Each European Member State provides recommendations for these calculations, giving unit values to use for:

- value of time, which typically depends on the type of vehicle (private car, HGV), and the travelled distance
- Vehicle costs, for private cars and HGV,
- Externalities (Noise, Air quality, Greenhouse gases).

In order to have harmonised methodology over Europe, it is recommended to use values from the European project HEATCO (Harmonised European Approaches for Transport Costing and Project Assessment).

The following tables extract from Heatco D5 summarise the Estimated Value Travel Time Savings (VTTS)

Table 0.3 Work (business) passenger trips (€$_{2002}$ per passenger per hour, factor prices)

Country	Business		
	Air	Bus	Car, Train
EU (25 Countries)	32.80	19.11	23.82

Table 0.4 Non-work passenger trips (€$_{2002}$ per passenger per hour, factor prices)

	Commute-Short Distance			Commute-Long Distance			Other-Short Distance			Other-Long Distance		
	Air	Bus	Car, train	Air	Bus	Car, train	Air	Bus	Car, train	Air	Bus	Car, train
EU (25 Countries)	12.65	6.10	8.48	16.25	7.83	10.89	10.61	5.11	7.11	13.62	6.56	9.13

Table 0.5 Freight trips (€$_{2002}$ per freight tonne per hour, factor prices)

Country	Per tonne of freight carried[1]	
	Road	Rail
EU (25 Countries)	2.98	1.22

[1] Value per tonne of freight carried and not for the maximum load of the vehicle or the weight of the vehicle.

The Heatco D5 report also gives values for each European country for the following externalities:

- Table 0.10. Estimated values for casualties avoided.
- Table 0.11. Cost factors for road transport emissions* per tonne of pollutant emitted in €2002 (factor prices).
- Table 0.13. Impact factors for road transport emissions* (lost life expectancy in years of life lost per 1000 tonnes of pollutant emitted).
- Table 0.15 Impact indicator for noise exposure
- Table 0.16 Values for greenhouse gas emissions in €2002 per tonne of CO2 equivalent emitted

2.2 The use of a traffic model

Basically, what have to be estimated in order of importance are the following quantities:

- **Travel time loss**
  It can be estimated as the number of vehicles (preferably distinguishing cars and trucks) multiplied by the average time loss. The difficulty is generally to estimate the individual time loss, which depends on the level of congestion, and on the alternative route(s). That is where a traffic model is useful.

- **Additional travelled distances**
  Exactly on the same principle as time loss, additional travelled distance can be estimated from the number of vehicles (preferably distinguishing cars and trucks) multiplied by the average extra distance travelled. If there is no alternative routes, then it is simply 0. The total additional travelled distance by type of vehicle is used to calculate the vehicle operating costs for users, and the transport externalities (for society)

- **Operator revenue and cost**
  This indicator depends on the needs of the road operator. The loss of revenue can be estimated as the decrease of traffic flows on the affected sections multiplied by the average toll (by type of traffic) on that section.
  Concerning the cost of operation, it may increase in the short term because of road works (out of our scope) of reparation and maintenance. On longer term, the cost are generally proportional to traffic volumes and then could decrease but only if the event is very long (months) and if the operator has the time to adapt its organisation. We can consider this last effect as null on the scale of one event.

- **Estimate the number of deleted trips**
  According to the global and relative increase of the generalised cost of transportation, it is possible to estimate a number of deleted trips. However, this is clearly of second order and can be regarded as insignificant, especially on the network level.

As we see here, rough calculations can be made to do first estimates for a cost-benefit analysis. But the use of a traffic model is recommended for the following reasons:

- It gives automatically the results described above. Thanks to the model, there is no need to make specific assumption of average time loss and average additional travelled distance for each modelled event.
- It includes fully all the congestion effects, as for example the time loss on other routes due to rerouted flows. The impacts on secondary roads that become congested are often of the same order than the time loss of the main diverted traffic.
- It allows running many scenarios keeping the consistency in the methodology between different scenarios (time loss will be evaluated on the same principles for every scenario).

All the (many) kinds of existing traffic models can be used in order to calculate the results above (or help doing the average estimations described above). Here we give a short description of the main categories of traffic model, and in which case they can be used. Indeed, there are many of them, but different types of traffic model will be more appropriate according to the type of the studied traffic event:

- Micro-simulation model representing the interaction between each vehicle can be used for traffic event such as speed limitation or lane closure. This type of model is generally site specific; they are quite expensive to implement, and concern generally very small geographic perimeter (few stretches of roads). In the Roadapt context, this type of model is suitable only if road authority wants to assess dynamic management measure (e.g. dynamic lane or speed control).
- Macroscopic traffic models, calibrated on an hourly basis, typically at peak periods. This type of model is usually those developed in urban areas. This type of model well takes into account the congestion effects, but they are generally based on urban areas, which is not sufficient for the use of the road authority at a national scale.
- Macroscopic traffic models calibrated on a daily average. This type of model is those used for interurban areas, and for motorway project assessment. This type of model is generally used on large networks (region, nation, or even international). With their global point of view, these models are the most suitable in the Roadapt context.
- Without any traffic model, very rough and simple calculations (as presented above) could also be made to estimate some time loss only, without taking into account diverted traffics (by using a simple hypothesis on the individual time loss per vehicle multiplied by the number of vehicles).

The results in difference between reference and scenario from the traffic model are then multiplied by the corresponding period of the traffic event.
If the event has duration of few hours:

- if a daily average traffic model is used, a coefficient (<1) can be used to estimate the loss over the period. For example, for an event of 2 hours, we could take the ratio 1/6 (assuming the daily traffic is spread over 12 hours of the day).
- If peak hour model is used, the result can be multiply by the number of hours of the event, eventually taking into account some reduction for off-peak period.

If the event has duration of several days:

- if a daily average traffic model is used, we can just multiply the result with the number of days
- If peak hour model is used, an estimation of the impacts over a day first need to be estimated, using a coefficient from peak hour traffic to daily average traffic (for example 12), and then multiply by the number of days of the event.

