Economic loss estimation along transportation corridors

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A method to estimate the economic loss of a disruption of a lifeline as a result of an unscheduled event

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SUMMARY

Unscheduled events may have sudden and significant impacts on the economy of a region. The damage to the production facilities and lifelines may spread across boundaries of regions or even countries via inter-industry relationships and can have serious economic impacts on other regions. The estimation of the damage of a disaster plays a role in risk assessment and it is necessary that all damage is included to provide a complete analysis of the consequences of a disaster. The report gives an overview of existing loss estimation models and presents a method to estimate the economic loss of a temporary disruption of the infrastructure.

Economic loss

Damage incurred as a result of an unscheduled event can be classified in tangible loss (monetary terms) and intangible loss (relative value). Tangible damage can be further classified in direct and the indirect damage. Direct damage may be thought of as a loss in asset value, whereas indirect damage can be considered to be the loss of income and/or production and impacts on the environment that cannot be readily stated in monetary terms. In this research, economic loss is refers to

1) the direct costs of the increase in transport costs due to damage to infrastructure

2) the indirect costs of the loss of trade through inter-industry links.

Theoretical framework

This research defines a method that combines the transport and economic system in order to estimate economic loss as a result of an unexpected event. The approach is based on the Input-Output approach and the classic four-step transport model.

Transport system

The transport model is useful in forecasting the load of the flow, both passenger and freight, on the network and in estimating changes in the network or transport modes. The freight and passenger transport will be modelled with the classic four-step model. The major advantage of this model is that it classifies the four main decisions 1)will I make the trip 2) where do I go 3) Which transport mode will I use and 4) which route will I take, in sub models. The answers of these questions are given in trip generation, distribution, modal split and assignment, respectively. The classic four-step model will be used in loss estimation, because it provides the load on the network and gives insight in the importance of a road in the network.

Economic system

The basis of the economy of a region is the circular flow, which represents the relationship between the households and firms in an economy. The literature describes several methods that describe the economy of a region, examples are the Input-Output (I-O) and the Computable General Equilibrium (CGE)approaches. The I-O approach is a commonly used method that quantifies systematically the

interrelationships between the sectors of an economic system. The method is general accepted and will be used in the economic loss estimation method that is represented in this report.

The economic loss method

The basis of the method is the classic four-step model and the Input-Output approach. The input is the Input-Output table, the location of the activities and the existing infrastructure (see Figure 1).

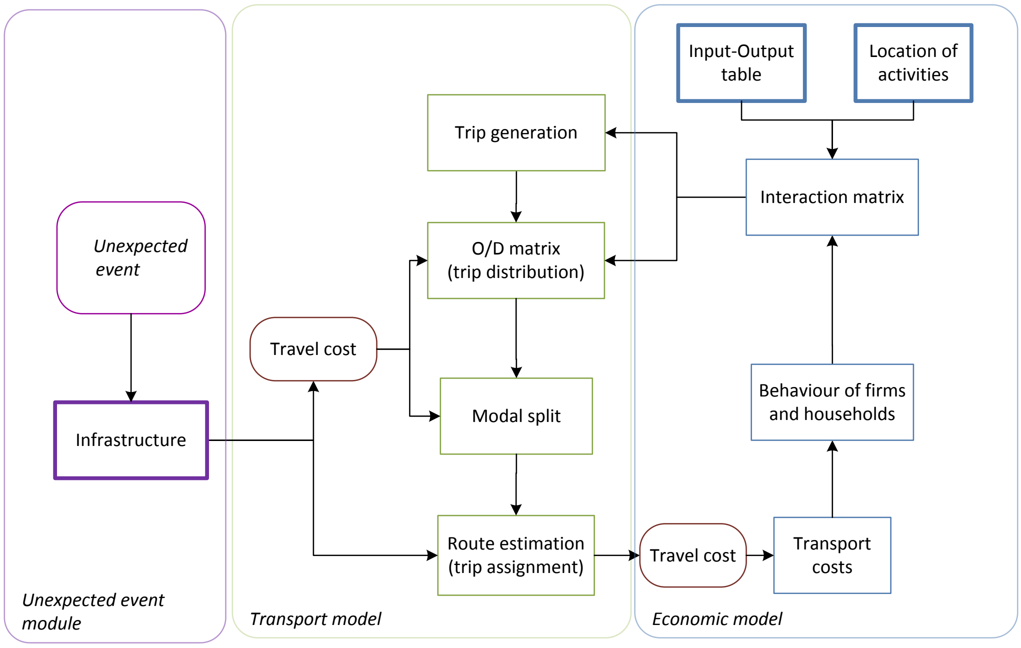

Figure 1 Economic loss estimation method

The role of the economic system is to describe the economic activities and the interaction with each other. The transport system gives insight in the distribution of the economic activities in the region. The travel costs are the basis for the loss estimation as a result of an unexpected event.

Long-run equilibrium

The initial position is a situation where both systems are in a long-run equilibrium situation. Long-run equilibrium is reached when the characteristics of the trips (distance, travel costs) between origin-destination pairs the behaviour of the households and firms is stabilised. This means that the travel costs will increase simultaneous in the region as a result of inflation or economic growth.

Effects of a disruption of the infrastructure

A disruption of the infrastructure due to an unscheduled event has two initial effects on the transport system. These are:

1) The infrastructure of a transport mode (e.g. road, rail track) is damaged, which means that trips need to be made with other modes that are still intact.

2) Trip makers need to choose another route, because a link in the route is not available as a result of the unscheduled event.

Both effects result in an increase of the travel costs of the trip, which will lead to higher transport costs for persons or freight. Households and firms react on this increase an will change their behaviour. For example, commuter traffic can choose not to make the trip because the travel costs are too high or the shopping traffic will choose another destination. The choices of the households and firms lead affect the trip generation and trip distribution. The next step of the method is the modal split with the modes that are still intact and the assignment of the trips over the network. This results in another shift in travel costs and therefore transport costs. These are the first round effects of the disruption of the infrastructure. The second round will result in another shift in travel costs. This can be continued until the difference in travel costs is negligible and a temporary equilibrium is reached where economic loss per day is stabilised until the infrastructure is reconstructed.

Economic loss

The economic loss of a temporary disruption of the infrastructure is divided in direct and indirect losses. The direct losses are based on the increase of the travel costs and indirect losses are based on the decrease of the gross output of the economic sectors in the region.

The method has been applied to analyse the economic loss of a landslide, with hypothetical scenarios in the Valtellina valley in Italy. If a road in the valley is disrupted by the landslide, the method gives an estimation of the economic loss of the region.

Conclusion

The theoretical framework can be used to estimate the economic loss of a temporary disruption of the infrastructure. It can be used as a tool for risk analysis and prevention efforts for unscheduled events. Examples are the assignment of vulnerable spots in the region and the prevention of the economic vulnerable infrastructure in the region.

PREFACE

This report is the result of my study Civil Engineering and Management at the University of Twente. One of the reasons I chose this study is because it involves a variety of aspects and it has the possibilities to integrate many disciplines. During my master I followed several courses in disaster management at ITC, which created my interest in risk assessment and damage estimation.

Economic loss estimation is a rather unknown and less researched topic in the civil engineering, but this does not mean it is less important. An example are the problems around climate change which is a hot item this moment. Extreme weather conditions will be even more extreme which can lead to more and larger disasters. Consequences of disasters involve besides physical damage to buildings, fatalities and diseases, economic loss, like higher transport costs or decrease of production. The latter consequences are less examined but play an important role in disaster management. This brought me on the idea to combine transport engineering and disaster management and the result is this report. I experienced my graduation period as a very interesting and pleasant time.

For helping me with my research and the preceding period, I would like to thank my tutors Anne van der Veen, Eric van Berkum and Cees van Westen. Anne, your enthusiasm and positive attitude towards problems were infectious and made my graduation a pleasant period. Eric, your constructive criticism were of great importance to improve my report adequately. Cees, thank you for accompanying me on the fieldtrip to Italy and for your help with the study case. I would like to thank the mountain risk group of the University of Milan for providing me information about the study area.

At last, I would like to thank my family and friends for supporting me during this period.

Sofie Buyck

Enschede, February 2008

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1 Introduction

This chapter introduces the problems of quantifying the economic damage caused by unscheduled events, such as natural disasters, construction failure or accidents. It provides insight into the need for this study and how it contributes to the problem of the quantification of the economic damage. Finally, the last section of this chapter gives an outline of the report.

1.1 Loss estimation

Unscheduled events may have sudden and significant impacts on the economy of a region. The damage to the production facilities and lifelines may spread across boundaries of regions or even countries via inter-industry relationships and can have serious economic impacts on other regions.

1.1.1 Definition of economic loss

Damage incurred as a result of an unscheduled event can be classified in tangible loss, which can be estimated directly in monetary terms, and intangible loss, which cannot be estimated in monetary terms. The tangible damage can be further classified in direct and the indirect damage. Direct damage may be thought of as a loss in asset value, whereas indirect damage can be considered to be the loss of income and/or production and impacts on the environment that cannot be readily stated in monetary terms. In this study, the term *economic loss* includes the losses of 1) the direct costs of the increase in transport costs due to damage to infrastructure and 2) the indirect costs of the loss of trade through inter-industry links (see Figure 2).

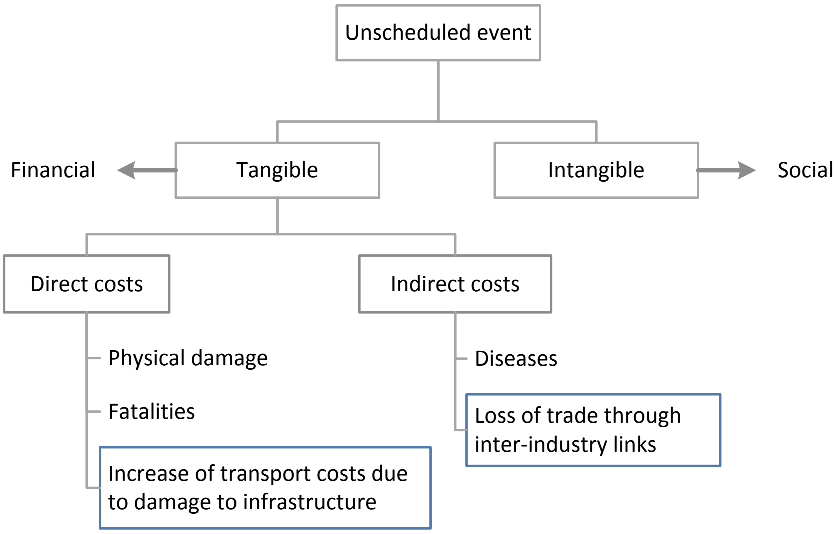

Figure 2 Types of losses (see *Queensland government, 2002* and *Westen, 2007*)

1.1.2 Risk analysis

Loss estimation plays a role in risk analysis. The term risk refers to the expected losses from a given hazard to a given element at risk, over a specified future time period. According to the way in which the element at risk is defined, the risk may be measured in terms of expected loss, or in terms of numbers of lives lost or the extent of physical damage to property (definition from *UNDRO, 1979*). The formula for risk is defined as:

$$Risk = Hazard \times vulnerability \times amount$$

Hazard	Probability of event with a certain magnitude (value between 0, will not happen, and 1, high probability)
Vulnerability	Degree of damage (value between 0, no damage, and 1 fully destroyed). Depends on: • magnitude of event • type of elements at risk
Amount	Quantification of the elements at risk (e.g. replacement costs of buildings and infrastructure, loss of function or economic activities, number of people).

Risk analysis is a part of risk management, which is the complete process of risk assessment and risk control (or risk treatment). If it is possible to give an estimation of the economic loss of the disruption of the infrastructure, risk analysis is more accurate.

1.2 Unscheduled events

Unscheduled events are, as the word implies, unpredictable regarding time, place and magnitude. Despite the existence of plans for disasters and calamities, they account each year for enormous damage in terms of both direct and indirect losses. There are several types of unexpected events, like natural disasters, large accidents and construction failure.

1.2.1 Natural disasters

Natural disasters occur all over the world, mostly in Asia. In 2006, 850 loss events were observed, mostly floods and windstorms. The deadliest event of that year was the earthquake in Indonesia in May, with 5750 fatalities (see *Munich Re, 2007*). The amount of large-scale disasters has increased dramatically since 1950, there are twice as much events measured and seven times as much damage was measured. The IFRC[1] publishes every year a World Disaster Report, which describes remarkable disasters or crises and the characteristics of the disasters of the last decade (see

[1] IFRC: International Federation of Red Cross and Red Crescent Societies

annex 1). The most occurred disaster of the last decade is flooding, but the windstorms caused the most estimated damage. Some remarkable disasters are:

- The earthquake in the Indian Ocean (2004) with a magnitude of 9 on the scale of Richter caused a tsunami which killed up to 210,000 people in Asia. This event is one of the deadliest catastrophes in modern history;
- The hurricane season of 2006 caused a lot of damage in North and Central America. Especially Katrina, which devastated the city of New Orleans and caused damage up to $ 130 billion. This makes Katrina the most expensive natural disasters in the United Stated;
- The heat wave in august 2003 claimed an estimated 35,000 lives in northwest Europe. In France alone, over 14,800 people died from the searing temperatures up to 40 degrees Celsius. The heat wave of 2006 killed over 2000 people, alone in the Netherlands 1000 people died.

These different types of disasters have a great impact on the economy of a society, because 1) communities are displaced, houses are destroyed and infrastructure is disrupted, and 2) the economy of a region is disrupted because no trade is possible, people do not have income because their workplace is destroyed, infections and diseases arise because of a lack of fresh water or food. The first group shows the direct consequence of a disaster and the second group is examples of indirect effects, which are not visible or visible after a while.

1.2.2 Accidents

Accidents account each year for high costs for the economy. Besides the social impact of the disaster to the people which are involved by the accident, the disturbance of the infrastructure, which can be closure of the highway of several lanes, has a direct and indirect impact on the economy. The direct impact is related directly to the accident, like the costs for assistance and repair of the pavement or building. The indirect costs are not visible but they can have a big impact on the economy. Think about the costs for enterprises when their trucks are delayed because of a traffic diversion due to the closure of a road or the costs of a temporary stop in the production. The disruption can hold for several hours, but when it is a large accident it can take several days. Some examples of large accidents are:

- The accident in Chernobyl nuclear power plant (1986).A reactor of the nuclear power plant exploded and caused further explosions and resulted in a fire that sent a plume of highly radioactive fallout into the atmosphere and over an extensive geographical area. The accident killed 56 people, and it is estimated that about 4000 people more died due to cancer as the result of the exposure to the radioactive plume (see *Bennet et al., 2006*).
- The accident in the Mont Blanc tunnel (1999). The Mont Bland tunnel, linking France and Italy, was closed for almost three years after a truck caught fire, killing 39 people in March 1999.
- The disruption of the railroad traffic between Hengelo and Almelo (2007). For about one month there was no railroad traffic possible between Hengelo and Almelo, because of malfunctioning of the safety system.

Besides large traffic accidents where the infrastructure is disrupted for a longer time period, smaller accidents, like trucks that turn over or multiple collisions, cause a lot of disruption of the infrastructure. Although the infrastructure is closed for a smaller time period (<day) the economy will have to deal with the indirect costs. The effects will be smaller than the large traffic accident, but the frequency is higher. Almost weekly a car or truck is involved in an accident where the road was closed for several hours.

Not only roads suffer from traffic accidents, rail infrastructure has to deal with accidents as well. These can be small disruptions like interferences with the signals or points, where the rail traffic is disrupted for several hours. But also on the rails crashes with vehicles or other trains happen, with a lot of damage and interruption for the traffic.

1.2.3 Construction failure

The failure of infrastructure is the last group of unexpected events that cause disruption to the infrastructure and economic loss to the society. The failure of infrastructure contains collapsing of bridges, roads and railways, and leakages in tunnels. The collapsing of bridges and roads can be triggered by a natural disaster, like an earthquake, but as well because of the failure of the material, like metal fatigue or decay of concrete. The majority of the leakage processes are slow, but a sudden crack can result in a temporally closure of the tunnel. Some remarkable events are:

- The most recent large-scale disaster came in August 2007, when the bridge over the Mississippi River in Minneapolis collapsed. Since the event the traffic is diverted via an alternative route.
- Rail tunnel collapsed (2005). In England a rail tunnel collapsed and caused at least a week of disruption for the rail traffic.

Despite the existence of plans for disasters and calamities, unscheduled events account each year for enormous damage in terms of both direct and indirect costs. A consequence of an event can be the disruption of a lifeline, which on its turn will cause more damage to the region in terms of economic loss. The damage that is caused by the disruption of a lifeline is less understood, and therefore this research will focus on this aspect of the total loss estimation.

1.3 Project frame

The following section provides the problem description, the research objective and questions and the research limitations.

1.3.1 Context

The most frequently cited reason for investigating unexpected events is to reduce their costs. But ironically, the economic aspects of hazards, disasters, mitigation, insurance and related issues are perhaps the least well understood (see *Mileti, 1999*). Researchers have studied the direct economic and social effects of events, including financial losses of the properties, financial assistance to recover, and emotional distress (see *UNDRO, 1979*). The consequences of an interruption of a lifeline are more than only the visible damage. If an electricity mast collapses and the power lines break, households and firms that are connected with that electricity mast will be cut off from power (see *Rose et al., 1997*). The economic loss of a region includes the losses due to a delay in production of firms or the costs due to an intervention in services. Kim and colleagues (see *Kim et al., 2001*) performed a study about the economic impact of an earthquake, emphasising the inter-industry relationship in conjunction with regional commodity flows and the assessment of seismic damages on a transportation network. Weaknesses of this research are that it does not distinguishes mode choice, not includes personal trips and assumes a fixed value of final demand

1.3.2 The need for this study

The literature provides several models that estimate economic loss of an unexpected event. These models are based on economic approaches and do not include the transport system. The behaviour of the transport system is not taken into account, which means that the route choice of the trips will not change as a result of the event. This weakness of the existing models creates the need to create a method that uses both, the transport and economic system, in the estimation of economic loss.

The proposed method should be able to estimate economic loss by the transport costs and it should be able to include the behaviour of the firms and household on a change in the transport costs. Furthermore it should be able to give a prediction of the vulnerable spots of a region for a better risk prevention.

1.3.3 Problem statement

The *lifelines* of a region are characterised as utilities that have a crucial role in sustaining social and economic systems and because of their network characteristics, lifelines are especially vulnerable to disruption. Examples of a lifeline are the infrastructure and the electricity network. Although their crucial role in the society, the costs due to the disruption of a lifeline, and in this report the infrastructure, and the influence of this on the regional economy are rather unknown. The problem statement of this research therefore is

> *What are the economic effects of a disruption of a lifeline and what is its influence on a region's economy?*

1.3.4 Research objective

The emphasis of this report will be on the subsequent loss of production of goods and services by business directly cut off from the infrastructure and by businesses indirectly affected because their suppliers or customers are cut off from the infrastructure. The research objective is

> The goal of the research is to develop a method to estimate the *economic loss* of a region caused by a *temporary disruption* of the infrastructure, as the result of an *unexpected event* and to apply the method to a case study.

With *economic loss* is referred to the direct and indirect economic impact of the disruption of the infrastructure. The direct economic impact is the direct change of production and demand due to the disruption of a lifeline due to an unexpected event. The indirect economic impact is the change in other sectors by a change of a sector based on inter-industry relationships. The temporal aspect of economic loss is defined as the time period between the disruption and the full reconstruction of the lifeline, when the economy of the region is functioning as before the event.

The *temporary disruption* implies that the infrastructure will be damaged for a certain period of time, but can be repaired. The disruption will not cause a change in the land-use of the region.

1.3.5 Research limitations

The limitations of the research are described in this section.

- Economic loss estimation includes only indirect damage of a disruption of a lifeline. Loss that results directly from the unscheduled event (e.g. collapsed houses) will not be taken into account
- The time period of where over economic loss is estimated is between the disruption and the complete restoration of the lifeline.
- Economic trends and investments in the infrastructure can influence the long-run equilibrium, but it is assumed that these effects are negligible during a temporary disruption. This means that the economic loss is the difference between the situation during and before the disruption of the infrastructure.
- Profit that results from a disruption of a lifeline will not be taken into account, because this usually is achieved after the lifeline is restored.
- The trips that are generated as a result of an unscheduled event (e.g. the place where the event occurred can attract curious people) will not be taken into account.
- Modelling the interactions between the economic activities is complex because activities can have a mutual dependence, which means that both activities deliver products or services to each other. A change in the output of an activity will generate further output effects through inter-industry links. With every

round, the effect become smaller until it is negligible. In this study the inter-industry effects of the initial and first round will be taken into account.

- Economic loss will be estimated for the next travel motives:
    - working-based trips: trips of commuters to their work
    - business-based trips: trips of employees during working hours or freight transport
    - shopping-based trips: trips to the supermarket
    - tourism-based trips: trips of tourists to their vacation location
- The trips with an educational motive will not be taken into account. These trips include children and students who travel to school mainly with public transport or by bike. A disruption of a lifeline can result in long travel distances for this group, which means that the trip will not be made. It is possible to estimate the increase in travel distance of this group, but it is difficult to express the economic loss of this group. The reason for this that it is possible that students and children will experience the economic disaster as a profit, because they do not have to go to school as a result of the disruption. To exclude these effect, the educational trips will not be taken into account.
- The recreational trips (e.g. trips to relatives and friends, sightseeing) will not be taken into account, because these trips do not have economic value, but personal value. It is not possible to express the loss of a trip with a recreational motive in monetary terms.

The terms sector, loss and unexpected are used interchangeably with commodity (or product), damage and unscheduled, respectively. The cost term is also used interchangeably with the length term because the costs unit is based on 'kilometres'.

1.3.6 Research questions

The research questions help to achieve the main goal and are divided into the main aspects of this research; the infrastructure, the economy and the relation between both parts.

1. What is the role of the infrastructure in a region and how can it been used in economic loss estimation?
2. How can the economy of a region been described and how can it been used in economic loss estimation?
3. How can the economic and transport model be integrated into a model that describes economic loss of the disruption of the infrastructure?

1.4 Outline of the report

The study exists of two parts, a theoretical framework and a practical application of the indirect cost model. The outline of this report is represented in Figure 3. First, a literature study will give insight in the applicability of land-use models. Although these models are used to determine long term effect, their usefulness in determining short-term effects will be explained. The following chapters will go further into the economic and transport models. Chapter five gives an overview of the existing methods in the literature that deal with loss estimation. The advantages and disadvantages of these models will be described and the chapter ends with a conclusion about the suitability of the models in the loss estimation of a disruption of a lifeline. Chapter six gives the proposed method to estimate the economic loss that is caused by a disruption of the infrastructure. The applicability of the proposed method will be represented with a case study. The last chapter gives the conclusions with respect to the proposed method and it represents several recommendation for further research. At the end of the report, a glossary is included with the important terms that is used in this research

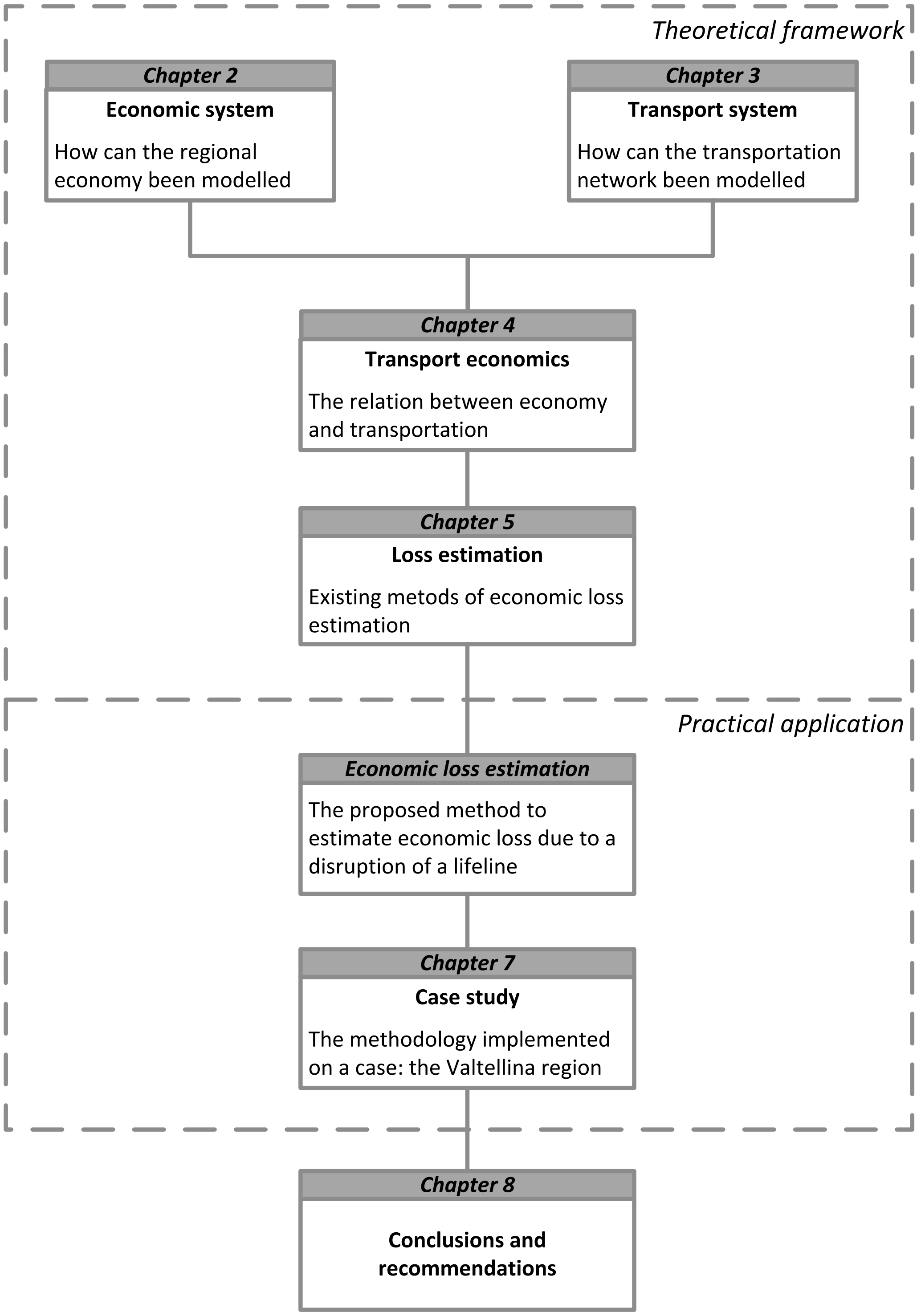

Figure 3 Outline of the report

2 The transport system

Unscheduled events may have a great impact on the transport system. A disruption of the infrastructure can influence the generation and distribution of trips or transport mode in the region. This chapter will start with an introduction in the transport demand and supply, followed by the transport model for passengers and the commodity flows.

2.1 Introduction

The transport system can be conceptualized as the set of relations between nodes, networks and demand (see Figure 4). The nodes are the locations where movements originate, end or are transferred. The demand for the movement of people or freight is a derived function of a variety of socioeconomic activities. The network is composed of a set of links derived from transport infrastructures. These components are related to each other though:

Locations: the level of spatial accumulation of socioeconomic activities defines demand and where this demand is taking place. The resistance between the demand and nodes is a function of accessibility of nodes to the demand they service.

Flows: The amount of traffic over the network, which is a function of the demand and the capacity of the linkages to support them. Flows are subject to the friction of distance, with distance being the resistance factor

Terminals: The terminals are characterized by their centrality and the linkages that radiate form them. The capacity of transport terminals to handle flows is the main resistance factor

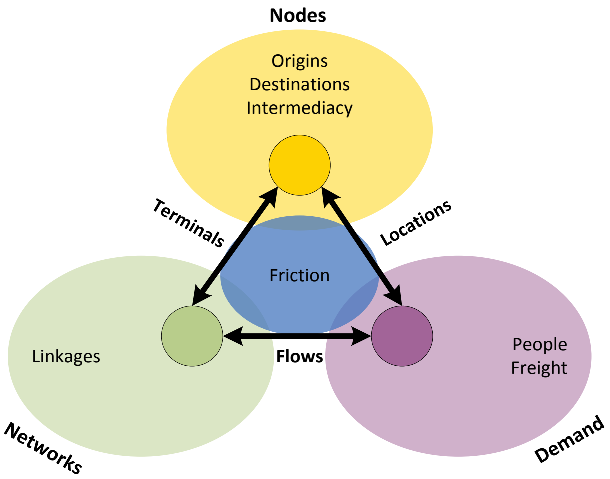

Figure 4 The transport system (see *Rodrigue et al., 2006*)

A region with numerous economic activities generates movements within and out of the region that must be supported by the transport system. The movements and infrastructure depend on each other. Without movements, the transport system would be useless and without the infrastructure movements could not occur, or would be too expensive. This independency can be visualized with two concepts, which are transport demand and supply (see Figure 5).

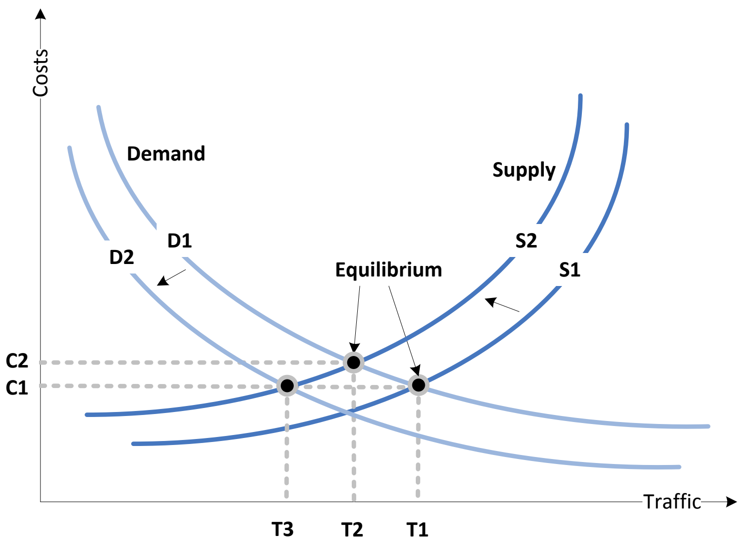

Figure 5 The classic demand/supply function (see *Rodrigue et al., 2006*)

Many transport systems behave in accordance with supply and demand, which are influenced by cost variations. The demand curve assumes that if transport costs are high, users of transport (freight of passengers) are less likely to use it, if the transport costs are low, the users would use the transport system more. The supply curve behaves inversely, if the costs are high, the transport providers would be willing to supply high quantities of services since high profits are likely to arise under these circumstances. It the costs are low, the quantity of transport services would be as low as many providers would see little benefits operating at a loss.

The equilibrium point represents the compromise between what users are willing to pay and what providers are willing to offer. A deterioration where a smaller amount of service is possible for the same cost will cause a shift in the supply curve, and a new equilibrium will be reached with a lower quantity T2 and at a higher price C2. This will cause a shift in the demand curve, and a new equilibrium will be reached with a lower quantity T3 at the initial price C1.

The transport demand is generated by the economy, which exists of persons, enterprises, and industries and which generates movements of people and freight. These movements create a pattern when they are expressed in space, reflecting mobility and accessibility. There are two reasons how transport demand can change; the quantity of passengers or freight transport increases, or the distance over which these passengers or freight are carried increases. The location of the resources and factories are related to freight movements. The location of the residential and commercial areas gives insight in the generation and attraction of movements.

2.2 Transport model

In transport planning, models are used to estimate trips between origins and destinations (as a device for network design and economic evaluation) and to simulate flow of links of the transport system (as an integral part of the model, and as an aid to traffic engineering). The traditional transport model consists of four submodels concerned respectively with trip generation, trip distribution, modal split, and assignment. The clarification of the steps are based on the book of Ortúzar and Willumsen (*Ortúzar and Willumsen, 2004*).

2.2.1 Trip generation

The first step of the transport model is concerned with elaborating the total number of trips generated by households in a zone. These trips can be home-based, where the home of the trip maker is either the origin or destination of the journey, or non-home-based, where neither the origin nor destination is the home of the trip maker. The result of this step is the total number of trips originating from a zone (generation) and attracted to each zone (attraction). They provide an idea of the level of trip making in the research area.

An example of estimating trip ends with help of attraction is with the area of the supermarket. The CROW[2] published a guideline for trip generation (see *CROW, 2007*) with factors to estimate the amount of trips for several motives, like shopping and working (see Table 1).

Table 1 The attraction of the average amount of vehicles per day as a function of m^2 sales area

Type of supermarket	Workday	Evening	Saturday
Local supermarket	1,1	1,3	1,2
District supermarket (full service)	1,4	2,1	1,9
Discounter	1,4	2,1	1,8

Another option to estimate the trip generation is through trip production. With help of the socio-economic data of a region, the amount of trips to the supermarket can be estimated. The parameters to estimate the amount of trips depend on the characteristics of the country or region. In the United States it is common to buy everything in the supermarket, while in French the people want to buy their baguettes in a bakery and their meat somewhere else. Two German researchers estimated the relationship between the transport modes, the purpose for the trip and amount of trips (see *Schnabel and Lohse, 1997*). With help of these parameters it is possible to estimate the production of the shopping trips. Which option is most suitable depends on the location of the region and the amount of data available.

The same author who suggest the average amount of vehicles for shopping (see Table 1), suggest that the amount of movements for companies in the Netherlands is

[2] Information and Technology Platform for Infrastructure, Traffic, Transport and Public Space

equal to 4,5 times the amount of workplaces in fulltime-equivalent. The amount of movements with vehicles for offices is equal to 2,5 times the amount of workplaces in fulltime-equivalent. But also here, the parameters depend on the characteristics of the country or region.

2.2.2 Trip distribution

The previous step derives the total number of trips originating from a zone and attracted to a zone. This step estimates the pattern of trip making, from where to where do trips take place. This step produces Origin-Destination matrices(O-D matrix)with in the rows the Origins and in the columns the Destinations. The sum of the trips in a row should equal the total number of trips generated in that zone, the sum of the trips in a column should correspond to the number of trips attracted to that zone. These conditions are:

$$\sum_j T_{ij} \, O_i \tag{1}$$

$$\sum_i T_{ij} \, D_j \tag{2}$$

A first method to derive the O-D matrix is the growth factor method. This method requires a basic trip matrix from a previous study or estimated from recent survey data. If the likely growth in the number of trips originating and/or attracted to each zone for a certain year is known, it is possible to estimate the O-D matrix for that year. It is also possible to apply a origin-specific growth factor (e.g. the shopping trips that are originating in each zone) to the corresponding rows in the trip matrix. By multiplying the corresponding rows with the origin-specific growth factor a new O-D matrix can be obtained.

An advantage of this method is its simplicity to understand and to make direct use of the observed trip matrices and forecasts of trip-end growth. This is the limitation of the method as well, because the method depend on the accuracy of the base-year trip matrix. Another limitation is that the method does not take into account changes in transport costs due to improvements or congestion in the network.

Another method to estimate the O-D matrix is the gravity model. The classic gravity model is originally generated from an analogy with Newton's gravitational law. They estimate trips for each cell in the matrix without directly using the observed trip pattern. The general form of the function is:

$$T_{ij} = A_i B_j O_i D_j f(c_{ij}) \tag{3}$$

Where

T_{ij}	Number of trips
A_i	Constant associated with production zone
B_j	Constant associated with attraction zone
O_i	Total number of trips origins in i
D_j	Total number of trips destinations in j
c_{ij}	Travel costs (in 'distance') between zones I and j

The sets of constants A_i and B_j are solved iteratively and can be checked that they ensure that the T_{ij} given in equation (3) satisfies the constraint equations (4) and (5)

$$A_i = \left[\sum_j B_j D_j f(c_{ij})\right]^{-1} \quad (4)$$

And

$$B_j = \left[\sum_i A_i O_i f(c_{ij})\right]^{-1} \quad (5)$$

The distribution function $f(c_{ij})$, called the deterrence function, represents the disincentive to travel as distance (time) or cost increases. It has usually a decreasing form, which implies that if the distance increases the incentive to travel decreases. The following functions are often used:

$$f(c_{ij}) = \alpha exp^{\left(\beta ln^2(c_{ij}+1)\right)} \quad \text{lognormal function} \quad (6)$$

$$f(c_{ij}) = exp^{(-\beta c_{ij})} \quad \text{exponential function} \quad (7)$$

$$f(c_{ij}) = {c_{ij}}^{-\alpha} exp^{(\beta c_{ij})} \quad \text{combined function} \quad (8)$$

The deterrence function can describe the willingness to travel for all transport modes, but it can be separated to different transport modes, where each mode has its own function. It is clear that each function will have different parameters, e.g. the deterrence function of walking will decline faster than the function of the car.

It is best to use the exponential or lognormal function because the willingness to travel a certain distance will not equal zero, so that there trips over large distances are still made. If α and β are unknown, it is possible to derive them from previous data or by determining the average willingness to travel. Another option is to classify several distance classes and divide the trips over these classes. With help of the interaction matrix and the costs matrix with the distances, the trips can be divided over the distance classes and by plotting this relation it is possible to derive the distribution function.

The cost matrix c_{ij} represents the costs in terms of distance to travel from *i* to *j*, and together with the trip ends that are derived in the trip generation they form the basis to estimate the Origin/Destination matrix with help of the gravity model.

Table 2 Cost matrix and trip-end totals for gravity model estimation (see Ortúzar and Willumsen, 2004)

Cost matrix (distance)				
	1	2	3	Target O_i
1	c_{11}	c_{12}	c_{13}	$\sum_{j=1...3} T_{1,j}$
2	c_{21}	c_{22}	c_{23}	$\sum_{j=1...3} T_{2,j}$
3	c_{31}	c_{32}	c_{33}	$\sum_{j=1...3} T_{3,j}$
Target D_j	$\sum_{i=1...3} T_{i,1}$	$\sum_{i=1...3} T_{i,2}$	$\sum_{i=1...3} T_{i,3}$	

2.2.3 Modal split

The modal split estimates the mode choice based on several factors. The factors are classified in three groups: characteristics of the trip maker (e.g. car availability, household structure, income, etc.), characteristics of the journey (e.g. trip purpose, time of day when trip is undertaken), and characteristics of the transport facility (e.g. relative travel time, costs, availability, comfort, etc.). The discrete choice models, (e.g. where individuals have to select an option from a finite set of alternatives) are good alternatives to model this step. One of the most popular discrete choice models is the *logit model*. The discrete choice models postulated that:

The probability of individuals choosing a given option is a function of their socioeconomic characteristics and the relative attractiveness of the option.

The attractiveness of an option is represented in the *utility function*. Each transport mode has a utility function, which is usually defined as a linear combination of variables, such as

$$V_{bus} = -0{,}25t_b - 0{,}42e - 0{,}1c_b \qquad (9)$$

Where *t* is in-vehicle time (min), *e* is access time (min) and *c* is travel cost (€ or km). The influence of each attribute, in terms of contribution to the overall satisfaction produced by the alternative, is given by its coefficient. Here for example, a unit change on the access time has approximately twice the impact as a unit change on in-vehicle time. To predict which alternative will be chosen by an individual, the value of its utility must be compared with the alternatives and transformed into a probability value between 0 and 1. This can be done with the logit model, for example

$$P_{bus} = \frac{exp^{V_{bus}}}{exp^{V_{bus}} + exp^{V_{car}}} \qquad (10)$$

2.2.4 Traffic assignment

The last step assigns the trips over the network by estimating the route a traveller will make to reach its destination. The basic premise in assignment is the assumption of a rational traveller, which means one choosing the route which offers the least perceived (and anticipated) individual costs. A number of factors are thought to influence the choice of route when driving between two points; these include journey time, distance, monetary cost (fuel and others), congestion and queues, type of manoeuvres required, type of road (motorway, trunk road, secondary road), scenery, signposting, road works, reliability of travel time and habit. The most common approximation is to consider only two factors in route choice: travel time and monetary costs, where the last one is often deemed proportional to travel distance.

The fact that different drivers often choose different routes when travelling between the same two points may be ascribed to two different types of reasons:

1. The stochastic effects: a difference in individual perceptions of what constitutes the ‘best route’; different individuals may not only incorporate different features in their generalised cost function but perceive them in different ways.
2. Capacity restraint: Congestion effects affecting shorter routes first and making their generalised costs comparable to initially less attractive routes.

Particular types of models are more suited to represent one or both of the above influences. A classification of traffic assignment methods is given in Figure 6.

		Stochastic effects included?	
		No	Yes
Is capacity restraint included?	No	All-or-nothing	Pure stochastic Dial’s, Burrell’s
	Yes	Wardrop’s equilibrium	Stochastic user equilibrium

Figure 6 Classification scheme for traffic assignment

In the following a description of the four methods is given, the two methods where stochastic effects are included (pure stochastic and stochastic user) are not specified but combined in the stochastic methods.

All-or-nothing assignment

This is the simplest rout choice and assignment. It assumes that there are no congestion effects, which means that link costs are fixed. Furthermore, it presumes that all drivers consider the same attributes for route choice, and that they perceive and weight them in the same way, which means that every driver from *i* to *j* takes the same route. The assignment algorithm loads the O/D matrix to the shortest path threes.

Stochastic methods

The stochastic methods of assignment emphasise the variability in perception of costs. These methods consider second best routes between each O-D pair. This generates problems because the number of alternative second-best routes may be extremely large. Two methods have a relatively widespread acceptance: *simulation-based* (Monte Carlo), which introduces variability in perceived costs, and *proportion-based*, which allocates flows to alternative routes from proportions calculated using logit expressions.

Wardrop's equilibrium

Several models concentrate on capacity restraint as a generator of the assignment of trips. These models use functions relating flow to costs of travel on a link and try to achieve the equilibrium of Wardrop (see *Wardrop, 1952*):

> *"Under equilibrium conditions traffic arranges itself in congested networks such that all used routes between an O-D pair have equal and minimum costs while all unused routes have greater or equal costs."*

The flows on the usable routes will satisfy Wardrop's equilibrium when the corresponding costs are identical.

Each assignment method has several steps which must be treated in turn.