2.3 Step by step summary of the proposed methodology

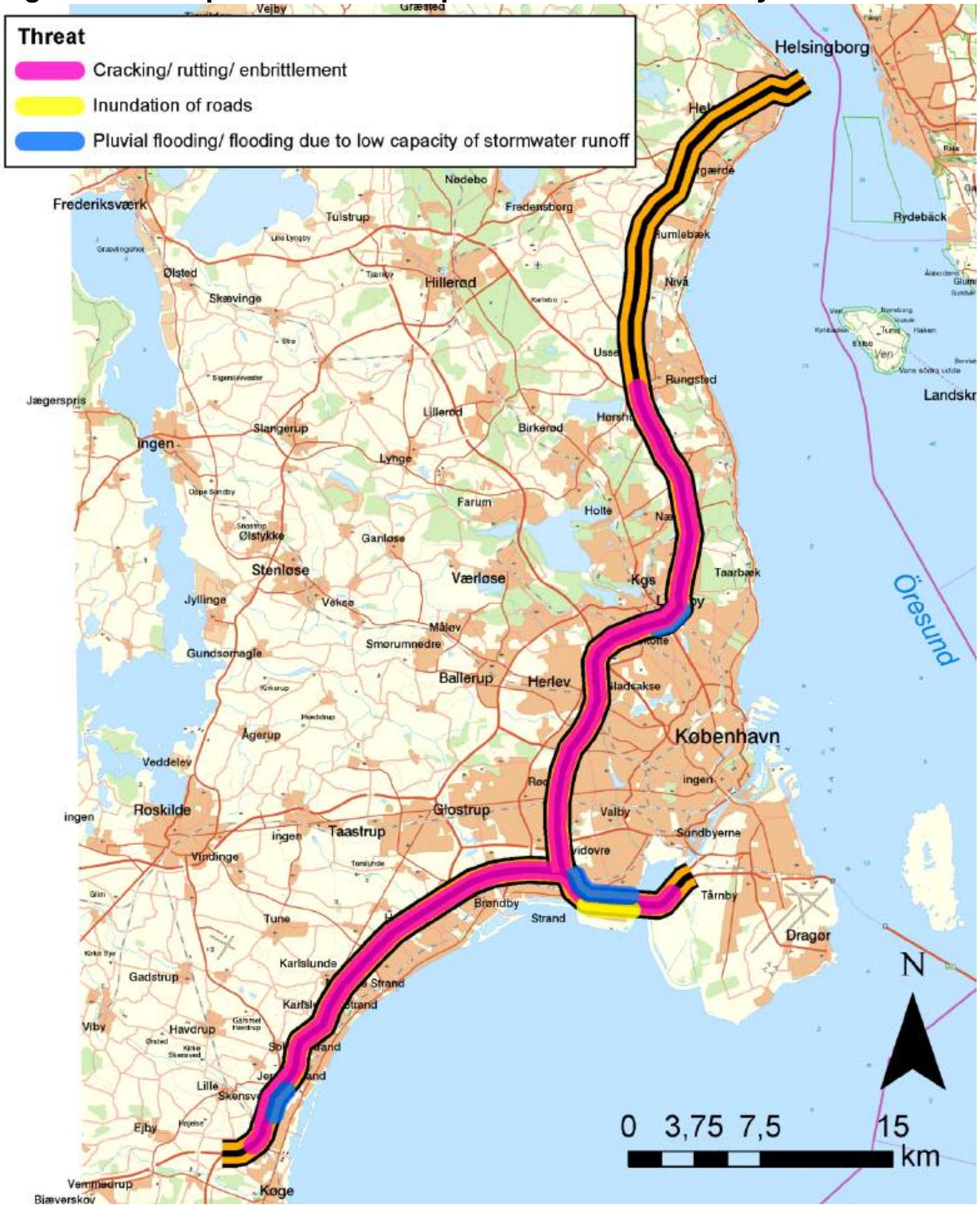
Here is a short summary of the steps to follow in order to use the proposed methodology for detailed economic assessment on the network level:

1. Define the events (the scenarios) we want to evaluate (see § 1.1and 1.2)
2. Choose the traffic model to use (see § 2.2)
3. Implement the traffic event(s) and/or scenarios in the model and run the model with and without each event (see with traffic modeller, or define simple hypothesis for rough estimations see § 2.2)
4. Calculate the main indicators of total travel time loss, additional travelled distance
5. Do the global Cost-Benefit Analysis (see reference documentations for Transport Project Assessment of Member States or the European project HEATCO)
6. Compare the results of different scenarios between them.

2.4 Application to the Øresund case study

According to the risk map below resulting from the quick scan analysis, the event selected to illustrate the socio-economic analysis is the closure of the motorway E20 South of Copenhagen. This section of road was selected for its importance in terms of traffic flows and the presence of high different risks (in particular flooding risk)

Figure 5: example of threats map – Øresund case study



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Using a simple approach for assessing the consequences of this event leads for example to set up a simple table as below:

In this scenario, the road is closed for 3 days. The whole traffic (50 000 cars/day and 10 000 heavy goods vehicles/day) is rerouted and the additional distance of the rerouting is 10 km which an additional travel time of 1/2h.

Operating costs of the vehicles are respectively € 0,10 and € 0,50 for car and HGV
The values of time are respectively € 15 and € 45 for car and HGV

Table 2: example of socio-economic impact results

	Value for Personal Car	Value for HGV	Total (Car+HGV)
Duration of incident (days)	3		
Number of vehicles per day (Car+Truck)	50 000	10 000	60 000
Individual additional distance travelled (km)	10	10	
Unit cost per km (€/km)	0,1	0,5	
Total cost for user (€)	150 000	150 000	300 000
Individual time loss (h)	0,5	0,5	
Value of time (€/h)	15	45	
Total loss time in €	1 125 000	675 000	1 800 000
Total loss (€)	1 275 000	825 000	2 100 000

This example is to illustrate the possibility of a simple methodology for obtaining an order of magnitude of the impact. It can be refined by splitting the day in different periods to reflect the variation of traffic along the day, resulting in a variation of the time loss, due to more or less congestion on the alternative road. A distribution of value of time along the day can be also introduced.

3 Socio-economic analysis on the local territory level

3.1 General framework

3.1.1 Background

Key role of highway network

Structuring, organization and socio-economic dynamics of territories are intrinsically linked to the service of transport offered by infrastructures, in particular the highway network.
In this sense we may use the expression "space-functional interactions" between transport infrastructure and territories; territory acting on transport networks and transport networks acting on the territory.
Disruptions of the transport system therefore have territorial effects, particularly on the socioeconomic system. These effects may impact the attractiveness, competitiveness of the territories, and the accessibility to main poles and vital sites.

Stakes of serving territories and territorial consequences of an network incident

Here are the main questions that arise:

- Within a given area, what are the activities at stake?
- What are the structural and/or strategic elements of a territory? For example: main transport equipment, specific sectors, economic poles, health centre, main tourist areas, clusters of research and development...
- What are the territories and poles at stakes?
- What are the components of the road network at stakes? (Sections? Nodes? Interchanges?) How to prioritize them?
- How to characterize the highway network accessibility from/to a territory?
- Finally, what will happen if the transport service is no longer guaranteed?

The analysis focuses on the identification and evaluation of territorial issues related to network effects with a climatic origin. That is to say, the sensitivity of the territories to potential incidents on the network as a consequence of weather events, in particular closure of highways. We note that this approach is too global and general to test small event impacts such as the ones induced by a decreased level of mobility (e.g. just a lane closure).

The analysis also aims to assess the consequences of the occurrence of a threat on:

- The social / societal activities (population, health , decision centres, safety)
- The economic activities,
- The attractiveness and competitiveness of the territories,
- The accessibility from/to vital poles and centres.

The consequences of network incidents can then be characterized in various ways:

- The nature of the principal activities impacted,

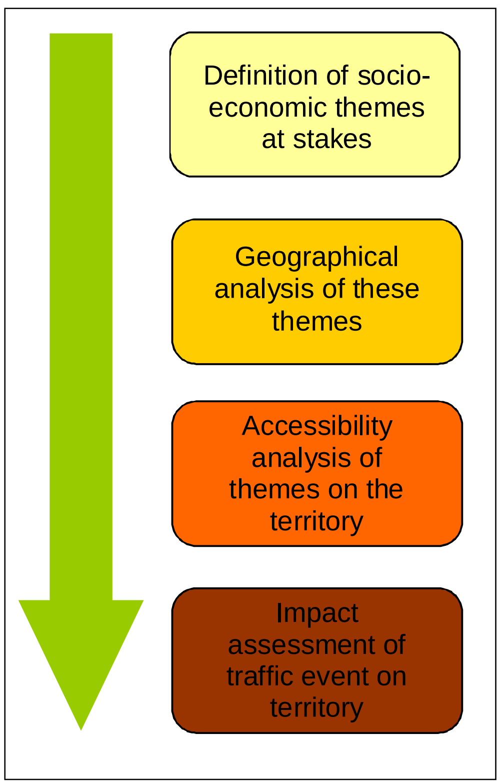
- Their location and their geographical coverage (they can have an impact on any part of the network, territories directly affected by the incidents, distant lands due to the effects of network cuts).
- Their intensity
- The duration and time of occurrence

3.1.2 Proposed methodology

The methodology presented here has been developed in the GERICI project (Risk Management related to Climate Change for Infrastructure) in France. It is composed of 4 steps:

1. Step 1: Definition of socio-economic themes at stakes
2. Step 2: Geographical analysis of socio-economic themes at stakes (synthesis map of territories issues)
3. Step 3: Analysis of the studied area's accessibility
4. Step 4: Evaluation of the territorial impacts of network incident.

Figure 6: The 4 steps of GERICI methodology



3.2 *Step 1: Selection of socio-economic themes at stakes*

The table below presents possible socio-economic themes that can then be used in the impact analysis.

Table 3: Socio-economic themes for territory analysis

Theme	Facilities	Why?	Proposed indicator
Population	Cities	Populated areas	Number of inhabitants (or density of inhabitants)
Employment	Business parks	Activities most sensitive to accessibility	Number (or density) of employments (if possible, per categories)
	Main Commercial Centres		
	Logistic Zones		
Health	Hospitals	Issue of healthcare for everyone	Number of health centre, and/or number of hospital beds (if available)
Defence	Military zone	Ability to react in case of international conflict	Number of zone
Complementary transport infrastructures	Train stations	Issue of accessibility of other territory Chance of modal shift of road network is closed	Traffic per station
	Tunnels (eg Channel)		Traffic per section
	Airports		Traffic per airport
	Highway interchanges		Traffic per section
	Ports		Traffic per port

The choice of socioeconomic themes to look at highly depends on the type of territory. Some themes will be more or less important in different regions. As an example, for the GERICI French case corresponding to the motorway network of SANEF in north-east France, the following themes hasn't been retained:

- Tourism: it is a small economic issue compared to others for this territory
- Local international exchange (cross border): too narrow for the selected perimeter
- School/University: low volume of flows, mainly short trips
- Research laboratory: essentially immaterial exchanges
- Military centre: confidential data.

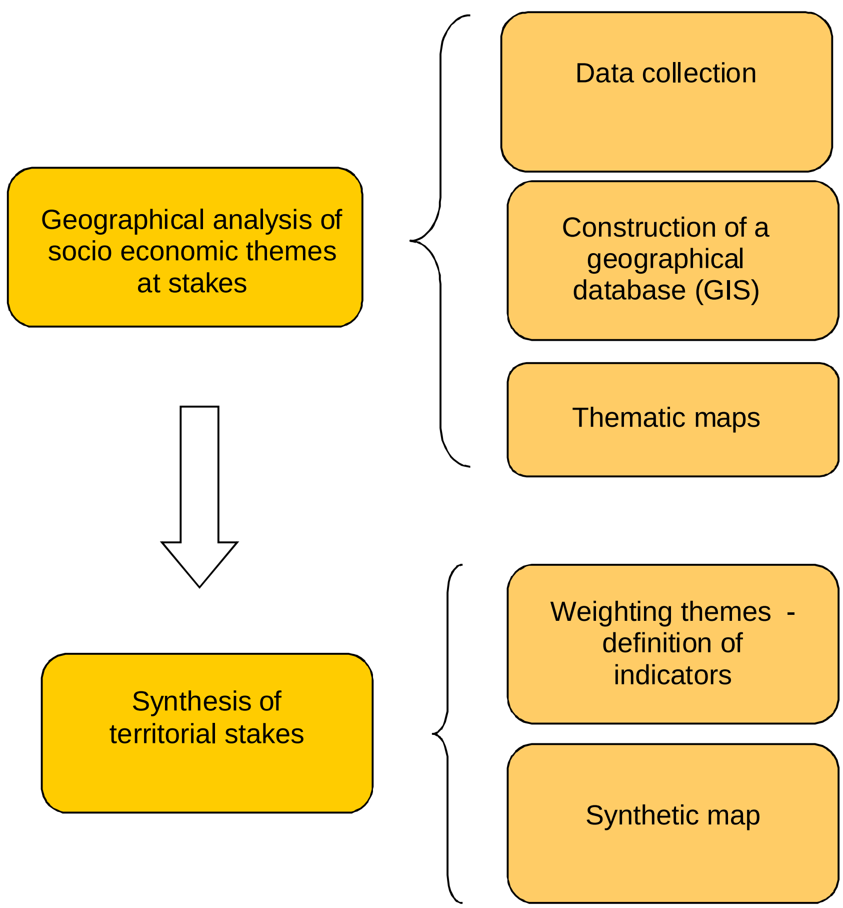
3.3 Step 2: Geographical analysis of socio-economic themes at stakes