- Tree building stage: identify a set of routes which are might be considered attractive to drivers. The data is stored in a particular data structure called a tree.
- Assign suitable proportions of the trip matrix to these routes or trees. This results in the flows on the links in the network.
- Convergence: follow an iterative pattern of successive approximations to an ideal solution, e.g. Wardrop's equilibrium. The iterative process will stop when a limit of accuracy is reached.

2.3 Commodity flow

Unlike passenger transport, much less research has been undertaken on modelling freight transport. The many aspects of freight demand make it more difficult to model than passenger movements. The freight transport is based on Wilson (see *Wilson, 1970*).

2.3.1 Freight generation

The technique used to obtain the total trip ends depends on the level of aggregation and the type of products considered:

- *Direct survey of demand and supply* is usable for inter-urban movements, but is not recommended for urban problems;
- *Macroeconomic models*, for example is the input-output nature, are based on regional rather than national data;
- *Growth-factor models* are often used in forecasting future trip ends;

- *Zonal multiple linear regression* is often used to obtain more aggregate measures of freight generations and attractions, in particular in urban areas;
- *Demand* may be associated with capacity in stead of industrial development

2.3.2 Freight distribution

A first approach to distribution modelling is the *gravity model*. The gravity model is based on analogies between spatial interaction in geography and spatial interaction in classical physics. The total amount of trips is:

$$T_{ij}^{k} = A_{i}^{k} B_{j}^{k} O_{i}^{k} D_{j}^{k} exp\left(-\beta^{k} c_{ij}^{k}\right) \qquad (11)$$

where

k	Commodity type index
T_{ij}^{k}	Tonnes of product k moved from i to j
A_{i}^{k}, B_{j}^{k}	Balancing factors
O_{i}^{k}, D_{j}^{k}	Supply and demand for product k at zone i (or j)
β^{k}	Calibration parameters, one per product k
c_{ij}^{k}	Generalised transport costs per tonne of product k between zones i and j

The generalised cost function formulation for freight demand (see *Kresge and Roberts, 1971*) is interpreted as follows for a certain commodity type *k*:

$$c_{ij}^{k} = f_{ij}^{k} + b_{1}^{k} s_{ij}^{k} + b_{2}^{k} \sigma s_{ij}^{k} + b_{3}^{k} w_{ij}^{k} + b_{4}^{k} p_{ij}^{k} \qquad (12)$$

Where

f_{ij}^{k}	out-of-pocket charge for using a service from i to j
s_{ij}^{k}	Door-to-door travel time from i to j
σs_{ij}^{k}	The variability of travel time s
w_{ij}^{k}	Waiting time or delay from request for service to actual delivery
p_{ij}^{k}	Probability of loss or damage to goods in transit
b_{n}^{k}	Constants, proportional to the value of the good (≥ 1)

A second approach is the *linear programming* (LP), which takes usually the form of a minimising program: minimise total haulage costs, subject to supply and demand constraints.

Minimise

$$Z = \sum_{ij} T_{ij} c_{ij} \tag{13}$$

Subject to

$$\sum_{i} T_{ij} = D_j \tag{14}$$

$$\sum_{j} T_{ij} = O_i \tag{15}$$

This approach is usable in industries with few firms, where there are low value goods and relatively high transport costs and where few demand points (zones) are. It can not represent aggregate behaviour for various commodities. The solution will tend to be too sparse, with particular destinations being served only by certain origins. The gravity model is quite flexible. By changing the value of β it is possible to vary the relative importance of cost compared with supply and demand constraints.

The relationship between the two approaches has been explored by Evans (*Evans, 1973*). She has shown that in the limit, β=0 in equation (11) will produce a matrix of movements where transport costs play no role; whereas a large value of β will generate a solution closer to a LP model where transport costs are dominant (β=∞is the LP solution). The gravity model can therefore been used to represent the whole range of client behaviour for destination choice, from almost indifferent to transport costs (electronic equipment) to significant to transport costs (sand).

2.3.3 Mode choice

The modal choice is usually modelled using a multinomial logit formulation based on generalised costs. This can turn out to be very approximate because the information can only capture those elements of mode choice incorporated in the generalised costs concept.

2.3.4 Assignment

The choice of the best route to take the goods from origin to destination depends on the movement. In an urban situation the capacity restraint will be relevant while in the case of inter-urban movement is can be sufficient to use a stochastic assignment model. However, different types of vehicles must be modelled in different ways: for example, heavy trucks will be sensitive to the hilliness of the routes, or vehicles carrying perishable goods need to minimise the transportation time.

2.4 Conclusion

This chapter provides insight in the working of the infrastructure and how the trips can be distributed over the network. The transport model is useful in forecasting the load of the flow, both passenger and freight, on the network and in estimating changes in the network or transport modes. The freight and passenger transport will be modelled in the same way, with the traditional four-step model. This model can be used in loss estimation, because it provides the load of trips on the network and gives insight in the importance of a road in the network.

3 THE ECONOMIC SYSTEM

An unscheduled event can have great impact on the functioning of an economy of a region. Because the economic activities depend on each other because the input of a certain activity is the output of another activity, a disruption in the economic system can have severe consequences for the whole region. This chapter gives insight in how the economy of a society is build up and how this can be represented in a model. It starts with an introduction of the flows within an economy, followed by the description of a regional economic model, the input-output model.

3.1 Circular flow

The economy of a region is illustrated by the circular flow of a closed economy (see Figure 7) is explained. The main actors in the diagram are households, who own the factors of production (labour) and who are the final consumer of produced commodities, and firms, who rent the factors of production from the households (labour) for the purpose of producing goods and services that the households then consumer. Although the government is represented, its role in the circular flow is often passive: to collect taxes and distribute these revenues to firms and households.

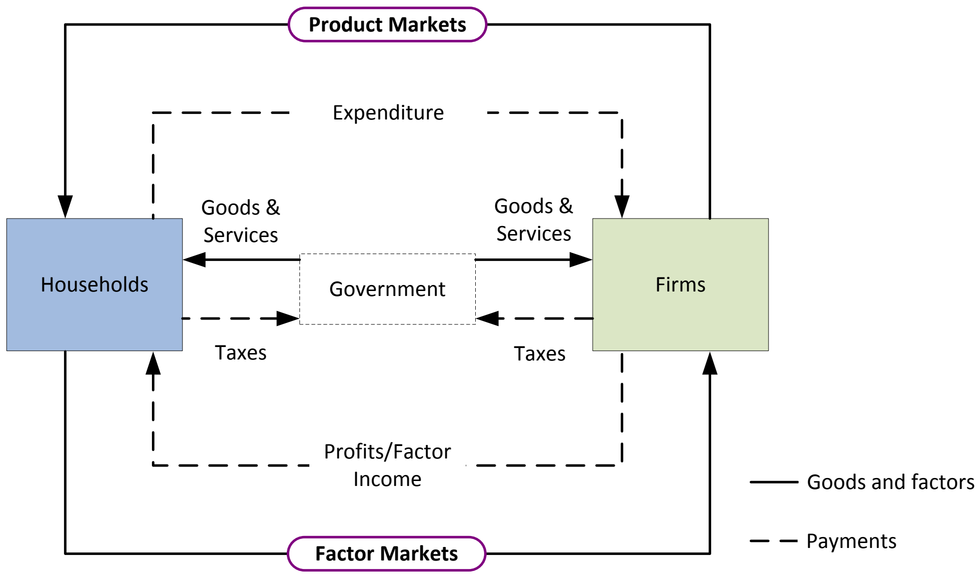

Figure 7 The circular flow of the economy (see *Mankiw, 1994*)

The circular flow can be traced by starting with the supply of factor inputs (e.g. labour and capital services) to the firms and continue to the supply of goods and services from the firms to the households, who in turn control the supply of factor services. But it can also be traced by starting with the payments the households receive for the services of labour and capital.

Equilibrium in the economic flow results in the conservation of both product and value. These rules are the cornerstones of the Walrasian general equilibrium that are described by Walker (see *Walker, 2006*). The conservation of product is an expression of the principle of no free disposability, which is the familiar condition of market clearance. It implies for a given commodity the quantity produced must equal the sum of the quantities of that are demanded by the other firms and households in the economy. The conservation of value implies that the value of a unit of each commodity in the economy must equal the sum of the values of all the inputs used to produce it. It reflects constancy of returns to scale in production and perfectly competitive markets for produced commodities, and thus implies that in equilibrium producers make zero profit. This condition implies that with unfettered competition firms will continue to enter the economy's markets for goods until profits are competed away to zero.

3.2 Input-output approach

The Input-Output model is e a method to describe the economy in a region. It is based on the notion that the production of output requires input. Its origin dates to the Eighteenth century French authors, who developed the 'Tableau économique', an early form of an input-output table. In 1965, Wassily Leontief published the input-output table in the current form (see *Leontief, 1965*).

3.2.1 The basic model

The Input-Output (I-O) method quantifies systematically the interrelationships between the various sectors of an economy system. The system may be as large as a nation or even the world economy, or as small as the economy of a region or even an enterprise. The size of the economic system does not affect the approach. It is a recognised tool to reflect the circularity of flows within an economy (see Figure 8). In this system, each industry (denoted A, B, and C in Figure 8) produces some amount of output. Part of this output will be used by the same industry for its own needs. Another part of the output will be trade between the other industries for their production needs. This flow of intermediate goods between the industries can stream in both directions. The final part of the output produced by each sector is allocated to the final demand categories, such as consumption, investments or exports. Last, the final demand categories are supplying labour and capital back to the productive industries, which closes the input-output circle of flows.

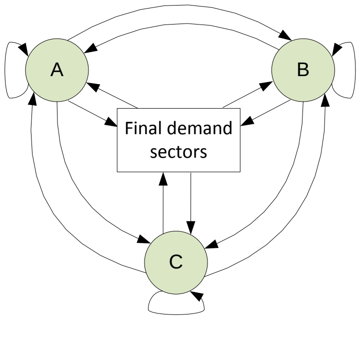

Figure 8 Scheme of inter- and intra industry flows in one region

The input-output circle of flows can be translated into an input-output table (see Figure 9). The basic unit of the table is the transaction between the parties (firms, industries, consumers, etc.). The transactions consist of intermediate deliveries, which means that the delivery is the input in another process and will be processed further in another firm, or final deliveries, where the delivery will go to the consumer, government or investment. (see *Bockarjova, 2007*).

Sectors		purchasing					Final demand				Total
		1	…	j	…	n	Consump-tion	Government Expenditures	Invest-mens	Export	
Selling sector	1	z		z		z					
	…	…	…	…		…					
	i	z		z		z	c_i	g_i	i_i	e_i	x_i
	…	…		…	…	…					
	n	z		z		z					
Payment sector	Labour			w_j							W
	Profit			n_j				0			N
	Import			m_j							M
Total				x_j			C	G	I	E	X

Figure 9 General form of an input-output table

Intermediate outputs

The column vectors in the input-output matrix represent the purchases of a sector *j*. The elements of this vector register both the origin magnitudes of sector's *j* inputs. The flow from sector *i* to sector *j* is given as z_{ij}:

$$\begin{bmatrix} z_{1j} \\ \vdots \\ z_{ij} \\ \vdots \\ z_{nj} \end{bmatrix} \tag{16}$$

The total intermediate output of sector *i* is given as:

$$[z_{i1} \quad \cdots \quad z_{ij} \quad \cdots \quad z_{in}] \tag{17}$$

The sum of the output of a certain sector needs to be equal to the input of all sectors which comes from that specific sector; otherwise deliveries will disappear to or appear from nothing:

$$\sum_{i=1\ldots n} z_{ik} = \sum_{j=1\ldots n} z_{kj} \tag{18}$$

A second equality follows out of previous one, stating that the sum of the total input of the sectors (columns) needs to be equal to the sum of the total output of the sectors (rows):

$$\sum_{\mathrm{k}=1\ldots\mathrm{n}} \sum_{i=1\ldots n} z_{ik} = \sum_{\mathrm{k}=1\ldots\mathrm{n}} \sum_{j=1\ldots n} z_{kj} = \sum_{\mathrm{i}=1\ldots\mathrm{n}} \sum_{j=1\ldots n} z_{ij} \qquad (19)$$

Total output

The total output of an activity *i* is the sum of the intermediate output and final demand and is represented as

$$x_i = \sum_j z_{ij} + \mathrm{c_i} + \mathrm{g_i} + \mathrm{i_i} + \mathrm{e_i} \qquad (20)$$

Where c_i, g_i, i_i and e_i are the column elements, respectively of private consumption, government expenditures, investments and exports which are also represented in Figure 9.

3.2.2 Interregional input-output models

The input-output scheme represented on page 39 can be expanded into an interregional input-output model (see Figure 10). In this model, besides the intraregional economic activities, interregional activities take place. Each region (denoted I, II, and III) has its own circle of flows, but the output produced by each industry in a region (denoted A, B, and C) are purchased by industries either in the same region or in another region (see *Bockarjova, 2007*).

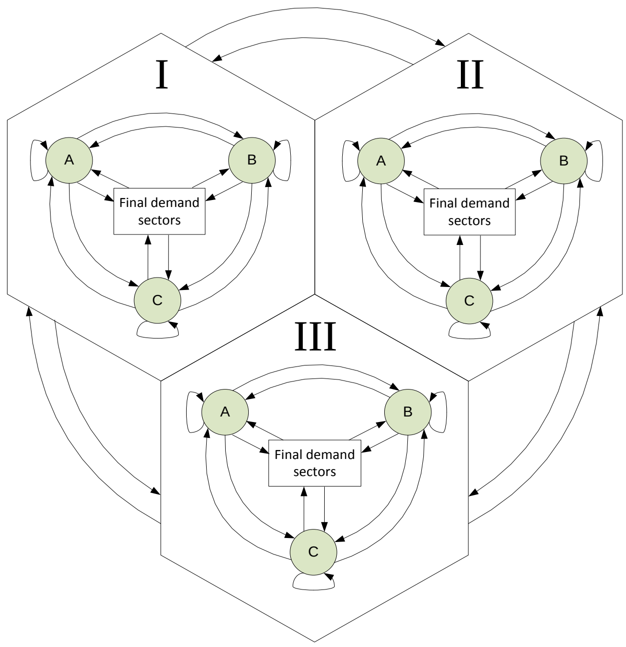

Figure 10 Scheme of inter-, intraregional economic flows

The schematic view of the interregional economic flows can be translated to an interregional input-output table (see Figure 11). The basis unit of this table is the transaction between the sectors in the different regions. The interregional input-output table is useful in elaborating the dependence of the regions to each other.

Economic activities		Purchasing sector		
		Region I … …	Region II … …	Region III … …
Selling sector	Region I … …			
	Region II … …			
	Region III … …			

Figure 11 General form of an interregional input-output table

3.2.3 Multipliers in the input-output model

The input-output models are constructed to provide a detailed industry-by-industry breakdown of the predicted effects of changes in final demand. It can be useful to describe the domino effect of a change in one variable upon others. In Input-Output analysis, there are many different multipliers. One multiplier is the ratio of the direct, indirect and induced effects to the direct (i.e. the initial) change itself

$$multiplier = \frac{direct\ effect + indirect\ effect}{direct\ effect}$$

According to Armstrong and Taylor (see *Armstrong and Taylor, 2000*), it is possible to obtain output, income and household multipliers from the input-output model. The sectoral output multipliers can be calculated with the Leontief inverse matrix B which is given as:

$$B = (I - A)^{-1} \tag{21}$$

I is the identity matrix (matrix with "1" in the diagonal,"0" in all other fields) and A is the matrix with the direct coefficients a_{ij} (production coefficient indicating the amount of *i*'s products needed to produce one unit of *j*'s product).

This matrix shows exactly how the output of each sector will be affected when the final demand for a region's output increases by €1. The effect of a change in a sector in the region is cumulative, which means that it will affect the other sectors directly but also indirectly through sectors which are related in the input-output table.

3.2.4 Strength and limitations of the Input-Output approach

The Input-Output method has its advantages and weaknesses. The strength of the approach is:

- Data are usually comprehensive and consistent. Input-Output tables contain all the formal market place activity that occurs in an economy, including the service sector which is frequently poorly represented. The tables frequently play an important role in the construction of the national accounts. This means that the data are checked for their accuracy, and that the tables are linked with traditional indicators of economic performance such as production and GNP.

- The Input-Output approach makes it possible to analyse the economy as an interconnected system of industries that directly and indirectly affect one another, tracing structural changes back through industrial interconnections. In analyzing an economy's reaction to changes in the economic environment, the ability to capture the indirect effects of a change is a unique strength of I-O analysis.
- The design of I-O tables allows a decomposition of structural change which identifies the sources of changes as well as the direction and magnitude of change. The approach allows the introduction of a variable which describes changes in producer's recipes, i.e. the way tin which industries are linked to one another. In a general sense, the I-O approach gives insight into how macroeconomic phenomena such as shifts in trade or changes in domestic demand correspond to microeconomic changes as industries respond to changing economic conditions.

Although the Input-Output analysis is a valuable technique, it has weaknesses as well. Some limitations of the approach are:

- One important obstacle of the approach is the high cost of collecting the necessary data to construct the I-O table, especially for large regions.
- The I-O analysis assumes constant returns to scale, i.e. a doubling of output requires a doubling of the inputs.
- I-O models ignore the existence of supply constraints, i.e. supply is infinite and perfectly elastic. A rapid output expansion may not be possible in the short term because of a shortage of necessary input, such as labour.

3.3 Other regional economic models

The Input-Output approach is not the only method of estimating the impact of changes in the demand for a region's output. This section describes another method that is described in Armstrong and Taylor (see *Armstrong and Taylor, 2000*), the Computable General Equilibrium (CGE) model.

The conceptual starting point of a Computable General Equilibrium (CGE) model is again the circular flow of commodities in a closed economy. It is a multi-market simulation model based on the simultaneous optimizing behaviour of individual consumers and firms in response to price signals, subject to economic account balances and resource constraints (see *Shoven and Walley, 1992*). Advantages of this approach are that CGE retains the multi-sector characteristics and emphasis on interdependence, but also incorporates input/output substitution, increasing or decreasing-returns-to-scale, behavioural content (in response to prices and changes in taste and preference), and non-infinite supply elasticities (including explicit resource constraints). A major shortcoming of CGE models is the assumption that all agents optimize and that the economy is always in equilibrium. The latter is not a problem when the period of analysis is more than one year and the external shock is small, but unscheduled events have the opposite characteristics.

CGE models are a standard tool of empirical analysis, and are widely used to analyze the aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets. The empirical code of most CGE models is an Input-Output table extended to include disaggregated institutional accounts, i.e. a social accounting matrix (SAM).

In general CGE models require considerable data, which in most cases, is difficult to obtain, especially at a regional level. For this reason the CGE models are not often used in the regional economy.

3.4 Summary and findings

This section gives insight in the relation between the transport and the economic system and represents the similarities and possibilities to integrate both systems.

The circular flow gives a representation of the relationship between the households and firms in an economy. It forms the basis of the methods that describe the economy of a region. Examples of such methods are the Input-Output model and the more complex Computable General Equilibrium (CGE). The Input-Output model is best suitable for loss estimation, because of its simplicity to represent the relationship between the economic activities. Although the CGE gives a better representation of the reality, it is too laborious for loss estimation and therefore will not be used. The Input-Output table has resemblance with the Origin-Destination matrix of the transport model (see Figure 12). Both tables represent the interaction between the origins and destinations in monetary terms (I-O) or Passenger Car Equivalents (O-D). This makes it possible to integrate the I-O table in the transport model. In loss estimation the regional I-O table will be used and not the interregional I-O table, because the regional I-O table is more vulnerable for changes in the economy and therefore more suitable in loss estimation on small scale.

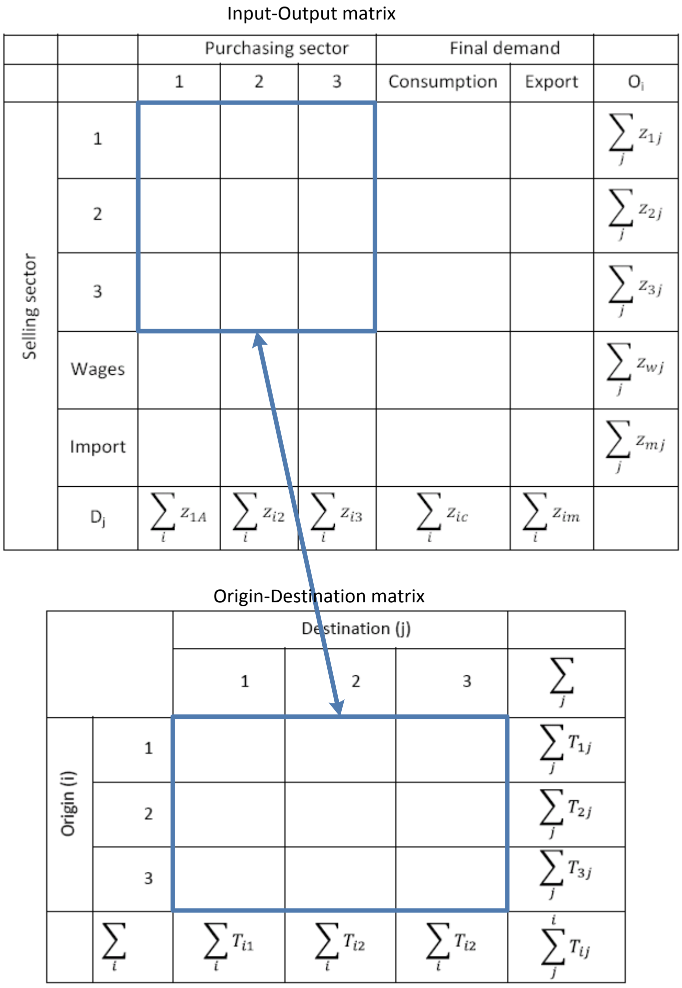

Figure 12 The resemblance between the I-O table and the O-D matrix

4 TRANSPORT ECONOMICS

The previous chapters gave more insight in the transport and economic system and how both are build up. This chapter focuses on the relation between both systems. It begins with a description of the transport costs, how they are built up and what factors can influence them. The next section describes the relation between the infrastructure and thus the transport costs and the economic development of a region.