For a better interpretation of the results, we recommend to use a GIS tool. This geographical analysis consists in the following tasks:

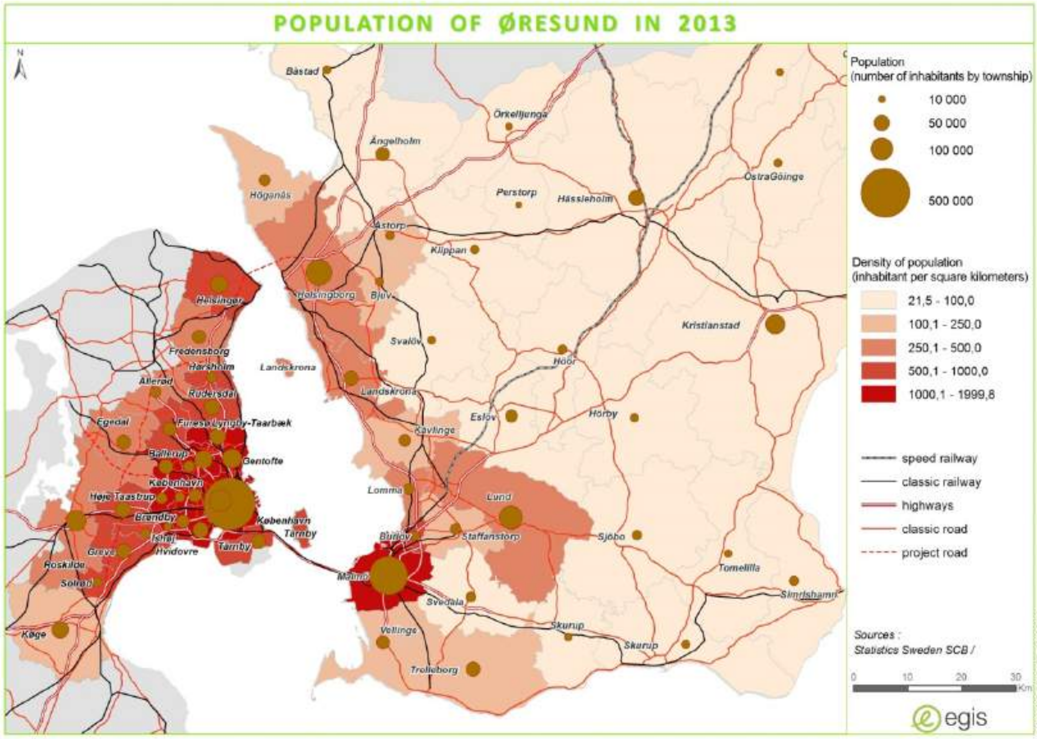
1. **Data Collection:** For each of the selected themes among those proposed in step 1, we choose and collect the spatialized relevant indicators, defining statistics classes then used for prioritization (from the distribution of the variables, a threshold may be defined)
2. Establishment of a **geo-referenced database under GIS**
3. Productions **thematic maps**, in order to visualize the results.
4. A final **synthetic map** is produced to define territories and prioritize issues.

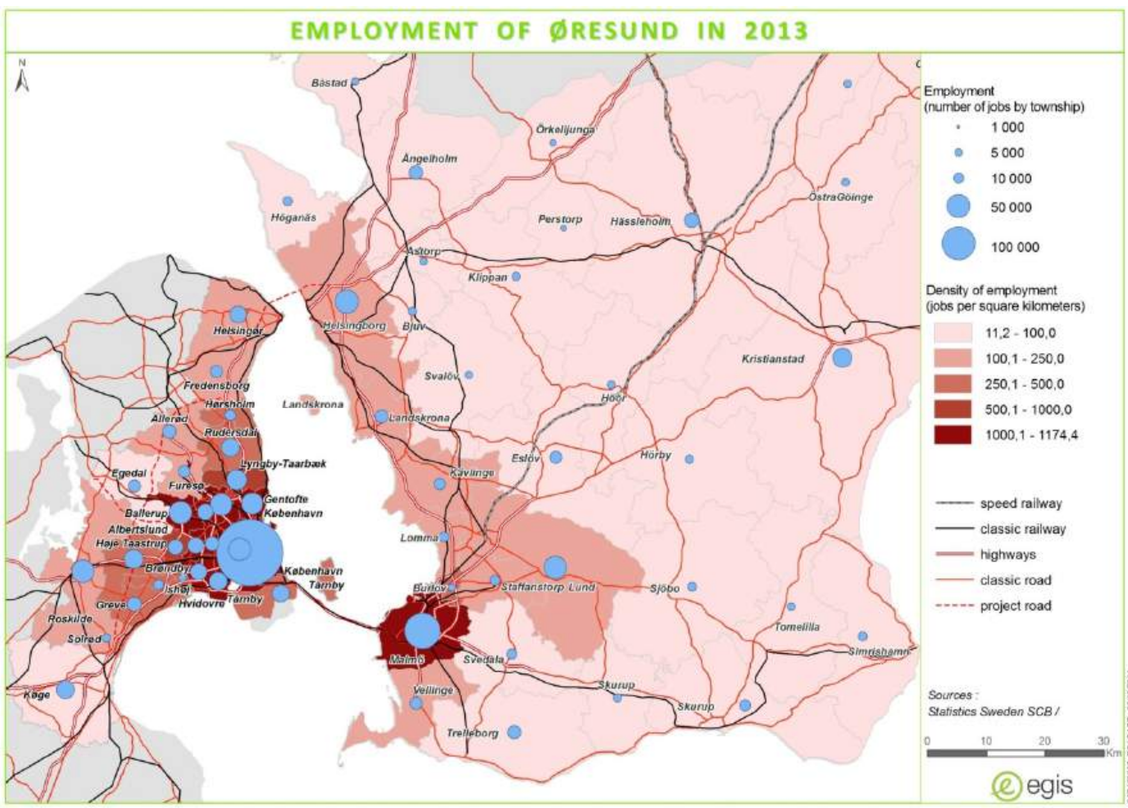
The methodology is presented in the following figure.

Figure 7: geographical analysis



Exemple of Thematic maps:



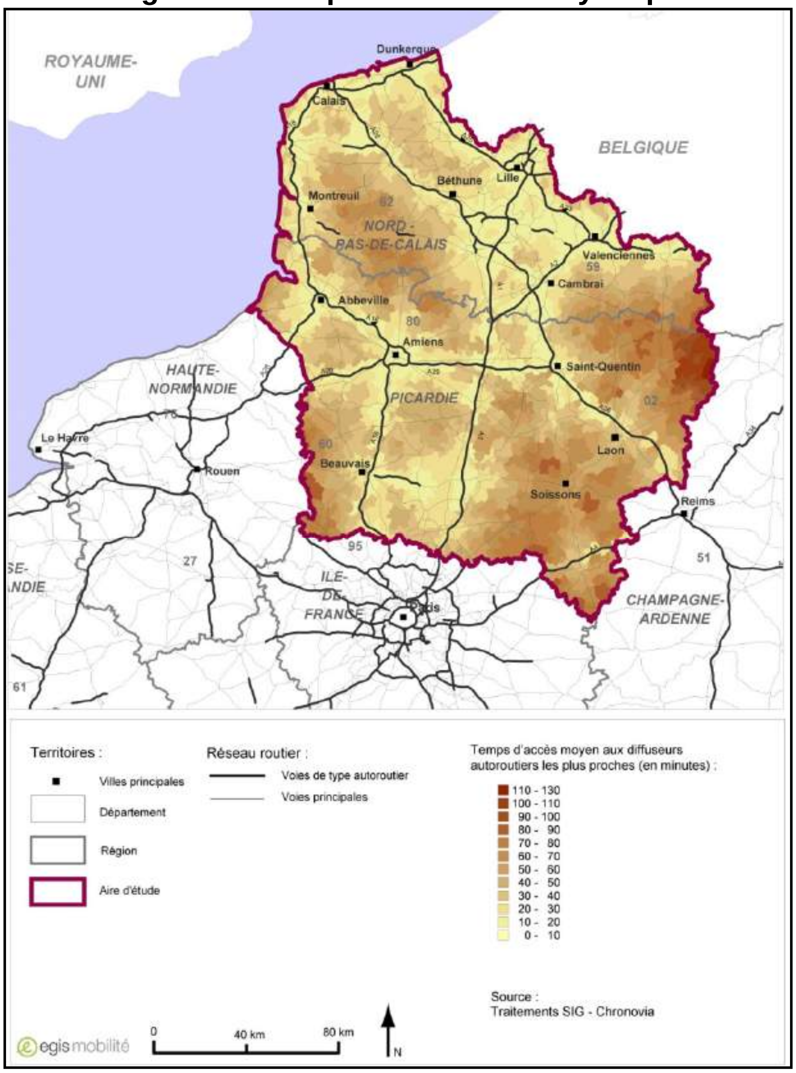


3.4 Step 3: Analysis of the studied area's accessibility

This step consists of the realisation of accessibility maps to the motorway network: a map representing the time needed to join each part of the territory to the closest motorway entry/exit.

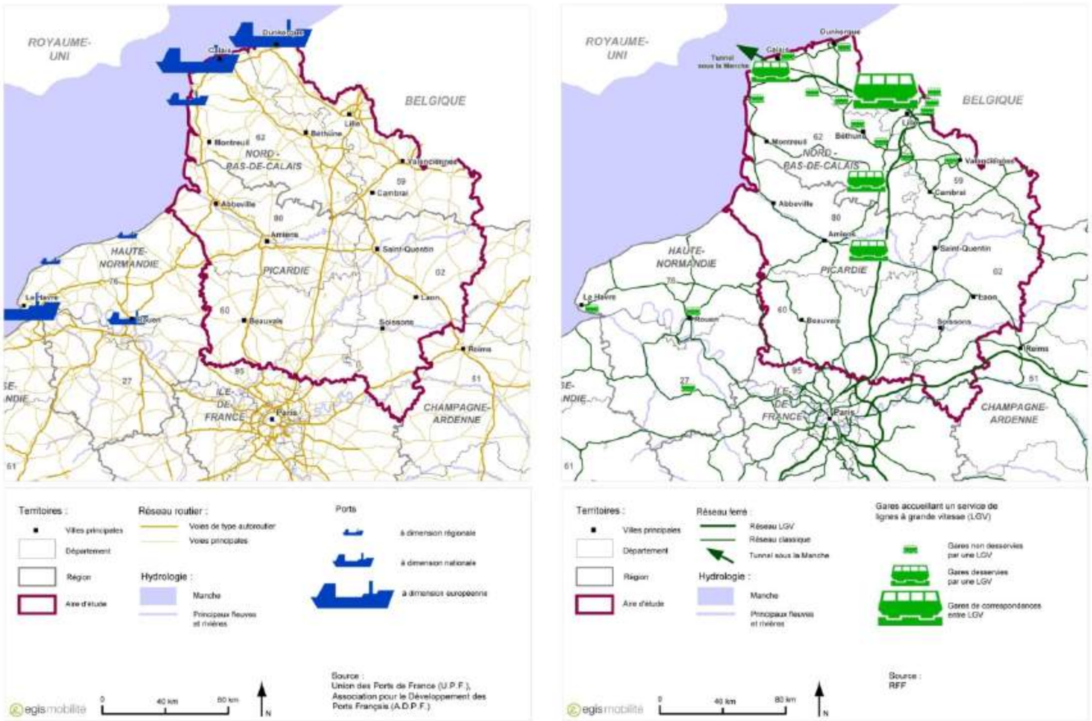
The following map gives the example made in the GERICI case study (on a perimeter corresponding to the North of France).