4.1 Transport costs

Although transport provides tremendous benefits to individuals and society, it also incurs significant costs, the transport cost. Rodrigue and colleagues (see *Rodrigue et al., 2006*) define transport costs as:

"Transport costs are a monetary measure of what the transport provider must pay to produce transportation services. They come as fixed (infrastructure) and variable (operating) costs, depending on a variety of conditions related to geography, infrastructure, administrative barriers, energy, and on how passengers and freight are carried. Three major components, related to transactions, shipments and the friction of distance, impact on transport costs."

The transport costs play a role in both the economic and the transport system. The transport costs can account for 20% of the total costs of a product, which means that an increase of these costs will cause an increase in the total costs. Empirical evidence underlines that a rise of 10 percent of the transport costs causes a reduction of the trade volumes of more than 20 percent (see *Rodrigue et al., 2006*). Within the transport model the transport costs play a role in trip distribution and modal split. Trip distribution is based on the distribution function, which is an costs function and represents the willingness to pay for a certain distance. Modal split is based on the utility function of a transport mode which included the transport costs of that mode as well.

The difference between the transport costs used in the transport and economic is that the economic system implies that transport costs are based on a fixed part (e.g. depreciation of the vehicle, insurance, maintenance) and a variable part depending on the distance. The transport costs used in the transport model usually depend on distance and do not include a fixed part. This means that the transport costs used in the economic system are the sum of the transport costs used in the transport model and the fixed costs of the vehicle.

4.1.1 Factors that influence transport costs

Rodrigue and colleagues (see *Rodrigue et al., 2006*) defined several significant conditions that affect transport costs:

- **Geography**: Its impacts involve distance and accessibility. Distance is commonly the most basic condition affecting transport cost. The friction of distance can be expressed in terms of length, time, economic costs or the amount of energy used. It depends on the type of transport mode involved and the efficiency of specific transport routes.
- **Type of product**: Different economic sectors incur different transport costs as they have their own transport intensity. For passengers, comfort must be provided, especially if long distance travel is involved.
- **Economies of scale**: The economies of scale or the possibilities to apply them as the larger the quantities transported, the lower the unit cost. Bulk commodities are highly suitable to obtain lower unit transport costs if they are transported in large quantities.
- **Infrastructure**: The efficiency and capacity of transport modes and terminals has a direct impact on the transport costs. Poor infrastructure imply higher transport costs, while developed transport systems tend to have lower transport costs because they are more reliable and can handle more movements.
- **Mode**: Different modes are characterized by different transport costs, since each has its own capacity limitations and operational conditions.

4.1.2 Types of transport costs

The transport costs are mainly estimated by the infrastructure, because they represent the geographical distance between origin and destination in travel time and travel costs of personal trips and freight transport. Types of transport costs are (see Figure 13):

- **Freight on board (FOB)**: The price of a good is the combination of the production costs and the transport costs from the factory to the consumer. In this case, the consumer pays for the transport costs, which means that the price of a commodity will vary according to transportation costs and distance.
- **Cost-Insurance-Freight (CIF)**: Considers the price of the good, insurance costs an transport costs. It implies a uniform delivered price for all customers everywhere, with no spatially variable transport price. The average transport price is built into the price of a good.
- **Linehaul costs**: Costs that are a function of the distance over which a unit of freight or passenger is carried.

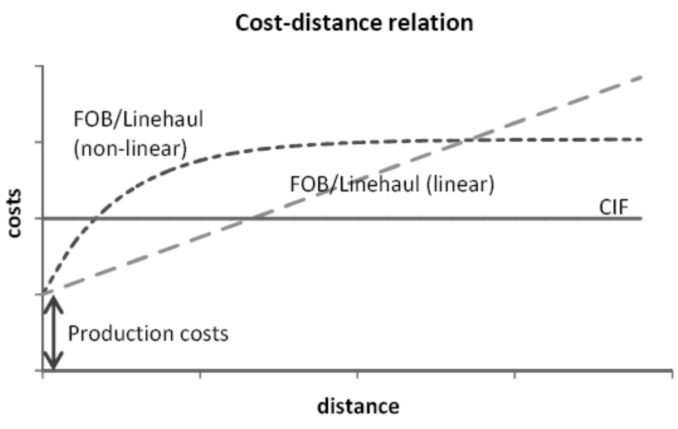

Figure 13 Transport costs

In loss estimation, the costs that depend on the trip length are of interest, because an increase of trip length as a result of an event can lead to economic loss. It is assumed that the production costs will not be influenced by the event. The transport costs per km are based on the c_{ij} that is used in the transport model in chapter 2. To estimate the total costs of a product from zone *i* to *j*, c_{ij} is denoted as the costs for commodity *k* (c^k) to travel 1 km times the distance *d* between zones *i* and *j*. The total costs of product *k* between zones *i* and *j* are:

$$tc_{ij}^k = p^k + c_{ij}^k \qquad (22)$$

With

$$c_{ij}^k = f^k + \partial^k d_{ij} \qquad (23)$$

where

tc_{ij}^k	Total costs of product *k* from zone *i* to *j*
p^k	Production costs of product *k*
c_{ij}^k	Transport costs of product *k* between zone *i* and *j*
f^k	Fixed transportation costs for product *k*
∂^k	Variable transport costs per km of product *k*
d_{ij}	Distance in km between zone *i* and *j*

The main causes of a variation in transport costs can be divided in variations in transport demand and in (capacity) supply. A second distinction can be made between generic and specific factors. In case of generic factors, the influence of these factors is stretched over a large network (e.g. country), specific factors have a local influence (e.g. around one destination or road) (see Table 3).

Table 3 Factors that cause variation in transport costs

	Generic	*Specific*
Transport demand (human)	season	(sport, festival) events
Capacity (roads)	weather	accidents, disasters

A variation in transport demand can cause more traffic on the roads and this can result in another route for the trip with a longer trip length, but that will go faster than go via the congested route.

A variation in the capacity of the roads can result from a closure of a road because of the weather (e.g. mountain passes because of snow) or because of an accident (e.g. tunnel). An unscheduled event can be classified as an specific factor that affects the capacity of the roads and will cause a variation in the transport costs.

The variation in transport costs of product *k* can cause a shift in the supply or demand of the product. This effect can be positive or negative for the economy, but this will be discussed in the next section.

4.2 Infrastructure and economic development

The interaction between land-use and transport has been investigated by several researchers. The so called Land Use Transportation Integration (LUTI) methods were proposed to model the behaviour of an entire urban region over an extended period of time. The heart of the LUTI models is the interaction between *transport*, *accessibility*, *land-use* and *activities* (see Figure 14).

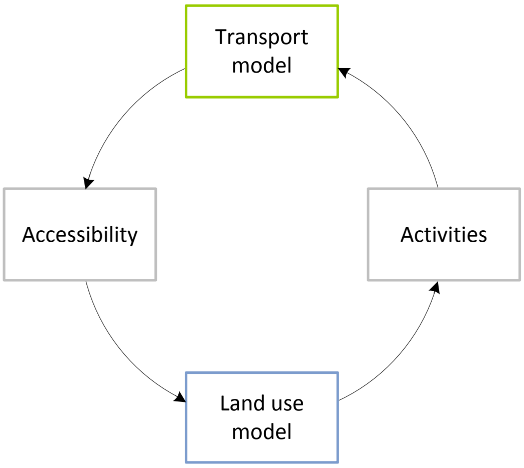

Figure 14 The 'land-use transport feedback cycle'

The working of the LUTI model is:

- The distribution of *land uses*, like residential, industrial or commercial, over the urban area determines the locations of human *activities* like living, working, or shopping.
- The distribution of human *activities* in space requires spatial interactions or trips in the *transport system* to overcome the distance between the locations of activities.
- The distribution of infrastructure in the *transport system* creates opportunities for spatial interactions and can be measured as *accessibility*
- The distribution of *accessibility* in space co-determines location decisions and so results in changes of the *land-use* system (*Wegener and Fürst, 1999*).

The LUTI models, and especially the dynamic models (for examples see *Macket, 1979, Eshenique et al., 1990, de la Barra, 1989, Wegener, 1982, Simmonds and Still, 1998*) are useful to describe the impact of a change in infrastructure on the economy over a longer time period (>year). An example of a LUTI model is the MOBILEC model and is described in the next section.

MOBILEC[3]

The MOBILEC model, a LUTI model, describes the relation between economy, mobility, infrastructure and other regional characteristics. It is a neoclassical growth model, but adapted that it can simulate the unemployment. The model is macro-economic on the level of regions. The main aspect of the model is the production function, which relates on one hand the adopted amounts of production factors and on the other hand the amount of final products. The usual production factors are labour and capital, but MOBILEC uses the infrastructure as a production factor as well. The part of the infrastructure that is utilized for production is a production function. With the infrastructure utilized is referred to the mobility for productive ends in terms of the numbers of travellers or tons of freight, carried by the infrastructure.

The productive mobility is related to freight transport and business traffic. If the motive of the travel is related to shopping, visiting family/friends, recreation, attending educational courses or driving/walking, it is related to consumptive mobility. However, the nature of mobility of the commuter traffic is more complicated, because it can be related to both types of mobility. It can be related to productive mobility from the point of view that commuter traffic is linked to productive performance outside the home. Looking from the point of view of the consumer's wish to live in a more attractive environment than the work environment, the commuter traffic can be characterised as consumptive mobility. The production function is related to productive mobility, and not the consumptive mobility, because the direction of causal connection is from mobility to the economy. The consumption function, related to the consumptive mobility, describes the relationship between income and consumption, where the causal connection is from the economy to mobility.

Specification of the model

The model starts with regional income in a period *t,* which determines regional savings and depending on the balance of government spending leads to investments. To what extent savings are used as investment in the region or elsewhere depend on the capital rate of return in relation to that in other regions. Regional investment is an extension of the stock of capital goods; in case of positive investments the region has a larger stock of capital at the beginning of the next time period *t+1* than at the beginning of time period *t*.

The neoclassical theory suggests that marginal labour productivity determines the wage rate. This relationship is reversed in MOBILEC in order to simulate unemployment. The wage rate is an exogenous (non-flexible) variable and determines marginal labour productivity. The price of productive mobility determines marginal mobility productivity.

The stock of capital goods, marginal labour productivity and marginal mobility productivity in period *t+1* simultaneously determine regional product, employment and productive mobility in period *t+1*. Regional product is related to regional income,

[3] MOBILEC: Mobility/Economy

which influences consumptive mobility and commuter traffic. Consumptive mobility also depends on the distance cost of consumptive mobility and travel time, and characteristics of the region in relation to other regions. Commuter traffic also depends on the distance cost of commuter traffic and travel time, and employment in the region in relation to other regions. At this point the process starts all over again and simulates a continuous process of development in the economy and mobility (see annex 2).

4.3 Conclusion

This section describes the transport costs, how these are built up and the relation between the transport costs and economic development. Several types of transport costs are distinguished, but this research will use the linehaul cost type where costs are a function of the distance over which a unit of freight or passenger is carried. Furthermore, it is assumed that the fixed part of the transport costs are constant during the disruption of the infrastructure, which means that the difference in transport costs can only be declared in the variable part that depends on the distance.

The relation between the infrastructure and economic development is described with help of the Land Use Transportation Interaction (LUTI) models. These models describe the influence of an investment in the economy on the transport system or the influence of an investment in the transport system on the economy of a region. These models assume long-run equilibrium in both systems and are not able to describe a short-run effect of an investment or a disaster. This makes the LUTI models not suitable for loss estimation of a temporary disruption of a lifeline, but these models can be useful in long-run effects of a disruption or in estimating the effects of the recovery after a disaster.

5 Loss estimation models in the literature

The impact of an event is complex, including not only the negative effects from damages and losses, but also the positive economic effects from recovery and reconstruction activities. This chapter gives insight in the types of loss and represents existing methods to estimate economic loss as a result of a disaster.

5.1 Direct and indirect loss

The definitions of direct and indirect loss estimation is based on The Impacts of Natural Disasters: A Framework for Loss Estimation (see *the Committee on Assessing the Costs of Natural Disasters, National Research Council, 1999*).

The direct loss is the damage resulting directly from the event and consists of two refined types of losses. Primary direct losses are those resulting from the immediate destruction caused by the event, such as shake damage from an earthquake or water and wind damage from a hurricane. Secondary direct losses are those additional impacts resulting from follow-on physical destruction, such as fire following an infrastructure failure or the need to repave the road after a large accident. The magnitude of the direct loss can be determined by the cost of restoring the economy or current market cost of the destroyed or disrupted economic objects, if the objects cannot be restored. Thus, direct estimable losses are the losses from the disruption or destruction of economic and residential structures and the property in them and destruction of bridges, highways, and railroads. In agriculture the loss is determined by the losses of agricultural production and cost of restoring the disturbed fertility of the soil for example as a consequence of flooding.

Indirect losses of unexpected events, or losses resulting from the consequences of physical destruction, have not been measured, studied, and modelled to the same extent as direct losses (the monetized losses of physical destruction). Unprecedented business interruption has focused attention on the need for more intensive scientific study and measurement of these indirect losses. Evidence to date suggests that the proportion of indirect impacts increases in larger events, and thus may constitute a larger fraction of total losses and damage in large events than in smaller events. By their nature, indirect losses are harder to measure than losses stemming directly from physical damage. For example, a ruptured power line is readily observed and the cost of its repair evaluated. Far less obvious are losses such as those of industries that are forced to close down because they lack critical power supplies, firms with power that lose business because suppliers or buyers lacked power, and firms that lose business because employees of firms affected by the power outage have reduced incomes and consequently spent less.

5.2 Theoretical approaches

Most researchers (for examples see *Rose and Benavides, 1998, Romanoff and Levine, 1977, Okuyama et al., 2002*) try to explain the impacts of transport infrastructure changes on the regional socio-economic development with help of economic models. This section deals with several approaches to estimate economic loss after an unscheduled event. In estimating the economic loss of an unscheduled event, two models are suggested by several researchers, namely the Input-Output approach and the Computable General Equilibrium (CGE) approach.

5.2.1 Input-Output approach

Rose and Benavides (see *Rose and Benavides, 1998*) and Rose and Liao (see *Rose and Liao, 2005*) provide an Input-Output analysis of a lifeline breakdown and its effects on the disruption of production activities. Rose (see *Rose, 2004*) provides methodological insight into economic disaster modelling and challenges associated with this. Rose and colleagues (see *Rose et al., 1997*) developed a method to estimate the direct and indirect effects of electricity lifeline disruptions. They estimated the indirect impacts from direct effects using Input-Output impact analysis. They assumed no resilience[4] for the moment, the lifeline disruptions can be translated into potential output reductions in each sector as:

$$\Delta X_j = \sum_s \sum_j d_e^s w_j^s \overline{X}_J \qquad (24)$$

where

X_j	Gross output of sector *j* for the entire region after the disaster
j	Economic sectors
s	Electricity service areas
d_e^s	Electricity disruption in service area s
w_j^s	Fraction of sector *j* output produced in the region s
$\overline{X}_J$	Gross output of sector *j* before the disaster

The gross output changes need to be translated into final demand changes because the latter are the conduits through which external shocks are transmitted. A decrease in electricity, d_e, translates into a change in final demand availability, ΔY_j, in a given sector as:

$$\Delta Y_j = (I - A_i)\Delta X = (I - A_i) d_e^s w^s \overline{X} \qquad (25)$$

Y_j	Final demand of sector *j*
X	Entire vector of gross outputs
A_i	Row vector of the matrix of technical coefficients a_{ij}

[4] Resilience is the ability of individuals, markets, and the economy as a whole to continue functioning when shocked by a disaster (see 6.2.1)

The standard I-O impact formula is used to determine total gross output impacts.

If resilience is taken into account, it will affect 1) the initial estimates of output reduction in each sector and 2) it will means that less electricity is needed per unit of output (because of conservation potential, back-up powers sources) and thus requires a decrease in the electricity input coefficient, denoted as a_{ej}. The resiliency of the sector *j* to electricity disruption is denoted as r_{ej}. By substituting a modified matrix A^* for A, by multiplying the electricity input coefficient in each sector, a_{ej}, by its corresponding $(1 - r_{ej})$. The two effects are combined in the next formula:

$$\Delta Y_j = (I - A_i^*)(1 - r_{ej}) d_e^s w^s \bar{X} \qquad (26)$$

The method is suitable in loss estimation because it is able to estimate the indirect effects from the direct effects with help of the Input-Output table. An advantage of the model is its simplicity, which makes it possible to estimate loss with few data. Furthermore, the model takes into account the variations in final demand as a result of the disruption and can deal with resiliency of the region. Besides the advantages, the model has weaknesses as well. A disadvantage of this method is that it is not able to include all of the factors affecting regional economic losses. First, there is likely to be significant damage to buildings, so that even with immediate restoration of electricity services, the economy would not likely revert to baseline production levels. Second, other lifeline services are also likely to be disrupted, and one needs to guard against double-counting, which means that losses are counted to more types of damages. The resilience can be understated because of the ignorance of the possibility of importing more crucial goods and services. In addition, many sectors can make up lost production by working overtime shifts after electricity is restored.

5.2.2 Sequential Interindustry Models

A Sequential Interindustry Model (SIM) is introduced by Levine and Romanoff (see *Romanoff and Levine, 1977*) in response to the need to analyze interindustry production in a dynamic economic environment. Assuming that time is divided into discrete intervals of equal duration, the SIM enhances the static Input-Output model to the dynamic one by supplementing the structure of production with a production chronology. Unlike the Input-Output method, the production in the SIM is not simultaneous, but occurs sequentially over a period of time. The interval of an industry production process is divided into two components, the production interval and the shipment interval with inputs and product inventories (see Figure 15). To create the dynamics in SIM, a distinction is made among three events in a production process, demand stimulus occur when goods are ordered, yield of supply happens when goods are delivered, and production yield occurs when goods are produced. Just as the demand in the Input-Output model it is not restricted to final demand but includes intermediate demand along the production sequences as well. Final demand stimulus is the ultimate system input, while final supply is the net system output.

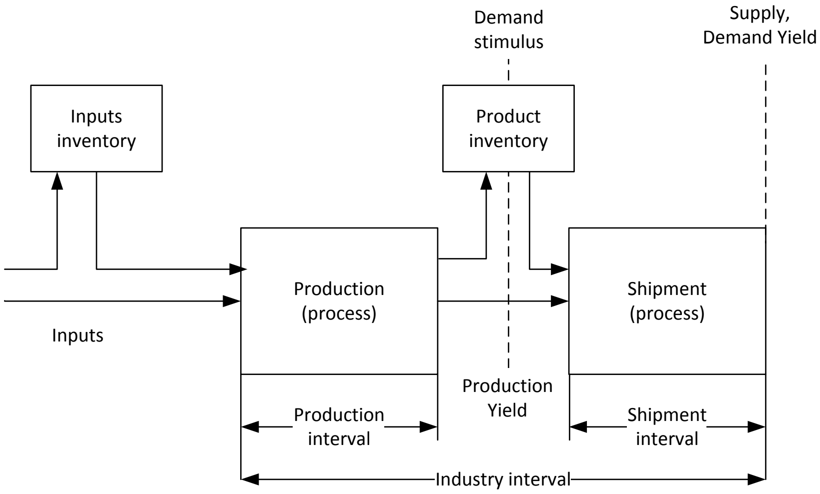

Figure 15 Production Intervals (see *Romanoff and Levine, 1981*)

Because of the temporal structure and adoption of production chronology, SIM has the capabilities to handle some issues that other economic models may have difficulties, such as uncertainty.

Okuyama and colleagues (see *Okuyama et al., 2002*) examined the intertemporal processes of the economic impacts from an unscheduled event. They did this by developing a SIM which can effectively introduce the dynamic process of production chronology in the static Input-Output framework. The SIM is especially valuable to analyze the impacts of an unscheduled event and its recovery and reconstruction processes over time.

5.2.3 Computable General Equilibrium approach

SCGE models typically are comparative static equilibrium models of interregional trade and location based in microeconomics, using utility and production functions with substitution between inputs. Firms often operate under economies of scale in markets with monopolistic competition. Tsuchiya and colleagues (see *Tsuchiya et al., 2007*) described the economic impacts of transport infrastructure disruptions using a Spatial Computable General Equilibrium (SCGE). The model can integrate two types of interregional flows of freight movement and passenger trips. The Dutch spatial plan bureau (RPB[5]) used an economic model called RAEM[6] to estimate the indirect effects of an infrastructure project on the economy (see *Thissen et al., 2006*).

The Dutch RAEM model

The RAEM model is a Spatial Computable General Equilibrium (SCGE) model for the Netherlands, based on the new economic geography literature. The model focuses on the interregional transport and labour flow. With regards to the labour flow, the

[5] RPB = *'Ruimtelijk Plan Bureau'*

[6] RAEM = '*Ruimtelijk Algemeen Evenwichts Model*', i.e. (spatial) computable general equilibrium model (see chapter 3)

model takes into account the commuter traffic and migration. It employs monopolistic competition for fourteen sectors as the basic market form, and calibrates most of its coefficients on recently constructed bi-regional input-output tables for the Netherlands. The general outline of the model is described and the way it fits in with evaluation schemes presently adopted by the Dutch government and the European Commission.

The RAEM model divides three types of transport costs: costs of commuter traffic, costs of freight transport from the factory to the shop and the costs that are related to travel from home to the shop. This is an advantage of the RAEM model, because most existing models in literature take only the costs of freight transport into account.

The description of the RAEM model is derived from Oosterhaven and colleagues (see *Oosterhaven et al., 2001* and *Knaap and Oosterhaven, 2002*). The RAEM model assumes that all markets are of the monopolistic competition type and each firm in each industry produces one and only one variety of the product of that industry.

A major shortcoming of the SCGE models lies in their assumption of an equilibrium state, attributable to the optimal decision-making of economic agents, i.e. the system assumes optimal adjustments of all endogenous factors. An advantage of this SCGE model is, while many SCGE models discuss the relationship between interregional commodity transport costs and regional economy, this model considers passenger flow as well.

5.2.4 Hybrid models

Hybrid models are computational algorithms that address supply shocks, post-event supply constraints, and time phased reconstruction, but a number of inputs are user defined and therefore the approach can be criticized as ad hoc.

HAZUS

An example of a hybrid model is HAZUS, developed for the US Federal Emergency Management Agency and the National Institute of Building Sciences (see *FEMA, 2001*). It is designed around a geographic information system and intended to simulate indirect economic loss from earthquakes, floods or windstorms. It can be used to evaluate hazards, vulnerability and risks to support mitigation planning efforts, and to support response and recovery following a natural disaster. HAZUS is able to predict physical damage to:

- Buildings and their contents
- Bridges
- Pipelines
- Other types of infrastructure

HAZUS exists of three modules: the earthquake, flood and hurricane module. The output of the modules contains direct damage, induced damage, direct and indirect losses (see figure 15)

	Earthquake (Ground Shaking, Ground Failure)	Flood (Frequency Depth, Discharge Velocity)	Hurricane Wind (Pressure | Missile | Rain)
Direct Damage			
General Building Stock	✓	✓	✓
Essential Facilities	✓	✓	✓
High Potential Loss Facilities	✓		✓
Transportation Systems	✓	✓	
Utility Systems	✓	✓	
Induced Damage			
Fire Following	✓		
Hazardous Materials Release	✓		✓
Debris Generation	✓	✓	✓
Direct Losses			
Cost of Repair	✓	✓	✓
Income Loss	✓	✓	✓
Crop Damage		✓	
Casualties	✓	Generic Output	
Shelter Needs	✓	✓	✓
Indirect Losses			
Supply Shortages	✓	✓	
Sales Decline	✓	✓	
Opportunity Costs	✓	✓	
Economic Loss	✓	✓	

Figure 16 the output of HAZUS (source: *FEMA, 2005*)

The Indirect Economic Loss Model (IELM) component of HAZUS was designed to determine how damage to a region's economic sectors would impact employment and income. The component is based on published inter-industry input-output tables, but permits differing assumptions with regard to imports, exports, excess capacity, and the amount of outside assistance received. The direct damage is represented as a percent of a sector's production surviving the disaster. The IELM algorithm is not a linear program, nor is it a Computable General Equilibrium (CGE) model. It assumes that household expenditure is exogenous, and it takes a regional accounting stance. Disadvantages of HAZUS are that it lacks ability to estimate business interruption losses from lifeline services and it provides no guidelines for model validation in general.

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5.3 Cost benefit analysis

The Dutch government initiated to carry out the research program Economic Effects of the infrastructure[7] (*OEEI, 2000*). The occasion to start the research program was the discussion about the social return of several infrastructural projects. Different approaches showed that there is a strong variation in the estimation of the economic effects of projects. This affected the trust in the foundation of a project which complicated a justifiable social judgment.

Infrastructure projects can cause a change in the transport demand, because users and suppliers react on the altered transport costs. Nevertheless, the benefits are determined through multiplying the individual estimated change in transport demand with the value of travel time. The participating institutes of the research program stated that there is a need of a model that represents the causal relation between the transport demand and the value of travel time.

Specification of cost-benefit-analysis

The main recommendation of the guide is that large infrastructural projects need to be reflected from a welfare-economic point of view. This implies that a cost-benefit-analysis (CBA) is used as a method for evaluation. The cost-benefit-analysis is a method which is often used nowadays, it exists of two general elements, the alternatives and scenarios, and the evaluation (see annex 3). The alternatives and scenarios need to be described clearly to eliminate an unnecessary source of uncertainties.

The evaluation of the project starts with the competition analysis, where the emphasis is on transport effects for supplier and users and the effects on other transport modes. This analysis serves as input for the economic cost-effectiveness analysis. The external effects are used to estimate the effects on the environment, which can be separated in effects that are expressed in money and effects that cannot be expressed in money. The sum of this analysis leads to a partial cost-benefit-analysis, where the emphasis is on the involved sectors and not the whole economy. In the case of large infrastructure projects, the indirect effects on the other sectors of the economy are estimated as well. The combination of the partial CBA and the indirect effects results in an integral CBA.

The Cost-Benefit-Analysis estimates the economic effects of alternatives of an infrastructure project. The analysis is used in the decision-making-process of a project. The alternative with the highest cost-effectiveness value will be executed.

[7] Onderzoeksprogramma Economische Effecten Infrastructuur (OEEI)

5.4 Conclusions

The Input-Output analysis is a good alternative to estimate loss of a temporary disruption. The I-O analysis will be used in the loss estimating method that is proposed in the next chapter. The advantages of the model are its simplicity which makes it an accessible method. In combination with a transport model it will be able to give a better representation of the inter-industry relationships and the economic loss of the sectors as a result of a disruption.

The SCGE models are too laborious to use in loss estimation of a disruption of a lifeline. Although the method its strength is that it makes use of several transport costs and the relation with the economy, the models are expensive, because they use lots of data. This research will use the Input-Output table that are used in the SCGE methods, but will not deal with the mitigation and labour of the region. The reason for this is that method that is proposed in this research deals with the time period during the temporary disruption of a lifeline and not with the long-run consequences of the disruption.

The hybrid models can not be used at this moment in loss estimated, because these are not yet able to estimate loss of lifelines. If in the future these models are able to estimate this loss, they can be useful in loss estimation of a lifeline.

The Cost-Benefit analysis is commonly used in the estimation of the economic effects of alternatives of an infrastructure project. It can be useful in loss estimation, but not in this research where the time period is between the disruption and the reconstruction of the infrastructure. In order to use the Cost-Benefit analysis, the time period needs to include a period after the reconstruction of the infrastructure as well. The Cost-Benefit analysis can be useful in the estimation of the total cost of an event, where the region its benefit from the recovery of a disaster is included. It is possible that a disaster causes economic growth of a region after the recovery.

6 Economic loss estimation method

The previous chapter gave insight in existing loss estimation methods. These methods deal with direct effects of an unscheduled event and the damage is caused by the event. This research deals with the effects of the disruption of a lifeline as a result of an unscheduled event. This chapter proposes a method to estimate the loss due to a disruption of a lifeline. It gives insight in the model description, the long-run equilibrium of the system and the consequences of a disruption of a lifeline.

6.1 The model description

The framework for estimating economic loss due to a temporary disruption of the infrastructure is based on the classic four-step transport model and the economic Input-Output approach (see Figure 17). The input for the model is the Input-Output table, the geographical dispersion of the activities, and the existing infrastructure in the region. During the steps of the model, the original Input-Output table is distributed over the network and the routes between the activities are estimated. The aim of this is to obtain the value of each road in the network, i.e. the importance of the road. If the infrastructure is temporary disrupted as a result of an unscheduled event, the method makes it possible to estimate the economic loss of the region. The model exists of seven steps:

1. Interaction matrix
2. Trip generation
3. Trip distribution
4. Modal split
5. Trip assignment
6. Transport costs
7. Behaviour of firms and households

If alls steps are executed, the system is in long-run equilibrium. The disruption of the infrastructure creates a change in behaviour of households and firms and will cause a change in the transport model and therefore on the transport costs. It is assumed that the geographical location of the activities remains the same during the disruption of the infrastructure, and that migration of people does not depend on the disruption, i.e. the land-use does not change.

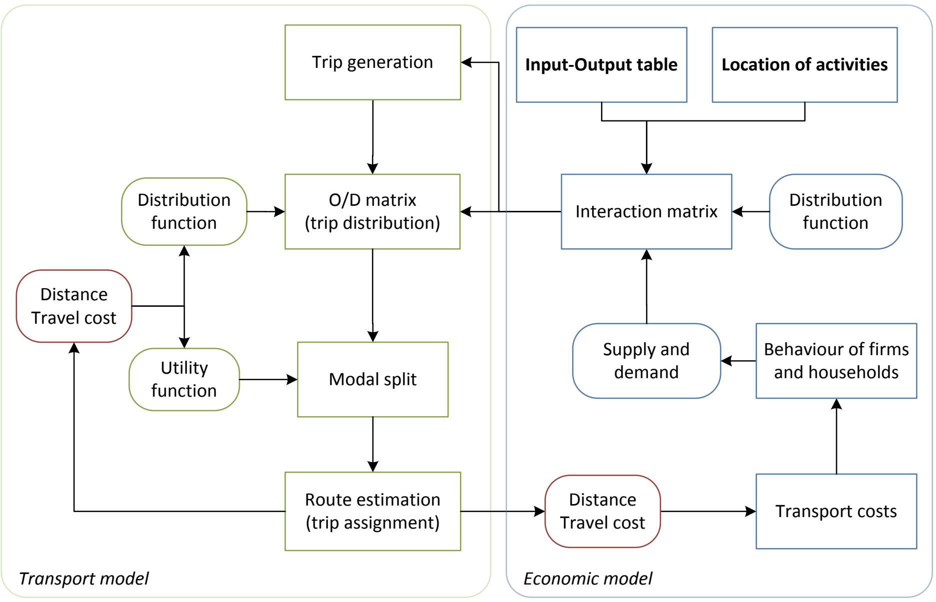


Figure 17 The methodology for estimating economic loss

The travel costs given in distance are represented on two places in the framework, in the transport model and in the economic model. In the transport model, travel costs are the input for the distribution function to estimate the Origin-Destination matrix, and for the utility function to estimate the modal split of the trips. The trip assignment results in travel costs for each trip over the network and is equal to the variable part of the total transport costs of a product or person. These transport costs exists of fixed costs (e.g. depreciation of the vehicle, insurance, maintenance) and variable costs depending on the distance a person of product is transported (travel costs).

1 Interaction matrix

The economic activities are dispersed over the region. A group of firms with the same activity can be agglomerated (see Figure 18), and it is possible that one activity can have several agglomerations in the area. The centre of the agglomeration is the reference point of that area and connects the agglomeration with other agglomerations through the existing infrastructure. It is assumed that the map with the agglomerations of activities is fixed and will not change as a result of the event.

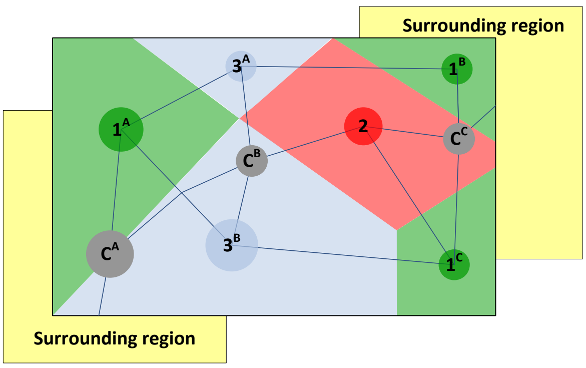


Figure 18 Agglomeration of activities

The Input-Output table represents the interaction between the different sectors in the area, e.g. agriculture, manufacturing, services etc. The import and export that are given in the table are not used in the estimation of the interaction matrix, because it is assumed that a temporary disruption will not affect the demand and supply from abroad. The transportation costs of these products are high and a small increase in these costs will not have a large effect on the demand and supply. The interaction with the surrounding regions will be taken into account, because these products are transferred via the road and an increase in transport costs can have influence on the behaviour of firms and households in the region.

The first step is to translate the Input-Output table into a table with the values of the output that is transported via the infrastructure. The output of the agriculture will exist of products that are transported over the road to their destination, but the output of the services can exists of money transfers from banks or insurance companies and will not be transported via the infrastructure.

The modified Input-Output table and the map with the agglomerations of activities need to be converted into a matrix with the interactions between the several agglomerations in the region (see Figure 19). The distribution of the output of a certain activity can be estimated with the distribution function of the transport model of the region. By comparing the trips with a professional motive leaving all zones that are classified as a certain activity *a* with the total output of that activity it is possible to derive the share of the different agglomerations of that activity.

If there is no data available of the trip generation, the total production of agglomeration (origin) *i* with activity *a* can be derived by multiplying the total output of activity *a* with a parameter that is related to characteristics of the agglomeration *i*. The total output *z* of agglomeration *i* with activity *a* is represented as:

$$\sum_{j} z_{ij}^{a} = \gamma_{i}^{a} \cdot \sum_{\mathrm{i}} \sum_{j} z_{ij}^{a} \qquad (27)$$

The parameter γ defines the share of the surface *s* of agglomeration *i* with activity *a* in respect to the total surface of activity *a*. If an activity is agglomerated in one location γ will equal 1. The parameter is estimated for all activities in the same way and is given as:

$$\gamma_{i}^{a} = s_{i}^{a} / \sum_{i} s_{i}^{a} \qquad (28)$$

The total output of a certain agglomeration equals the sum of the output of the activities of that agglomeration:

$$\sum_{j} z_{ij} = \sum_{a} \sum_{j} z_{ij}^{a} \qquad (29)$$

The same method is used to determine the attraction of the agglomerations. The values of total production and attraction of the agglomerations (in €/day) create the boundary conditions for the interaction matrix of the activities in the region.

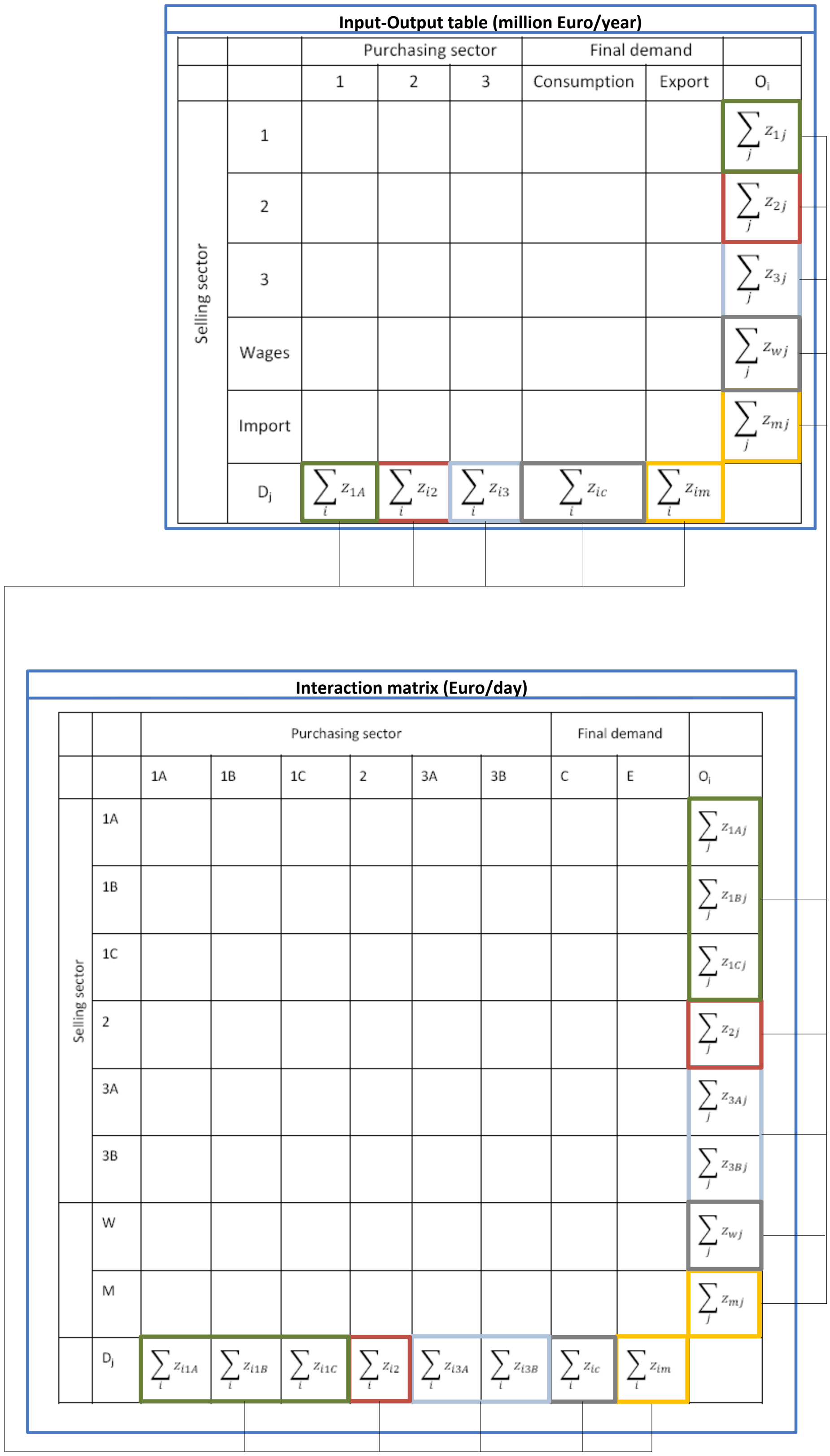


Figure 19 The activity interaction matrix

2 Trip generation

The trip generation is the first step of the transport model. The professional trips, including the freight transport and business trips are based on the interaction matrix from the previous step. The generation of trips with this motive is represented in the interaction matrix. From the personal trips, tourism is described as well in this matrix and it is not necessary to include this motive in the trip generation, because of these trips the destination is known and the origins are located outside the region. What remains are the commuter trips and the trips with a recreational motive. The last group will not be taken into account, because these trips occur normally on quiet time periods of the day and will not cause congestion or a longer travel time for the other travellers. The commuter trips can be estimated with the existing transport model. When trip generation of these trips is estimated, the trips need to be transformed to the same unity as the other motives (in Euros/hour).

3 Trip distribution & 4 Modal split

The next two steps of the transport model can be performed simultaneously, depending on the transport model of the region. The cost matrix that is used in the gravity model is based on the amount of travel time between the activities and communities via the existing infrastructure. The travel time between the surrounding regions is represented as the travel time through the whole region from one entrance to another. These costs will not be included in the region’s economy, but they can influence the travel time of the intraregional traffic. The outcome of these two steps are Origin-Destination matrices for each transport mode.

5 Trip assignment

The last step is the assignment of the trips over the network. This can be done with the al-or-nothing method, because the trips are expressed in money and not in vehicles. A capacity restraint can be introduced by assigning a maximum value to a road. The result of this step is the assignment of the output of the activities over the network. It will be clear for which purpose a road is used in the network and what the economic value is of that road in terms of Euros transported.

6 Transport costs

The transport costs are determined for each activity. They consists of fixed and variable costs depending on the distance. The transport costs *c* of the output of activity *a* in origin *i* that is transported to destination *j* is represented as (see equation 23):

$$c_{ij}^{a} = f^{a} + \partial^{a} d_{ij} \tag{30}$$

where

f^a	Fixed transport costs related to the activity *a*
∂^a	Variable costs per km of activity *a*
d_{ij}	Distance between zone *i* and *j*

The increase of the transport costs of activity *a* in the region gives insight in the economic loss of the sector that produces product *a* as a result of an unexpected event. The total transport costs for product *a* are given as:

$$c^a = \sum_i \sum_j c_{ij}^a \qquad (31)$$

The total transport costs *c* for all products in the region are given as

$$c = \sum_a c^a \qquad (32)$$

The variation of the transport costs after and before the event represents the economic loss of the region due to the disruption of the lifeline. The impact of the increase of the transport costs depends on the distance where over the activities are transported. For example, the increase in transport cost will not have great impact on the import and export of the region because these activities are transported over large distances and an increase in the distance will not affect the supply or demand unless the region is still accessible. But if the distance between the origin and destination of an activity was relative small and increases due to the disruption, the households and firms will react on this change. How the households and firms will react is described below.