Figure 8: example of accessibility maps



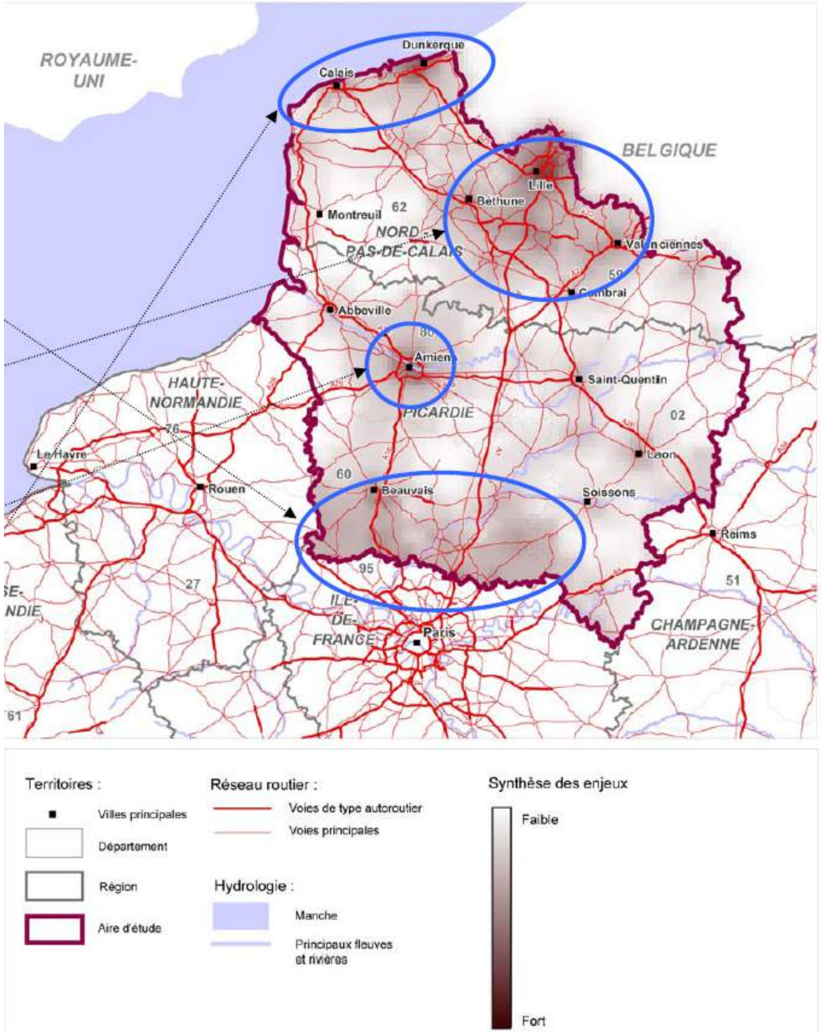
Accessibility to economically important nodes has to be considered as well. The following maps give such information: access to railway stations, access to ports.

Figure 9: accessibility maps, ports and railway stations



By compiling all issues at stake concerning the economic potential of a territory, a sensitivity map can be established. The following map gives an example (GERICI study) where the darker shaded zones represent the highest stakes. (Circled in blue).

Figure 10 : issues at stake (synthesis)



3.5 Step 4: Evaluation of the territorial impacts of network incident

The objective of this step is to evaluate the impact of a network event in terms of accessibility to the territory.
Once the network has been defined (for example, the closure of a road stretch) the new corresponding accessibility map can be calculated.

A specific map should also be drawn showing directly the difference between the accessibility map of reference (from step 3) and the new decreased accessibility. This map will show the increased travel time due to the event, for all locations in the territory.

3.6 Application to the Øresund Case Study

Figure 11: accessibility map, Øresund case study, reference case

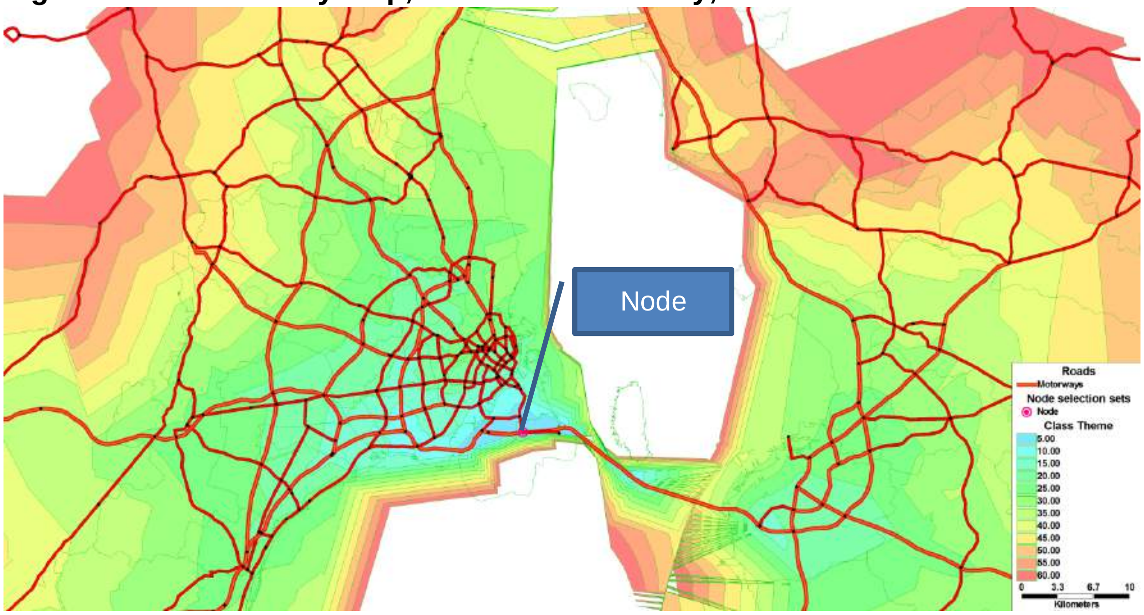
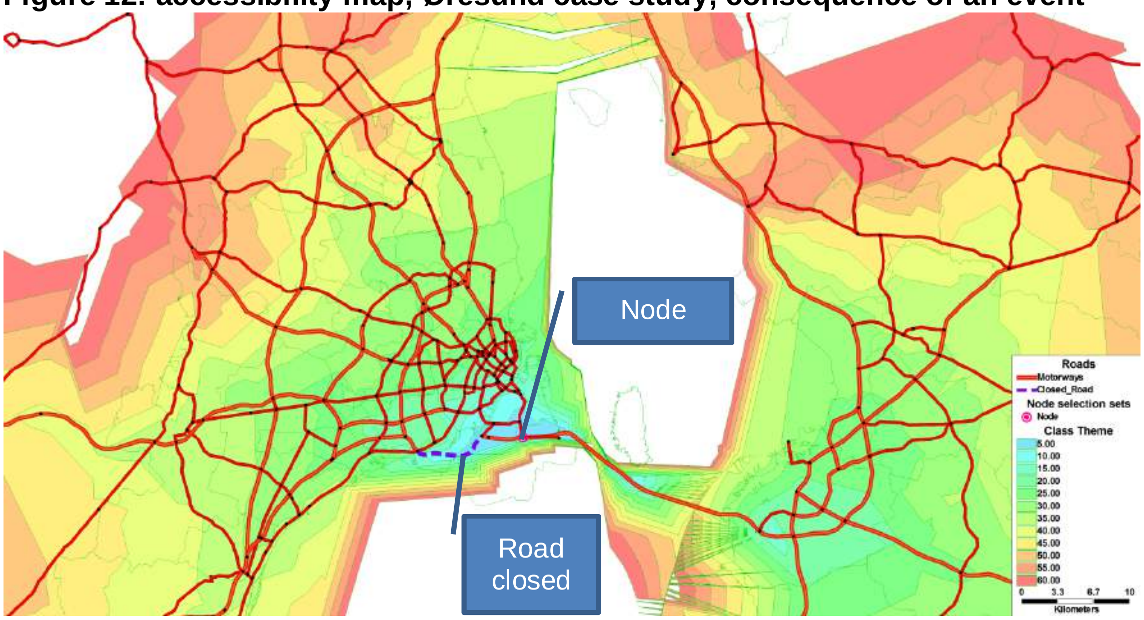


Figure 12: accessibility map, Øresund case study, consequence of an event



Finally, conclusion can be derived from the comparison between the decreased accessibility and the main themes at stake from step 2.
The network event can be evaluated semi-quantitatively in terms of impacts for each socio-economic theme on a scale of sensitivity with several levels.
On the maps above, the colours indicate the travel time distribution to a selected central node, south of Copenhagen (simulation of road closure that can be compared to the reference case)

4 Impact analysis on the economic system as a whole

4.1 Qualitative impacts on logistic and supply chains

4.1.1 General background

The first well known European study of supply chain disruption and the level of professional knowledge on supply chain vulnerabilities were carried out by Cranfield University in 2003 [11]. This investigation has established that:

- supply chains were quite vulnerable to weather-inflicted disruptions,
- awareness of disruption threats was poor among supply chain managers,
- little knowledge existed on damages the supply chain operations may suffer from weather disasters in short-and-medium terms and,
- the industry was lacking best practice for systematic reduction of supply chain risks generated by natural hazards.

Extreme weather events may threaten individual companies, their personnel, and collaborative arrangements such as supply chains. Managerial literature indicates that there is no one best way for overcoming negative impacts of these occurrences. One reason for that is that such events fall into high-impact/low probability risk category and therefore there is a scarcity of historical data needed for devising universally effective prevention, containment and mitigation tools. Another reason is that such low-frequency incidents are hard to predict and avert making it difficult to justify why resources should be devoted to proactively manage this type of risk. If a risk never materialises, the expenses incurred on risk assessment and management are hard to justify to company leadership and/or shareholders.

There is no doubt that supply chain disruptions are costly. Thus in order to prevent, mitigate and neutralise negative consequences of chain disruptions one needs to understand how an abrupt cessation of goods movement and/or stoppage of material flows may affect not only the focal transport operator but also other segments in supply chain structure. This was demonstrated by Hurricane Katrina in 2005, which in addition to considerable human and material losses inflicted on American society, has also disrupted 10% -15% of gasoline supply within the entire country (Canadian Competition Bureau 2006). A more recent example is the earthquake in Japan which in March 2011 damaged several plants producing microchips and other electronic components for equipment manufacturers in the US and Taiwan. This contagion has spread to Europe causing transient shortages of smart phones, tablets and other high-tech consumer electronics. Yet, the risks caused by weather-related disruptions in Europe are quite scarcely addressed by supply chain management literature.

One reason could be that as compared to disruptions paralysing manufacturing plants and/or warehouses which result in large supply shortages, a rupture in movement of goods within a supply pipeline may be potentially less contagious because it halts only transfer of merchandise and/or materials. The uniqueness of transportation disruption consists thus in that although the goods in transit have been stopped, the remaining supply network operations may still function undisturbed. Although a disruption in transportation will certainly delay the arrival of goods at destination, a distinction is made here between a transportation disruption and a transportation delay.

However, transport interruption is a risk that can quickly cripple the entire supply chain because in addition to halting the flow movement, stoppages in materials and/or goods transfer spread quickly to upstream and/or downstream supply chain segments causing stock outs, inventory depletion, production downtimes, unsatisfied customer orders, information distortion and/or stoppages in goods transit.

4.1.2 Vulnerability of road freight transport

Random goods arrivals caused by disruptions in road freight vehicle journeys and material flows invoke immediate, substantial and negative consequences on transport operators, logistics service providers, shippers and manufacturers. Results from study performed by Fowkes et al. (2004) [12] on why the freight transport industry values journey time reliability so high have showed that supply breakdowns and delivery delays:

1) Increase the overall journey times with fixed departure times
2) Increase spreads (or range) in arrival times for a fixed departure times
3) Delay schedules by requiring that departure times were effectively put back
4) Disturb inventory levels at upstream and downstream supply segments jeopardising manufacturing operations and inbound and outbound material movements

The needs for supply reliability reveals that in many instances effective operations depend on a high level of certainty as to the expected arrival times of freight vehicles either for loading and unloading. Reasons for time certainty emergence can be divided into two broad groups – those related to the nature of demand for freight transport, and those concerned with supply side issue.

Demand considerations

- Perishable goods
- Just-in-time delivery requirements
- Quick response demands
- Port arrivals and railway departure deadlines
- Hub and spoke operations

Supply consideration

- Two-way loading,
- Consolidation of deliveries: optimisation of the truck filling by multiplying distribution and collecting stops
- Driving hours' implications
- Scope of round the clock operations,
- Warehousing management.

4.2 Methodologies to evaluate loss in revenue for local businesses, and GDP loss

Accessibility measures

There are various models for evaluating the accessibility to the various economic poles in a territory. The following method has been proposed by Jean Poulit in 1974 [15], based on the logarithm of product supply at each destination. It takes into account the opportunity Q*j* (number of employments) at destination j. The utility *Sij* of travelling from origin *i* to destination *j*, subtracting travel cost *(Cij) is:*

$$S_{ij} = \lambda \log\left(Q_j\right) - C_{ij}$$

Where $\lambda = \alpha$ / a , α is the value of time (VoT) and a is an empirical coefficient used in the gravity trip distribution model. These parameters have been estimated using travel survey data (see IAURIF/THEMA, 2005).
Accessibility from origin i is the log-sum of the accessibilities over all the destinations, j, given by :

$$S_i = \lambda \log\left(\sum_j Q_j \exp\left[-\frac{C_{ij}}{\lambda}\right]\right)$$

It can be presented in monetary units as traveller's surplus.

This global indicator per zone is then calculated in two different scenarios: normal operating, and the degraded situation.
The difference between the two situations shows the impact per zone of the modelled incident. Results can be added over all zones of the perimeter to give a total loss value in €.

4.3 Application to the Øresund Case Study

The following maps illustrate the application of this method to the Øresund case study:

- The reference maps illustrates by zone the economic potential created by the travels from the living areas to employment poles. E.G. the red zones presents a daily economic potential above 400 000€. Of course these figures cannot be interpreted in absolute value as the calibration of the model was not feasible with the existing data.
- But more interesting is the second map that illustrates the loss in economic potential due to the closure of a road stretch. It highlights clearly the most impacted zones in red: in that case, as the event is close to the city area which presents the highest economic potential, the impact is amplified.

The advantage of this analysis, compared to the former one based only on travel time is to reflect better the "real" economic impact.