7 Behaviour of firms and households

The behaviour of the firms and households is represented with the standard Leontief model (see *Leontief, 1965*):

$$X = AX + f \qquad (33)$$

Where X is the *nx1* vector of sectoral gross outputs (it is assumed that each of the *n* sectors produces exactly one good), *f* is the final demand function (including consumption, government expenditure, import and export) and A is the *nxn* matrix of input coefficients a_{ij}. The elements of $a_{ij} = \frac{X_{ij}}{X_j}$ denote the amount of product *i* required, as an input in process *j*, for production of one unit of output of good *j*. It is assumed that there is no substitution between inputs into *j* sector, meaning that the proportion between inputs in *j* sector is constant, a_{ij} is fixed. Equation (30) can be rewritten with the Leontief inverse into:

$$X = Bf \qquad (34)$$

Where $B = (I - A)^{-1}$ is the Leontief inverse, or multiplier matrix (see 3.2.3). *I* is the identity matrix (matrix with “1” in diagonal, “0” in all other fields), and A is the matrix of direct coefficients a_{ij}. A change in output can be derived from a change in the final demand:

$$\Delta X = B\Delta f \qquad (35)$$

In the long-run equilibrium of the system there will be no change in final demand which means that the interaction matrix will not change.

6.1.2 Long-run equilibrium

The long-run equilibrium position is reached when the seven steps of the previous section are completed. The value of the transport costs that are estimated in the sixth step will not cause a change in the behaviour of the households and firms in the last step.

Equilibrium is reached when the Input-Output table is geographically distributed over the region, the steps of the transport model are executed and the value of the transport and production costs is estimated. The households and firms will not react on the production costs, because these are connected to the data of the Input-Output table of the region. From the long-run situation, the distribution of the outputs of the agglomerations of the activities is estimated and the value of road in the network is known. The corresponding transport costs of the trips are known and serve as the reference value for the short-run equilibrium.

6.2 Unexpected event module

The unexpected event module contains the unexpected event that causes a disruption of the infrastructure. The level of disruption depends on the recovery factor of the network (see Figure 20).

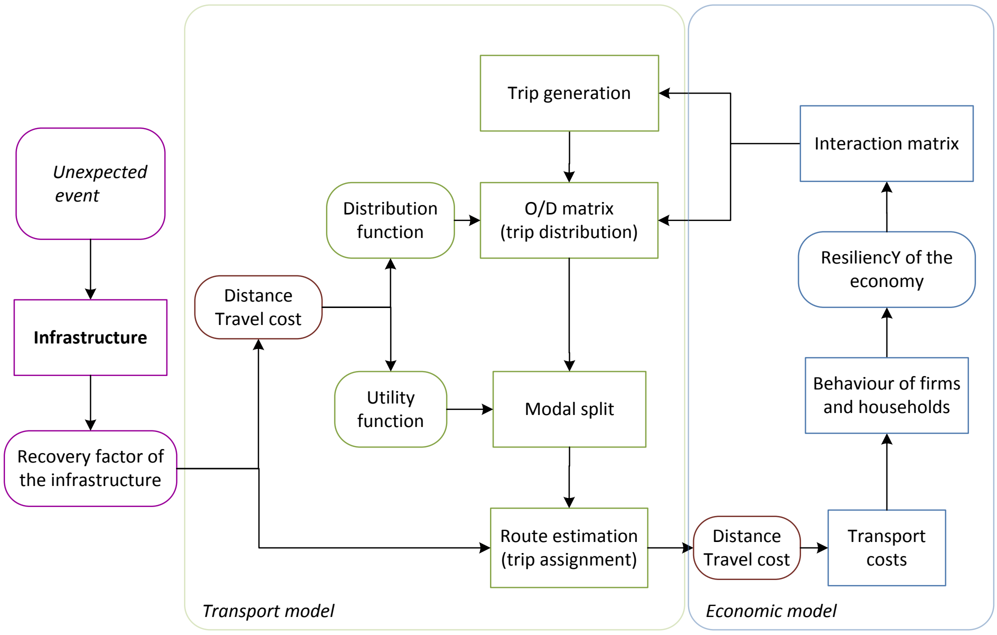


Figure 20 The unexpected event module

6.2.1 Resilience of the systems

The recovery of the systems can be compared with the resilience of the systems. Rose (see *Rose, 2004*) refers with resilience to the ability of individuals, markets, and the economy as a whole to continue functioning when shocked by a disaster. A more general definition is the ability of a system to recover from a severe shock. Resilience of the system takes places at two moments 1) directly after the event and 2) as the result of the behaviour of the firms and households in the region. The resilience can take place at two levels (see Table 4).

Table 4 Resilience factors

		Level	
		Micro	Macro
Sector	Economy	Individual behaviour of firms, households and organisations	Regional economy
	Transport	Individual roads	Entire network (I/C ratio)

- Microeconomic: the ability of an individual firms or organisation to recover from the shock. The ability to substitute for inputs in short supply, use inventories, and reschedule lost production for a later day by working overtime or extra shifts.
- Macroeconomic: the ability of the whole economy of a region to recover from the shock. Firms that are able to function can take over the production of other firms that are damaged due to the event. Other regions can give help, financial or material, to the region that is damaged due to the event.
- Individual road level: the ability of a single road to recover from the shock. The disruption of the road can be (partly) solved directly after the disaster. An example is a blockage, e.g. trees or cars, on the road that can be removed with the result that the road can be used again.
- Network level: the ability of the network to deal with the disruption of a road or several roads in the network. Is the capacity of the other roads sufficient to cope with a higher intensity? The intensity/capacity ration (I/C ratio) plays a role in the amount of resilience of the network.

Will an X percent loss of a lifeline result in an X percent direct loss in economic activity for a given firm? The answer is “no” given the presence of resilience. Rose (see *Rose, 2004*) uses as measure of resilience the deviation from the linear proportional relation between the percentage utility disruption and the percentage reduction in customer output.

The value of the resilience factor depends on the magnitude of the event, the structure of the economy and the quality of the infrastructure.

6.2.2 Effects of the disruption

The disruption of the infrastructure has several effects on the pattern of movement. The effects of the unscheduled event are classified in five groups, four of them can be connected to the transport model. The last effect is temporal and will not be taken into account in this research.

- Generation effect: a decrease or increase in the total amount of movements. This effect causes a change in the trip generation, i.e. it is possible that trips with a motive like recreation or tourism will not be made as a result of the event. On the other hand a disaster can generate trips, for example trips to the location of the disaster of curious people who want to see the disaster. In the loss estimation, only the decrease of generated trips will be taken into account.

- Distributive effect: a different distribution of origins and destinations. The trip distribution will change as a result of the event. Trips can have another destination than before the event, i.e. shopping trips can go to another supermarket which is still accessible.
- Substitution effect: a shift to another transport mode. The trips will be made with another transport mode than before the event. If the railway connection is destroyed due to the disaster, the trips that were made by train will be made with another transport mode.
- Route effect: a shift in route choice. Some routes can not be used anymore as a result of the disruption of the infrastructure. The trips will be assigned to new route and cause more traffic on the other intact roads, which results in longer travel times for all trips.
- Temporal effect: a shift in the moment of the trip. The temporal effect causes a shift in the moment the trip is made. This can cause a shift in the assignment, depending on the time period where the model is based on. If the network is assigned over twenty-four hours, there will be no large effect, but if the model runs for each hour there can be shift in the amount of trips over the network. This effect will not play an important role in this research, because the assignment is over twenty-four hours.

6.3 Economic loss

The economic loss is based on the effects of the disruption of the infrastructure and this the transport costs on the economy. The cycle starts with the initial effects of the event which cause on their turn higher order effects in the region. The economy will reach a temporary short-run equilibrium where the losses per day are constant over the period.

6.3.1 Initial effects

The basis of the estimation of initial effects is the situation before the unexpected event. As a result of the event, the infrastructure will be temporary disrupted, to what extent depends on the resilience factor of the infrastructure. The effect of the disruption has a direct effect on the last two steps, and an indirect effect on all four steps of the transport model, the amount of trips change, the destination of trips can change, there can be shift in the modal split, and the route estimation changes as a result of the disruption of a road. The value of the effects depends on the location of the disruption and the seriousness of the disruption. Because of shift in the distribution of the network, the transport and production costs of the activities will change as well. The direct economic loss is determined as the difference in the transport costs before and after the event. The indirect economic loss is given as the decrease of the gross output of the region as a result of the event. The sum of the direct and indirect loss equals the economic loss the region, and is given as:

$$L_0 = \left(c_{s,0} - c_{\mathrm{lr}}\right) + \left(X_{\mathrm{lr}} - X_{s,0}\right) \tag{36}$$

where

L_{0i}	Economic loss of the region (Euros/day)
c_{lr}	Total transport costs in long-run equilibrium
$c_{s,0}$	Total transport costs initial effects in scenario *s* (where *s*=1 or 2)
X_{lr}	Gross output of all activities in long-run equilibrium
$X_{s,0}$	Gross output of all activities in scenario *s* (where *s*=1 or 2)

The initial effect causes an increase of the transport costs, but gross output of the region remains the same, which means that the economic loss of the region is equal to:

$$L_0 = (c_s - c_{\mathrm{lr}}) \tag{37}$$

The households and firms will react on this increase of the transport costs, which means that the economic loss of the initial effect can not be used to estimate the total loss over the period of the disruption.

The time period of the initial effects depends on the magnitude of the event. If it is a small event, the reaction of the households and firms will not have a great influence on the gross output of the region. If it is a large event, the households and firms will react on the event and change their behaviour. In this case, the initial effects are negligible and the loss is estimated after the first round and higher order effects.

6.3.2 First round effects

The firms and households will react on the change in transport costs and change their behaviour. The effects of an unexpected event can have influence on the final demand function and the input coefficients a_{ij}. The final demand function is capable to assess the effect on the economy of a change in *f*. In the case of a disruption of a lifeline it is likely that the consumption will decrease as a result of an increase of the transport costs, which means that the final demand function decreases. The decrease of the final demand function means that the gross output X decline as well. The decrease in the gross output will affect the interaction table which was estimated in step 1 of the method.

The behaviour of the firms and households cause a shift in demand and supply of the region and interaction matrix. To estimate the economic loss of the first round effects of the disruption of the lifeline, the seven steps from the method need be followed again with the new interaction matrix. The economic loss of the region in the first round equals:

$$L_1 = \left(c_{s,1} - c_0\right) + \left(X_0 - X_{s,1}\right) \tag{38}$$

where

L_1	Economic loss of the region in first round (Euros/day)
c_0	Total transport costs in long-run equilibrium
$c_{s,1}$	Total transport costs initial effects in scenario *s* (where *s*=1 or 2)
X_0	Gross output of all activities in long-run equilibrium
$X_{s,1}$	Gross output of all activities in scenario *s* (where *s*=1 or 2)

After the first round, the economic system will react again on the change in transport costs, which means that the households and firms will react on the new transport costs and the effects will work through the system until they are negligible. These are the higher order effects and are not taken into account in this research.

The total economic loss depends on the period of the disruption of the infrastructure, which on its turn depends on the magnitude of the event. Because only the first round effects of the event are taken into account, the total economic loss, *TL*, of the region is given as:

$$TL = tL_1 \tag{39}$$

Where *t* represent the duration of the disruption (in days) and depends on the magnitude of the disaster.

7 CASE STUDY: VALTELLINA VALLEY

The method that is represented in the previous chapter will be illustrated with help of a study case. The data of the study case is not accurate which means that the absolute values that are obtained with the method will not compare the reality. The relative values will be used to draw conclusions from the study case.

7.1 Study area

The study area of the project is the province of Sondrio, also known as the Valtellina valley, in the Lombardy region of northern Italy, bordering Switzerland (see Figure 21). The province covers 3212 km^2 and the majority of this exists of a valley, called the Valtellina valley, which goes from the west to the east of the province. The province has about 180,000 inhabitants (see *CONIstat, 2008*), of which approximately 22,000 people live in the capital Sondrio. Other important places in the area are Morbegno (11,433 inhabitants), Tirano (9,136 inhabitants) and Bormio (4,088 inhabitants). The area is divided into five mountain communities, Chiavenna, Morbegno, Sondrio, Tirano and Alta Valtellina. These communities are the regions that will be used in this report.

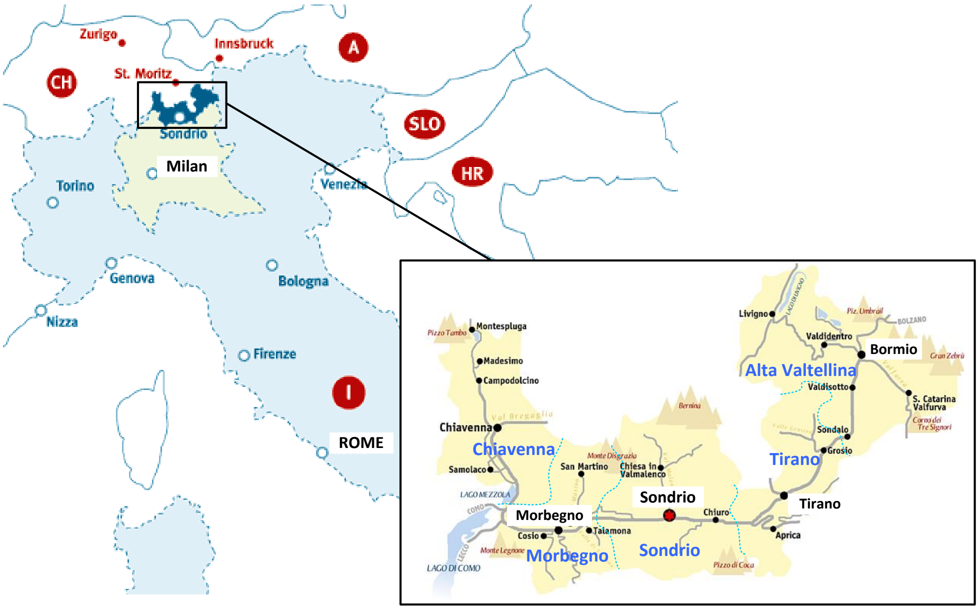


Figure 21 The research area (see *Valtellina, 2008*)

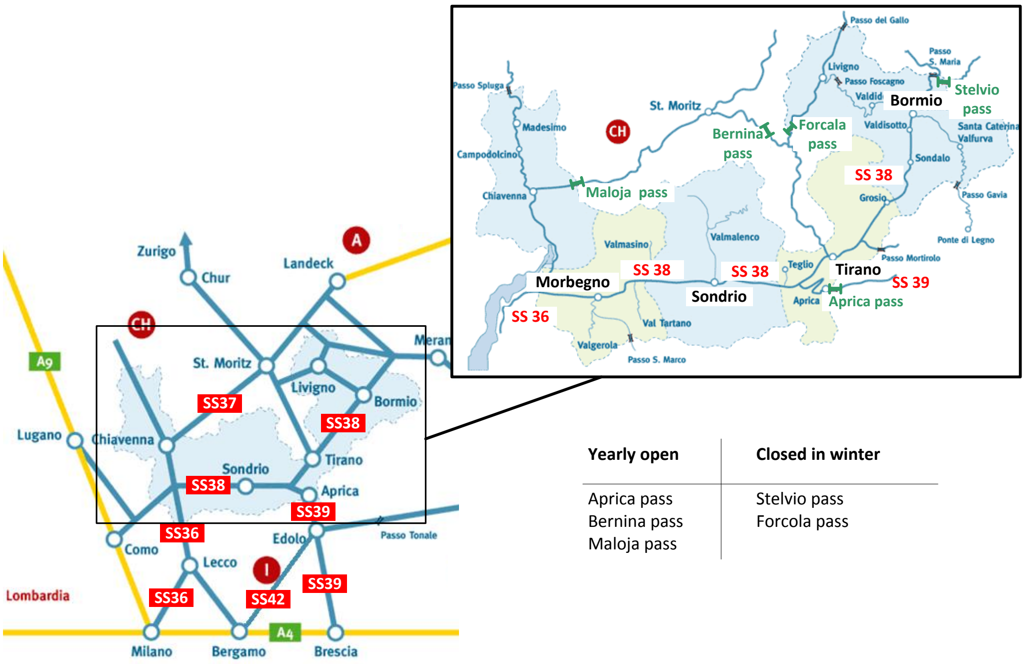
7.1.1 Economic activities

The gross domestic product (GDP) of the province of Sondrio 2005 was 4090.8 million Euros, which is 1.6% of the added value of Lombardy. The economic position of the province of Sondrio increased last years with 4.5% in 2004 1.5% in 2005, which is higher than the average increase of the other provinces of Lombardy (4.0% in 2004 and 0.3% in 2005). The community of Sondrio has the largest share in the GDP of the province, but the GDP/residents ratio of Alta Valtellina is higher because it has less inhabitants (see *Camera di Commercio di Sondrio, 2007*).

The two main economic activities of the region are viticulture and tourism. The Valtellina Valley, and especially Sondrio and surroundings are well known for its wine. The vineyards are located on the terraces in the valley between Sondrio and Tirano. The grapes are harvested from August until October. Chiavenna, Bormio and surroundings (known as Alta Valtellina) and Chiesa in Valmalenco are popular vacation areas in the region. People visit the area to hike or mountain bike in summer and in winter these places are popular ski resorts.

7.1.2 Infrastructure

The villages in the valley are connected with one road, the *"Strada Statale 38"* (SS 38), which goes from Morbegno to Tirano. The national road 38 seems to be a major mobility structure for residents of the region. Furthermore, there is a peak on Saturdays, which suggests that the contribution of non-working travels is high. This depends on both the tourism flow and the development of a large number of big shopping centres in the region.



Yearly open	Closed in winter
Aprica pass	Stelvio pass
Bernina pass	Forcola pass
Maloja pass	

Figure 22 The road network. Left: Sondrio; right: Lombardy region

7.2 Landslides

The most common definition for a landslide is made by Cruden (see *Cruden, 1991*): "*A landslide is the movement of a mass of rock, earth or debris down a slope.*" This simple definition avoids the complication of implying size, cause, rate or scale of movement. Because landslides are mostly 'secondary disasters' this phenomena receives little analytical, programmatic or media attention. But together with flooding it is the greatest cause of death of the hurricanes in the Americas.

All landslides have two things in common 1) they are the result of failure of the soil and rock materials that make up the hill slope and 2) they are driven by gravity. Movement occurs when the shear stress exceeds the shear strength of the material.

Landslides are events that occur in space and time. It is usually possible to identify both one or more landslide causes and one landslide trigger. The difference between the cause and the trigger is subtle, but important. Wieczorek (see *Wieczorek, 1996*) summarized the difference between the cause and trigger as: *"Landslides can have several causes, including geological, morphological, physical and human, but only one trigger*." The trigger is an external stimulus that produces an immediate change in the strength/stress relationships in the slope, resulting in movement. Landslide triggers are usually extreme natural events: earthquakes, volcanic eruptions, heavy rainfall, storms, and in some cases can occur through general instability with no significant trigger event.

- Several studies were conducted to determine the correlation between earthquakes and landslide occurrence, size and specific geological features (*Hancox et al., 1997; Keefer, 1984*). The studies found that it is should be possible to predict the size and location of landslides given the magnitude and location of the earthquake, the rock type, topography, and other geological data.

- The main trigger of the majority of the landslides is heavy or prolonged rainfall. Many attempts have made to establish relationships between rainfall and landslides. These relationships are based on the assumption that there exists a direct relationship between the occurrence of landslides and the quantity of rainfall. The important features in determining the potential for rainfall-induced landslides are the same as for landslides triggered by earthquakes, but instead of considering the seismicity of the area, the heavy rainfall potential needs to be assessed.

- If a slope is instable and high, it is possible a landslide can occur without a significant trigger event. An example is the Mount Cook landslide in New Zealand 1991. It is unclear if there was some unknown process acting within the landslide, or there was in fact a trigger which could not be determined caused the landslide.

7.2.1 Types of landslides

When a landslide is triggered, the material is transported down the slope by mechanisms including sliding, flowing, or falling. The movement varies from extremely slow (creeping) in landslides moving only millimetres per year to a sudden and extremely rapid (meters per second) avalanche or debris. The sudden and rapid movements are most dangerous because there is no warning time and because of the speed at which the landslide can travel down the slope and the impact of it. The run out distance of a landslide can vary between a few centimetres to many kilometres depending of the volume of soil travelled through the valley and can be classified into rock, predominantly course material (e.g. debris flow) or predominantly fine material (e.g. earth flow).

7.2.2 Magnitude of landslides

It is difficult to scale the magnitude, because it depends on several characteristics, such as volume, material type and nature, and extent of runout (see *Crozier, 1996*). The usefulness of the landslide susceptibility map depends on the maintenance of appropriate records indicating the magnitude and frequency of on-going landslide activity and its relationship with terrain and triggering conditions. Although it is still only possible to predict slope failure in most general terms and virtually impossible to forecast the location, magnitude and timing of specific future events, regional scale landslide risk studies could result in the identification of tracts of land with different levels of hazard and risk.