Figure 13: accessibility in monetary terms, reference

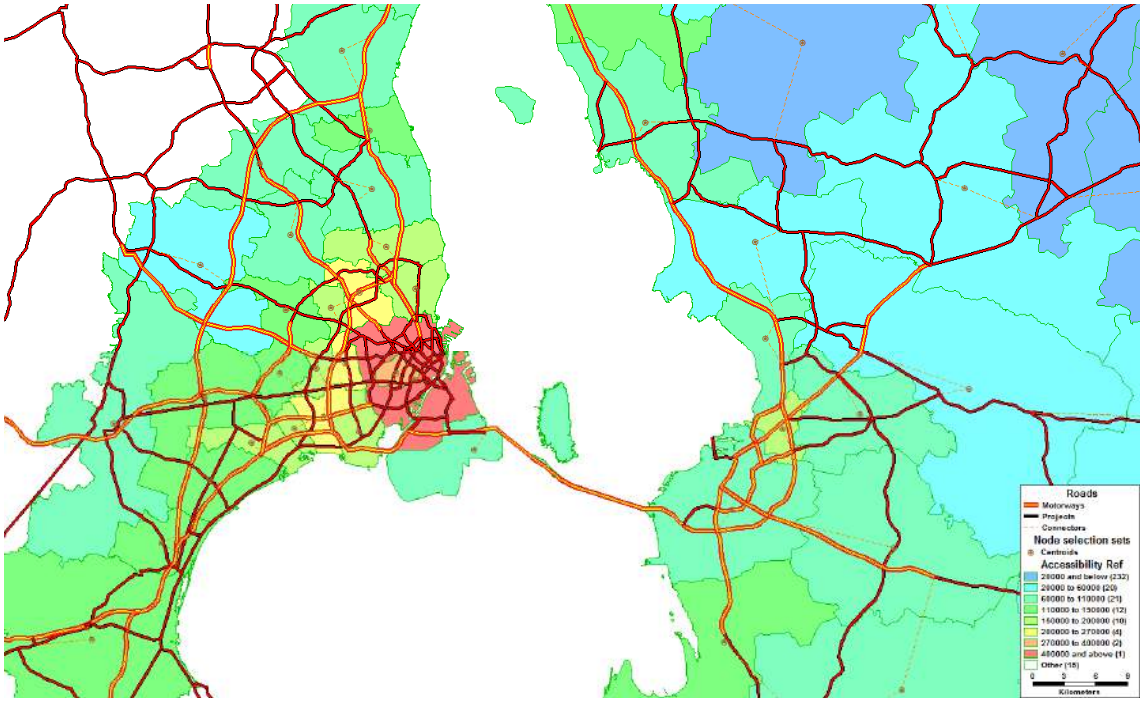
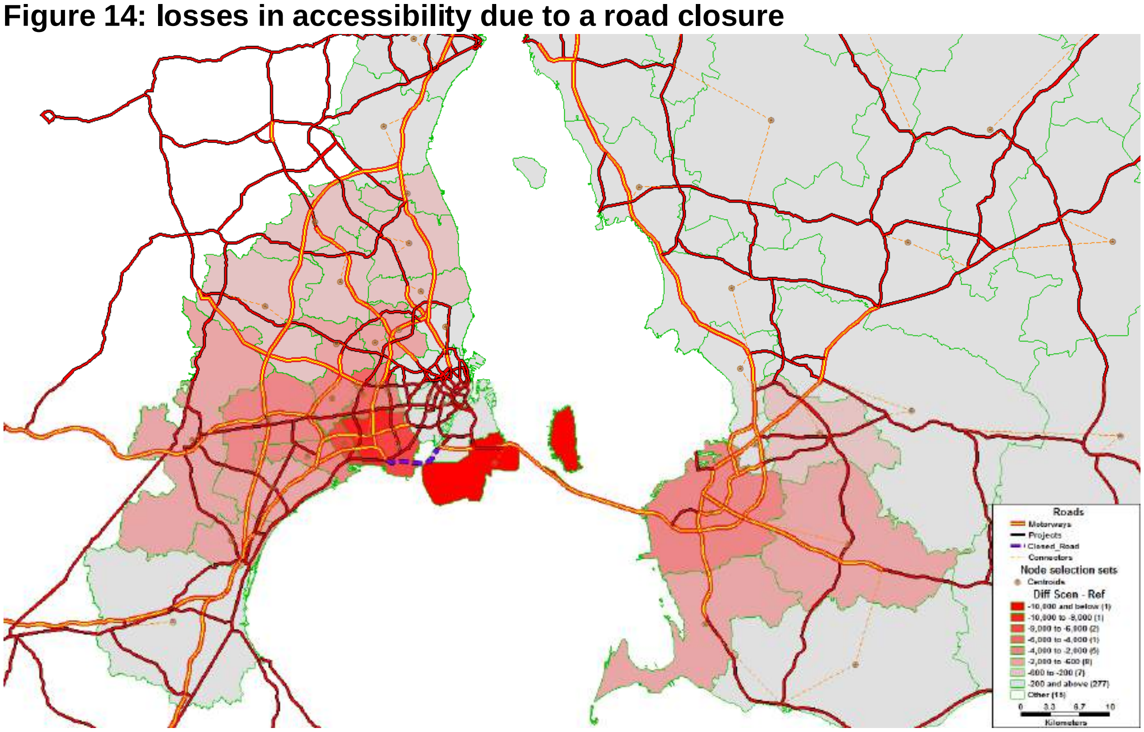


Figure 14: losses in accessibility due to a road closure



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5 Conclusions and recommendations

The guidelines on socio-economic assessment provide some methods on how perform the analysis at different scales. It is worth to mention that the 3 scales are not alternative, but complementary.

In addition, it depends on the final objectives and stakeholder:

- the network level is more appropriate for meeting the needs of the road network owner or operator and giving them some elements to decide on the measures to be taken at the network level. By comparing the potential impact of various climate threats, it allows to prioritise the measures to be taken.

- the territory level analysis allows to evaluate the impacts in terms of travel time, these travel times being translated in economic value. This level of analysis is of interest for Transport authorities in general. In addition, this level is more adapted for local threats.

- the methodology on extended economic level will be more suitable for threats that are spread over large area. It addresses economic concerns as a whole, and not only transport. It may influence the decisions for land development and not only transports.

In any case, all these methodology needs to relay on traffic/transport modelling tools. Our recommendation is that they rely on the tools already used in the region/country in order to benefit from the existing data and simulations that could have been performed for other purpose. A good liaison with organisations and people already in charge of transport planning policy and land development is essential.

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