7.2.3 Landslide risk in Valtellina

The province of Sondrio is vulnerable for landslides. The most destructive and expensive landslide that occurred recently in Italy was the 1987 *Val Pola Rock Avalanche* (see Figure 23). About 40 millions m^3 of rock moved down the mountain into the valley where it blocked the Adda River. The landslide claimed 27 lives and a total cost of about 400 million Euros including destruction of villages, road closure, warning systems, the construction of permanent outlet tunnels and earth movements. The amount of total economic loss is not given. The landslide was triggered by heavy rainfall. About four times the average rainfall for the area felt in seven days, while the 0°C isotherm remained between 3500 and 4000 m a.s.l. causing rapid glacier melting. The Val Pola creek deeply eroded its valley flanks, and the eroded material caused debris flows which created a large alluvial fan damming the Adda River valley and causing formation of a shallow lake. The maximum avalanche deposit thickness was about 90 m in the valley.

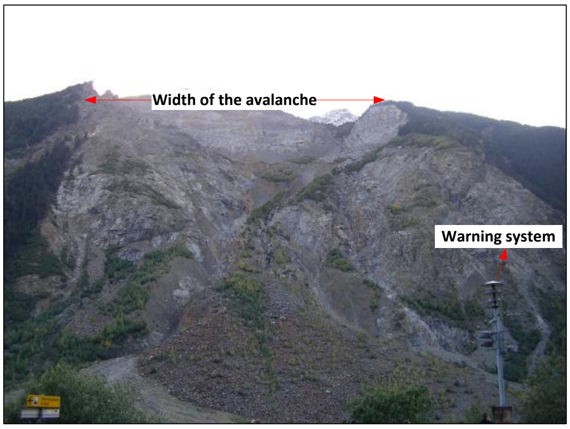


Figure 23 The Val Pola Rock Avalanche (photo taken during fieldwork Sep 2007)

The vulnerability of the Valtellina Valley is represented in a vulnerability map (see *GeoIFFINET , 2007*). Two vulnerable spots in the Valley are the road between Morbegno and Sondrio and the junction at Teglio. These two places will be used in the loss estimation as a result of a landslide (see annex 4).

Guzetti (see *Guzetti, 2000*) shows that 30 percent of the landslides, which occurred in Italy in the past, happened in the autumn. This can be explained because landslides can be triggered by heavy rain and autumn is a rainy season. The lowest value of recorded landslides, 5 percent, occurred in December (see annex 5).

7.3 Long-run equilibrium

The long-run equilibrium represents the economic situation before the unexpected event. The last step of the mode, the behaviour of firms and households is not taken into account, because the system reaches equilibrium and firms and households will not react. The indicator to estimate the economic loss is the increase of the transport costs as a result of a landslide that creates a disruption of the infrastructure.

1 Interaction matrix

The interaction matrix is based on the Input-Output table of the region and the geographical representation of the economic activities.

Input-Output table

The Input-Output table is based on the I-O table of Italy and with help of the economic data of Sondrio, the table is converted into a table for the region (see *Yamano and Ahmad,2006*) . The conversion of this table will not lead to the correct I-O table of the region, but it will serve as an indication (see annex 6).

The geographical representation of the activities

The five types of activities that are represented in the I-O table of the region are located in several places in the region. The region is divided in ten places where activities can take place. Two important places are Piantedo in the Southwest, and Aprica in the Southeast (see Figure 24). Both places play are role in manufacturing and services, Piantedo also in construction and Aprica in tourism. The vineyards for the wine are located on the terraces in the valley between Sondrio and Tirano. The ski resorts are located in the upper part of the region, especially in Alta Valtellina (Bormio and surroundings) and Chiesa in Valmalenco.

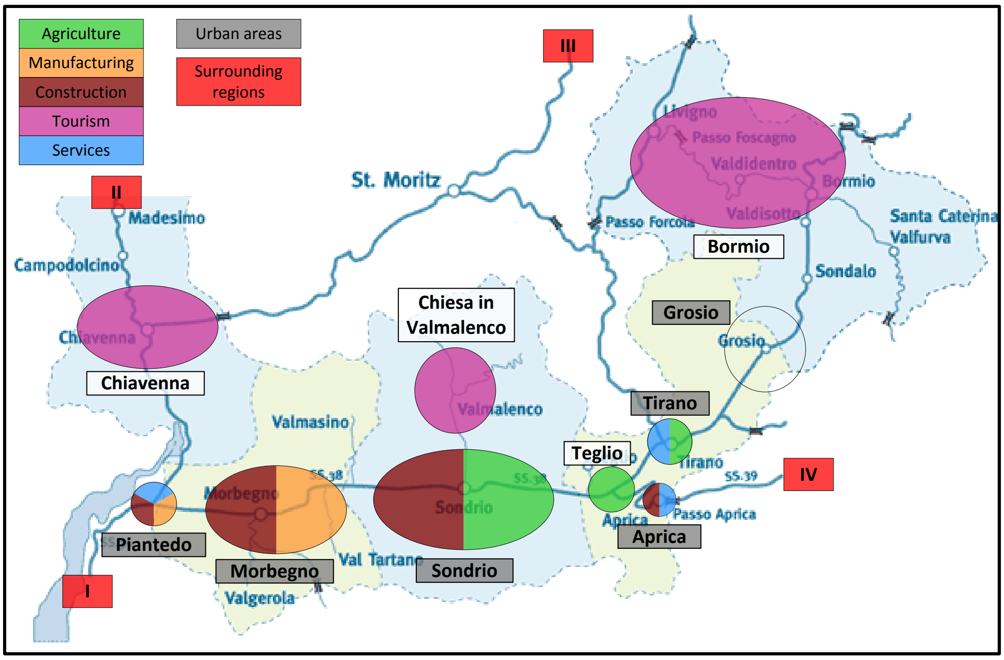


Figure 24 activities in Sondrio (size of circle represents surface of sub region

The populated areas in region are located in the valley, where more people live per sq km, the highest density of population is in Tirano with 147 persons/km^2. The density of population is used to calculate the amount of generated trips with the shopping or working motive.

The region's export and import is leaves and enters the region via four entrances, two two Switzerland (*II* and *III* in the figure above) and two to the rest of Italy (*I* and *IV* in the figure above). It is assumed that the tourists travel from region *II* and *III*, and that agriculture exports its products to *I*, because this is the common route from Milan to the Valtellina Valley. The route to region *IV* is less attractive for the export and import of the region. The output of construction and manufacturing is exported to and imported from all four regions.

Interaction matrix

The next step is to calculate the share of each place in an activity, e.g. what is the share of Chiavenna in the tourism sector. The share of a place in a certain sector depends on the density of companies that are active in that sector. By using the density of companies in a place the share of the smaller regions can be taken into account. It is possible that a large place with a lot of active companies can have a smaller share in the total output of a certain sector than a smaller place with less companies (see annex 7).

The interaction matrix for the intermediate production is calculated with help of the distribution function of the transport model and the total output and input of the each of the ten places in the region, the so called *trip ends*. It is assumed that the intermediate products are transported by car or truck and therefore the car is the only transport mode that is available. The distribution function is exponential and represents the willingness to travel against the transport costs, e.g. distance or travel time.

7.3.1 The transport network

The four steps of the transport model are determined with help of the program OmniTRANS[8]. Before the program can run the four steps, it needs input like a network with links and centroids, distribution functions for the modes that are available in the network and the trip ends. The trip ends in monetary transactions are estimated in the previous step and are used as the trip ends of the transport model. Because the capacity constraint of the roads cannot be used in this case, the monetary transactions (from now on 'the trips') will be assignment over 24 hours. A capacity constraint is useful when the trips are assigned dynamic over an hour or when the trips are expressed in Passenger Car Equivalents.

The Valtellina Valley is given as a network with ten centroids that represent the places where activities take place and four centroids that represent the import and export. The links between the centroids represent the infrastructure of the area and the lengths of the links are the distances between the centres of the places. The region has two transport modes, the roads for cars connect all centroids and the

[8] OmniTRANS is an Integrated Multi-Modal Transportation Planning Package

transit line for the train connects Piantedo with Tirano and intermediate places (see Figure 25) .

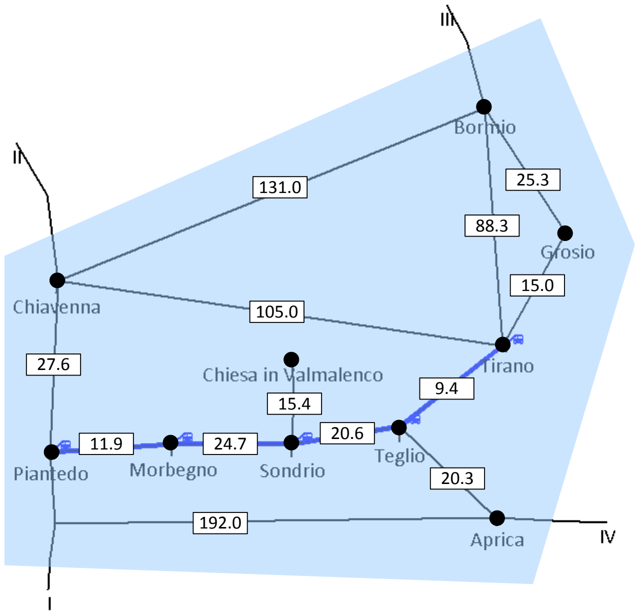


Figure 25 Schematic view of the infrastructure in Sondrio (with distances)

The distribution functions represent the willingness the travel a certain distance and are given as lognormal functions. It is assumed that the business trips, import and export do not depend on distance and therefore the distribution function of these motives is equal to 1. The other two motives, shopping and working, have the same distribution function for the car as the train and has a descending form according the lognormal function.

2 Trip generation

The shopping and tourism motives are combined, because both motives are based on the consumption of the Input-Output table.

The trips are classified in home-based trips and non-home-based trips. The trip ends of the working, tourism and shopping motive are home-based trips, which means that the trip production is the home end of the trip. The business trips, import and export are non-home-based trips, which means that trip production is the origin of the trip.

The production of the working and shopping motive is based on population density of the areas (centroids). Centroids with a high population density will have a higher production than centroids with a lower density.

The attraction of the working and shopping motive depends on the economic activity in the centroid. Places with a high economic activity will attract more people than places with a low economic activity.

In this case the trip ends for the business motive are determined in the first step of the model and are represented in the interaction matrix. The results for the long-run equilibrium are represented in the annexes (see annex 8).

3 Trip distribution & 4 Modal split

With help of the distribution functions the trips are distributed over the network. It is possible to set values of the matrix intrazonal diagonal (intrazonals) trips. These trips are made in the centroid and will not be assigned over the network. The outcome of the trip distribution of the business motive are the values of the intermediate consumption/production of the interaction matrix, i.e. how much money is transferred from one centroid to another (see annex 9)The trips with the shopping or working motive are distributed over the two transport modes. For shopping, about 25 percent of the trips is made by train and 75 percent by car, for working 30 and 70 percent, respectively.

5 Trip assignment

The last step is the assignment of the trips over the network. The trips are assigned according the All-Or-Nothing method, where the all trips choose the shortest path and the capacity of the road is not taken into consideration. This step assigns in total €22.754.350 over the network. This value includes all trips made in the network, the passenger as well as the tourism and consumption. The assignment specified for each motive are given in the annexes (see annex 10).

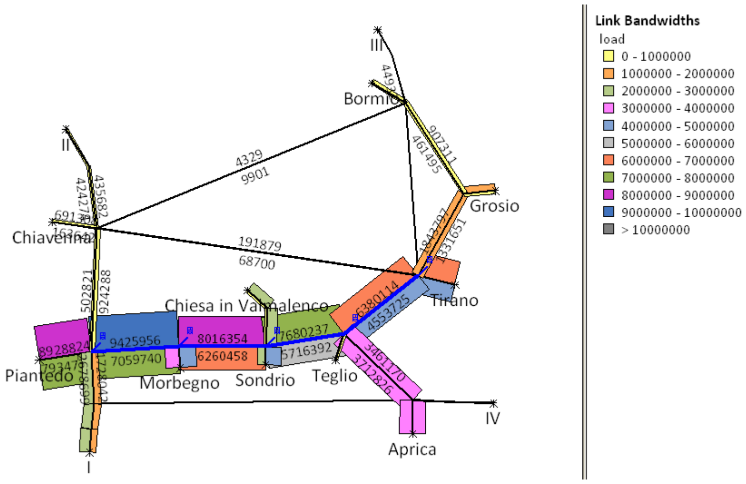


Figure 26 Assignment of all trips over the network (Euros/day)

6 Transport costs

The transport cost function for an activity are given as (see 6.1):

$$c_{ij}^{a} = f^{a} + \partial^{a} d_{ij} \tag{40}$$

In the long-run equilibrium, transport costs depend on the economic trend of the region and will not cause a sudden change in behaviour in the households or firms. In this case the transport costs are based on the distance between zone *i* and *j* and is for all activities the same (see annex 11).

7.4 Economic loss estimation of a disruption of the infrastructure

The study case assumes that a landslide is triggered in the region and causes besides direct damage a disruption of the infrastructure. The economic loss of the region includes a) the increase of the transport costs as a result of the increase in trip lengths and b) the decrease of the output of the economic sectors as a result of the decrease in inputs of the sectors (see chapter 1, Figure 2). The economic loss as a result of the landslide is estimated for two scenarios:

1) between Morbegno-Sondrio where the road is disrupted but the railway is intact
2) at the junction at Teglio where both the road and the railway are disrupted.

The loss estimation is calculated for a landslide that occurred in the month August, during the harvest of the grapes and the tourism season and (see Figure 27).

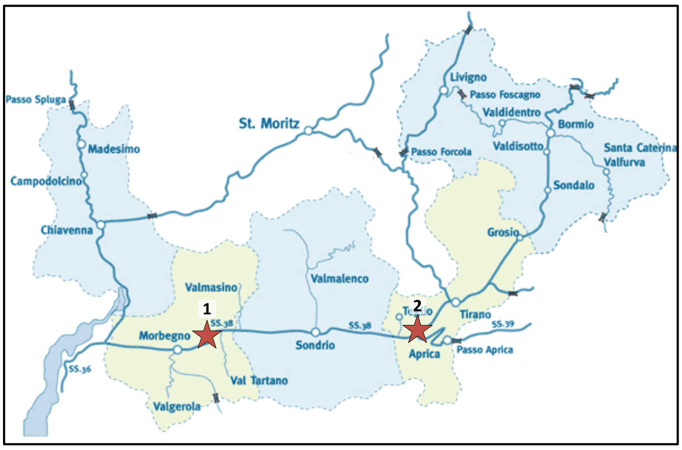


Figure 27 The two scenarios where the infrastructure is disrupted

7.4.1 Resilience of the system

The infrastructure will be totally disrupted on the location where the landslide occurs and will not have any capacity left. This means that on a micro level, the infrastructure does not have any resilience, and the trips that were assigned over this road will be diverted to the other existing roads. Resilience of the infrastructure on macro level includes the ability of the network to assign trips to other routes because of the disruption. In this case, the capacity of the network is not taken into account because the trips are assigned with the all-or-nothing method, which is not based on the capacity of the roads.

The economic activities of the region will react on the disruption, but business trips will remain the same as before the event. Tourism will decrease because fewer tourists will visit the region, and shopping trips will cause a shift in trip distribution, but the amount of trips will remain the same. commuter traffic will decrease, because this motive will avoid long distance trips (see Table 5).

Table 5 Consequences of the event on the infrastructure

		Level	
		Micro	Macro
Scenario	1	Road Morbegno-Sondrio cannot be used Train connection Morbegno-Sondrio remains intact	Other roads in the network have sufficient capacity to process the trips Train has sufficient capacity to process the trips
	2	Road Sondrio-Tirano cannot be used Road Aprica-Teglio remains open Train connection Sondrio-Tirano cannot be used	Other roads in the network have sufficient capacity to process the trips

7.4.2 Initial effect on the economy of a region

If the infrastructure is disrupted and the train connection is damaged, trips that used this road or transport mode will have to use another mode or route.

The share of the train in the model split increases because this mode is still intact in the first scenario. This means more people will use the train to travel between Piantedo and Morbegno.

The trip assignment in scenario 1 shows that the route via Switzerland (road Chiavenna -Tirano) is used to connect the Western and the Eastern part of the region (see Figure 28).

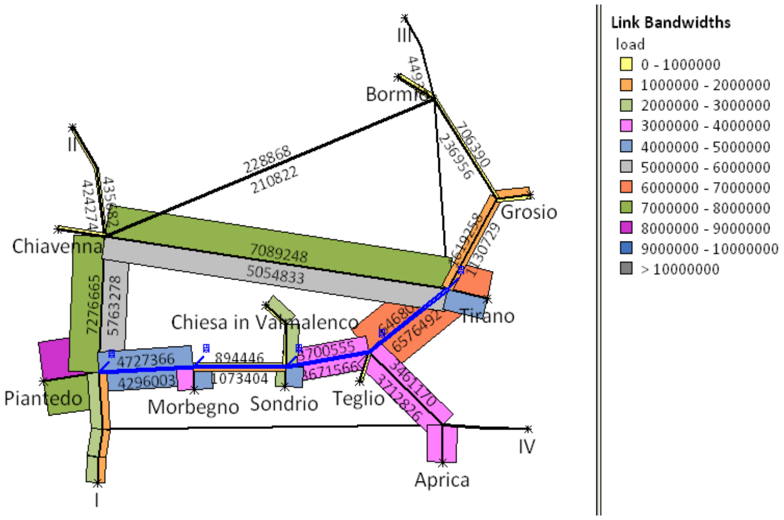


Figure 28 Trip assignment over the network, scenario 1, initial effect (Euros/day)

In the second scenario the connection between three economic important places, Sondrio, Tirano and Aprica is disrupted. Trips from Aprica need to make a large diversion to reach the other part of the valley (see Figure 29).

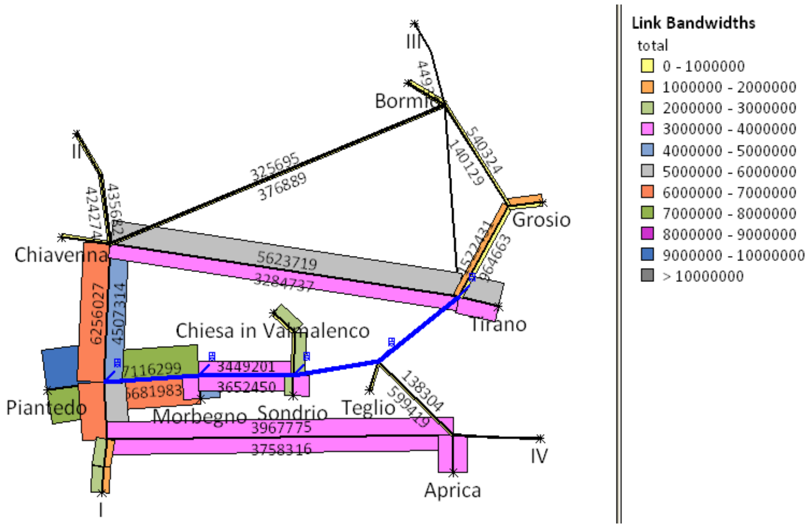


Figure 29 Trip assignment over the network, scenario 2, initial effect (Euros/day)

6 Transport costs

The disruption of the infrastructure results in larger trips lengths and thus higher travel costs (see annex 12). The travel costs are the variable part of the transport costs of a product or person, which means that an increase of X percent in travel costs results in an increase of X percent in transport costs. The increase of the transport costs after the initial effects are not estimated because the households and firms will react on this increase. This leads to new travel costs and transport costs of the products and persons.

Export and import are not taken into account because a small increase in the trip length will not cause great impact on the behaviour of households and firms.

7.4.3 First round effects on the economy of the region

The first round of the effects of the landslide starts with the behaviour of the firms and households as a reaction on the increase of the transport costs. The choices of the users of the system are filled in the transport model, which results in the transport costs after the first round of the effects.

7 Behaviour of households and firms

The households and firms will react on the increase of the transport costs though deciding not make the trip, choose another destination for their trip or another transport mode (see Table 6). This behaviour represents the resilience of the economy. It is assumed that the behaviour of the business trips is not influenced by the disruption.

Table 6 Reaction of the households and firms on an increase of transport costs

		Level	
		Micro	Macro
Scenario	1	Commuter traffic between Morbegno-Sondrio decreases Shift in destination of the shopping trips in Sondrio and Morbegno	The tourism – consumption relation decreases, because tourists will not visit the area Amount of business trips remains the same as before the disruption Amount of trips for export and import remains the same as before the disruption
	2	Commuter traffic between Tirano and Morbegno decreases Shift in destination of the shopping trips in Tirano, Aprica and Sondrio	The tourism – consumption relation decreases, because tourists will not visit the area Amount of business trips remains the same as before the disruption Amount of trips for export and import remains the same as before the disruption

An assumption is made for the behaviour of the households and firms. The effects on the four steps of the transport model are:

Trip generation

- The working motive is not willing to travel more than twice the distance it was before the event. If it is more, the trip will not be made. If the interruption takes more than one week the trips will be made again (see annex 13);
- The amount tourists that visit the region decreases 50 percent;

Trip distribution

- Shift in the distribution of trips with a shopping motive;

Modal split

- Transit mode is partly disrupted and cannot be used. The users of the transit mode with a working motive will not make their trip;

Trip assignment

- Road is disrupted and cannot be used. The trips will be diverted over the other roads

2 Trip generation

The amount of trips with the working motive decreases as a result of the disruption of the infrastructure. In the long-run situation about 3.6 million Euro/day was generated in both months, assumed that the commuter traffic does not depend on the season. In case of scenario 1 the trip generation decreases with 0.7 million Euro/day and in the second scenario the generation decreases with 1.3 million Euro/day. In the first scenario, when the connection between Morbegno and Sondrio is disturbed, the commuter traffic in the valley between Piantedo and Tirano decreases. In the second case, when the junction at Teglio is disturbed, the commuter traffic between Aprica, Tirano, Alta Valtellina and the valley where Sondrio and Morbegno are located decreases.

Because of the decrease of the tourism in the region, the trips with the shopping motive will decrease as well. In the first scenario, Alta Valtellina and Chiesa in Valmalenco are inaccessible which means that the tourists will not visit that area and the area will not have revenues in this sector. Although Chiavenna is still accessible, the tourism will decrease here as well because of the event. In the second scenario Alta Valtellina is inaccessible and will not have revenues in the tourism sector. The tourism in the other two areas will decrease as well. The trip generation of the working motive is different because the commuter traffic will not travel more than the twice their distance as before the event, which means that between certain trips will not be made in the first week after the event (see annex 14). The variations in the trip generation is given in the next table (see Table 7).

Table 7 Variation in the trip ends as a result of the behaviour of firms and households for trips with a shopping/tourism and working motive (in Euros/day)

	Long-run equilibrium	Scenario 1	Scenario 2
Shopping/Tourism	€ 7,8 million	€ 6,5 million	€ 7,4 million
Working	€ 3,6 million	€ 2,9 million	€ 2,4 million

3 Trip distribution & 4 modal split

The Origin/Destination matrix of the shopping/tourism motive changes as a result of the disruption of the infrastructure. The O/D matrices of the business, import, export remains the same as before the event. The first round effects cause a shift from the car to the train in the both scenarios, which means that more trips are made by train.

5 Trip assignment

The trips between Morbegno and Sondrio are the trips made by train. The car makes uses the route via Switzerland to connect the Eastern with the Western part of the Valtellina Valley (see Figure 30).

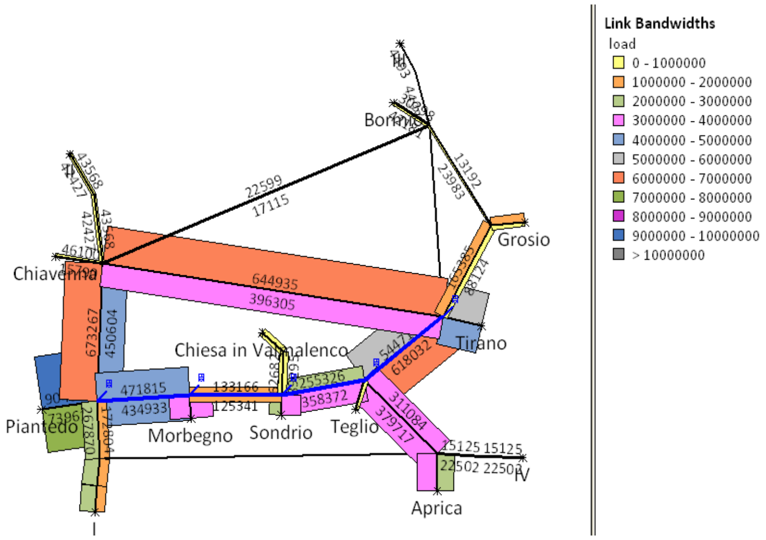


Figure 30 Trip assignment over the network, scenario 1, first round (Euros/day)

The trip assignment of the second scenario shows that the trips between Tirano, Aprica and Sondrio make use of the diversion (see Figure 31).

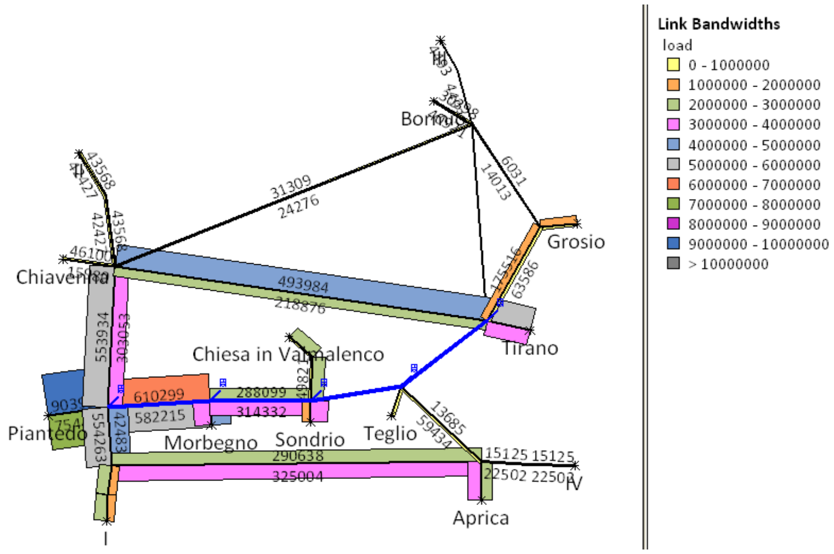


Figure 31 Trip assignment over the network, scenario 2, first round (Euros/day)

6 Transport costs

The transport costs of the first round effects are lower than the transport costs of the initial effects, because the gross output decreases as a result of the behaviour of firms and households. For commuter traffic and shopping trips, the trip length decreases back to the length they were in the long-run equilibrium. This can be declared because the makers of these trips reacted on the increase of the trip length by not making the trip or choosing another destination or transport mode. The length of the business trips remains the same as in the initial effects, because the makers of these trips did not react on the increase of the trip length.

7.5 Economic loss

The economic loss distinguished to activity *a* due to the disruption of the infrastructure is based on the loss function from 6.4.2:

$$L = (c_s - c_0) + (X_0 - X_s) \qquad (41)$$

Direct economic loss

The direct economic loss $(c_s - c_0)$ is the increase in the transport cost due to the disruption. The transport costs of an activity *a* are given as:

$$c_{ij,m}^{a} = {f_m}^{a} + {\partial_m}^{a} d_{ij,m} \qquad (42)$$

If f_s^a = f_0^a and ∂_s^a = ∂_0^a , the economic loss depends on the increase of the trip length d_{ij}. The increase of the transport costs for a trip with motive activity *a* is given as:

$$\Delta c_{ij}^{a} = {\partial_m}^{a}\left(d_{ij,m,s} - d_{ij,m,0}\right) \qquad (43)$$

The total economic loss is estimated by multiplying the increase in transport costs per trip with motive activity *a* with the amount of trips that are made between zone *i* and *j*:

$$ {L_{d,ij,m}}^{a} = {n_{ij,m}}^{a} \cdot \Delta c_{ij,m}^{a} \qquad (44)$$

Where

${L_{d,ij,m}}^{a}$	Direct economic loss of trip with activity a between *i* and *j* made with
${n_{ij,m}}^{a}$	Amount of vehicle trips with activity *a* between *i* and *j* made with mode *m*
${\partial_m}^{a}$	Transport costs per km for activity *a* with mode *m*

The amount of vehicles can be obtained with the amount of trips in monetary terms and parameter that represent the value of the goods and the amount of products in one vehicle:

$$ {n_{ij,m}}^{a} = \frac{{T_{ij,m}}^{a}}{g^{a}} \cdot \frac{1}{\beta_m {q_m}^{a}} \qquad (45)$$

Where

${T_{ij,m}}^{a}$	Trips in monetary terms of activity *a* between zone *i* and *j* (Euros)
g^a	Value of product *a* (Euros/product (tonnes), person)
${q_m}^a$	Amount of products in one vehicle of mode *m* (tonnes product,
β_m	Occupancy of one vehicle of mode *m* (%)

The total direct economic loss for activity *a* is:

$$ {L_d}^a = \sum_m \sum_{ij} {L_{d,ij,m}}^a \quad (46) $$

The total direct loss for the region per day is:

$$ L_d = \sum_a {L_d}^a \quad (47) $$

Values for the parameters for the Valtellina region are available, but are based on used parameters in the literature (see Table 8). They serve only to give an indication of the direct loss.

Table 8 Values for the parameters g^a, q^a, β and ∂^a

a	g^a	${q_c}^a$	β_c	${\partial_c}^a$	${q_t}^a$	β_t	${\partial_t}^a$
Business	700	5	60	7	-	-	-
Wages	20	5	30	2,5	1500	30	0,25
Consumption/Tourism	5	30	100	1,5	1500	20	0,25

The direct economic loss as a result of a disruption of the infrastructure is 2,6 million Euro per day in scenario 1 and 4,0 million Euro in scenario 2 (for specification, see Table 9).

Table 9 The direct economic loss per day during the disruption (in million Euro/day) for car and train

	Scenario 1 $L_{d,1}$	Scenario 2 $L_{d,2}$
Business	1,4	2,2
Wages	0,3	0,5
Consumption/Tourism	0,9	1,3
Total direct economic loss	**2,6**	**4,0**

Indirect economic loss

The indirect economic loss, L_{ind}, $(X_0 - X_s)$ is 1,7 million Euro per day for scenario 1, and 1,3 million Euro per day for scenario 2 (see Table 10).

Table 10 The indirect economic loss per day during the disruption (in million Euro/day) for car and train

	Long-run equilibrium	Scenario 1		Scenario 2	
	(X_0)	(X_1)	$L_{ind,2}$	(X_2)	$L_{ind,2}$
Business	8,4	8,4	0	8,4	0
Wages	3,3	2,9	0,4	2,4	0,9
Consumption/Tourism	7,8	6,5	1,3	7,4	0,4
Total indirect economic loss	19,5	17,8	**1,7**	18,2	**1,3**

Total economic loss

The economic loss as a result of a disruption of the infrastructure in the Valtellina valley is 3,4 million Euro per day in scenario 1 and 4,0 million Euro per day in scenario 2 (for specification, see Table 11).

Table 11 Total economic loss per day during the disruption of the infrastructure (in million Euro/day)

	Scenario 1			Scenario 2		
	Direct	Indirect	**Total**	Direct	Indirect	**Total**
Business	1,4	0	**1,4**	2,2	0	**2,2**
Wages	0,3	0,4	**0,7**	0,5	0,9	**1,4**
Consumption/Tourism	0,9	1,3	**2,2**	1,3	0,4	**1,7**
Total loss			**4,3**			**5,3**

7.6 Conclusions

The study case is used to illustrate the proposed method to estimate economic loss of a temporary disruption of the infrastructure that is caused by an unexpected event. Although the Input of the method, including the Input-Output table, distribution function and parameter to transform the monetary transactions in amount of PAEs, it gives an indication of the effects of a landslide in the region.

Economic loss is estimated for two scenarios where a landslide causes a disruption of the infrastructure. In the first scenario, the road between Piantedo and Morbegno is blocked, and in the second one, both, the road and rail track on the junction at Teglio are disrupted.

From the economic data the conclusion can be drawn that the valley of the area (Piantedo-Sondrio-Aprica-Tirano) is the main area where economic activities take place. A disruption of the infrastructure here will result in high losses to the economy of the region.

The economic loss of the temporary disruption of the infrastructure which is caused by a landslide is 4,3 million Euro per day of disruption in the first scenario and 5,3 million Euro per day of disruption in the second scenario. This means that the second location where the disruption took place is more vulnerable for the economy of the region.

To estimate economic loss of a region the following data is necessary:

- Input-Output table of the region
- Location of the activities
- Infrastructure with capacities and transport modes
- Parameters for the distribution function
- Value of the product (Euros/product)
- Amount of products in one vehicle (products/vehicle)
- Occupancy of the vehicle (%)
- Costs per km to transport a certain product

8 Conclusions and recommendations

This chapter gives the conclusions of the research and recommendations for future research.

8.1 Conclusions

This research contains an overview over the existing loss estimation models that are used in risk analysis and introduces a method to estimate the economic loss of a temporary disruption of a lifeline, in order to answer the problem statement:

> *What are the economic effects of a disruption of a lifeline and what is its influence on a region's economy?*

The proposed method is based on a transport and an economic model and is able to estimate the economic loss per day of a temporary disruption of the infrastructure. The conclusions of this research are presented by answering the research questions and comparing this research with the literature.

8.1.1 Research questions

What is the role of the infrastructure in a region and how can it been used in economic loss estimation?

The infrastructure makes it possible to transport freight and persons, which means that infrastructure connects economic activities in a region.

The classic four-step model is used in the loss estimation method, because of it classifies the four main decisions of a trip maker 1) will I make the trip 2)where to I go 3) how will I make the trip and 4) which route will I choose. These decisions are represented in trip generation, distribution, modal split and assignment, respectively.

The infrastructure plays a role in all these decisions, and a disruption of the infrastructure can influence all four steps of the transport model.

How can the economy of a region been described and how can it been used in loss estimation?

The economy of a region can be described with several methods, for example the Input-Output method and Computable General Equilibrium models. The Input-Output model describes the inter-industry links in a region and forms a good basis of loss estimation of a disruption of the infrastructure. The multipliers give a detailed industry-by-industry breakdown of the predicted effects of changes in final demand. The multipliers are used to describe the domino effect of a change in one variable upon others.

The output of the I-O matrix are (partly) transported over the network to go from the selling sector to the purchasing sector or consumer. A disruption of a lifeline, in this case the infrastructure, causes a disruption in the Input-Output matrix. This results in a decrease of the output, or an increase of the input of the sectors in a region.

How can the economic and transport model be integrated into a model that describes economic loss of the disruption of the infrastructure?

The resemblance between the Input-Output table of the economic model and the Origin-Destination matrix of the transport model makes it possible to integrate both systems. The I-O table is distributed over the network by using the classic four-step model. A disruption of the infrastructure results in higher transport costs because trip length increases which leads to a decrease in final demand because certain trips are not made during the disruption. Because the I-O table is distributed over the network, the losses can be distinguished to economic sectors.

8.1.2 Relation with the literature

- The literature focuses on direct economic loss from a disaster, for example loss of production of firms because they are destroyed. The proposed method focuses on economic loss of the disruption of a lifeline and includes losses of firms that use the disrupted lifeline. The estimation of the economic loss of a disruption of a lifeline means that the estimation of damage due to a disaster will be more accurate.
- The proposed method separates the transportation networks into several modes. The advantage of this distinction is that the disruption of one transportation line can cause a shift in modal split and can reduce economic loss. Furthermore, it gives a better representation of the transport costs in the region.
- The proposed method includes the personal trips: commuter traffic, tourism and shopping. These trips are influenced as well due to a disruption and these will cause losses as well. The method to estimate economic loss due to the disruption of the infrastructure includes in this way all trips with economic value.
- The proposed method distinguishes economic loss in direct loss which is the increase of the transport costs and indirect loss which is the decrease of final demand and gross output of the economic sectors in the region. The shift in final demand is the result of the decrease of the capacity of the transportation network.

Strengths and weaknesses of the method

The proposed method has several advantages and disadvantages with regards to the existing methods to estimate economic loss.

Strengths

- The form of the Input-Output table of the economic model is similar to the form of the Origin-Destination matrix of the transport model, which makes it possible to integrate the economic system in the transport model.
- The model gives insight in the value of the infrastructure through the distribution of the economic activities over the transport network. The value of the infrastructure can be used as a measure to define the vulnerable spots in the region.
- The initial effects of the unexpected event influence first the transport system of the region. The transport costs are estimated for each Origin-Destination pair and do not have to increase simultaneous for all trips in the region. This approach gives a better insight in the effects on the transport costs than the economic based methods.
- The behaviour of the firms and households is based on the transport costs and does not have to be similar in the whole region. It is possible that several firms and households will not react on the unexpected event because they do not use the specific road that is disturbed.
- The feedback between the economic and transport model makes it possible to estimate the higher order effects of the unexpected event, because the transport model reacts on the behaviour of the firms and households and the economic model on the transport costs.

Disadvantages

- The resilience of the infrastructure is not taken into account, because trips are given in monetary values and not in vehicles. This means that the transport costs that are calculated with the model can be underestimated.
- Travel delay is not taken into account, because the method is uses the All-Or-Nothing assigning method, which do not take into account the capacity of the roads and congestion.
- It is expensive to obtain an Input-Output table for a region. The accuracy of the output of the model depends on the I-O table and the conversion of another I-O table will not lead to the accurate results.
- It is assumed that the land-use of the region will not change as a result of the unexpected event, but the land-use depends on the duration and location of the disruption.
- The model assumes that the gravity point of an economic activity is located in the centre of that area, but it is better to define the gravity point with help of the location and size of the firms with the same activity.
- The transport costs assumed to be linear with the length of the trip, while this is a non-linear relationship in reality.

8.2 Recommendations

The recommendations contain future research of the weaknesses of the method and studies to validate the method.

- Application of the Computable General Equilibrium (CGE) model. The CGE model is based on the Input-Output method, but takes more economic factors into account by including social data.
- Further research to the relationship between the transport costs per km and the distance of the trip. This research assumes a linear relation between the costs and the distance, but in reality this relationship is not linear. Furthermore, the transport costs function contains a distance from where the transport costs do not influence the behaviour of the firms and households is unclear at this moment and need to be defined.
- Further research to the total economic loss of the disruption of a lifeline including the time period after the reconstruction of the lifeline. In this research, trips that are postponed until the disruption is solved are taken into account as loss, while in the total damage estimation, where the period after the reconstruction is taken into account, these trips are seen as benefit after the reconstruction. This means that the total damage of the disruption is overestimated in this research. With help of for example a Cost-Benefit analysis, the total damage of a disruption can be estimated.
- The validation of the method needs to be executed by comparing the results of this method with measured economic loss.
- Further research to the resilience factors of the infrastructure and economy. The resilience of the economy includes for example the stock of raw products to produce the final product of the firm. If the trips are expressed in vehicles it is possible to estimate the intensity/capacity ratios of the roads and is it possible to integrate travel delay in economic loss estimation.

GLOSSARY

Circular flow	Movement of money in an economy: a model of the economy in which money moves in one direction and flows of real resources move in the other. It is a simplified illustration of basically three flows: the flow of incomes to households from businesses, the flow of resources to businesses from households, and the flow of government expenditures to business and households.
Direct (economic) loss	The direct economic loss is the direct change of production and demand due to the disruption of a lifeline due to an unexpected event.
Economic distance	The length a trip may be before transport costs exceed the value of the freight. Because of lower unit transport costs, a small, valuable commodity can be transported profitably further than a bulky commodity of the same value.
(Economic) loss	With *economic loss* is meant the sum of the direct and indirect economic loss of a region due to a disruption of the infrastructure. The economic loss is measured in Euros/day.
Final demand	The final part of the output produced by each sector is allocated to the final demand, such as consumption, investments or exports. The final demand are supplies labour and capital back to the productive industries.
First round effect	The first round effect is the economic loss that is estimated with the modified interaction matrix.
Indirect (economic) loss	The indirect economic loss is the change in other sectors by a change of a sector based on inter-industry relationships.

Initial effect	The initial effect is the economic loss that is estimated with the interaction matrix of before the unscheduled event.
Interaction matrix	A matrix that represents the interactions between the subregions in the region (in Euro/day).
Inter-industry relationship	The relationship between the industries in a region.
Intermediate demand	The delivery is the input in another process and will be processed further in another firm.
Higher order effects	The economic loss that follows after the first round effects, until the loss is negligible and the system reaches a temporary 'equilibrium' where the economic loss is constant until the infrastructure is reconstructed.
Landslide	The movement of a mass of rock, earth or debris down a slope (see *Cruden, 1991*)
Leontief inverse	$B = (I - A)^{-1}$ is the Leontief inverse, or multiplier matrix. *I* is the identity matrix (matrix with "1" in diagonal, "0" in all other fields), and A is the matrix of direct coefficients a_{ij}
Lifeline	Uutilities that have a crucial role in sustaining social and economic systems and because of their network characteristics, lifelines are especially vulnerable to disruption. Examples are : pipelines, infrastructure, electricity.
Long-run equilibrium	represents the situation before the unscheduled event. The firms and households will not change their behaviour, which means that the interaction matrix will not change.

Resilience	The ability of individuals, markets, and the economy as a whole to continue functioning when shocked by a disaster (see *Rose, 2004*).
Short-run equilibrium	Represents the temporary 'equilibrium' between the disruption and the reconstruction of the infrastructure, in the situation that the higher order effects are negligible and economic loss is a constant value per day.
Temporary disruption	The infrastructure is damaged for a certain period of time, but can be repaired. The disruption does not cause a change in the land-use of the region.
Transport costs	a monetary measure of what the transport provider must pay to produce transportation services (see *Rodrigue et al., 2006*)
Trip ends	Total number of trips originating in zone i (O_i) or the total number of trips attracted to zone *j* (D_j).
Unscheduled event	are, unpredictable regarding time, place and magnitude. Examples are: landslides, earthquakes, accidents or construction failure.

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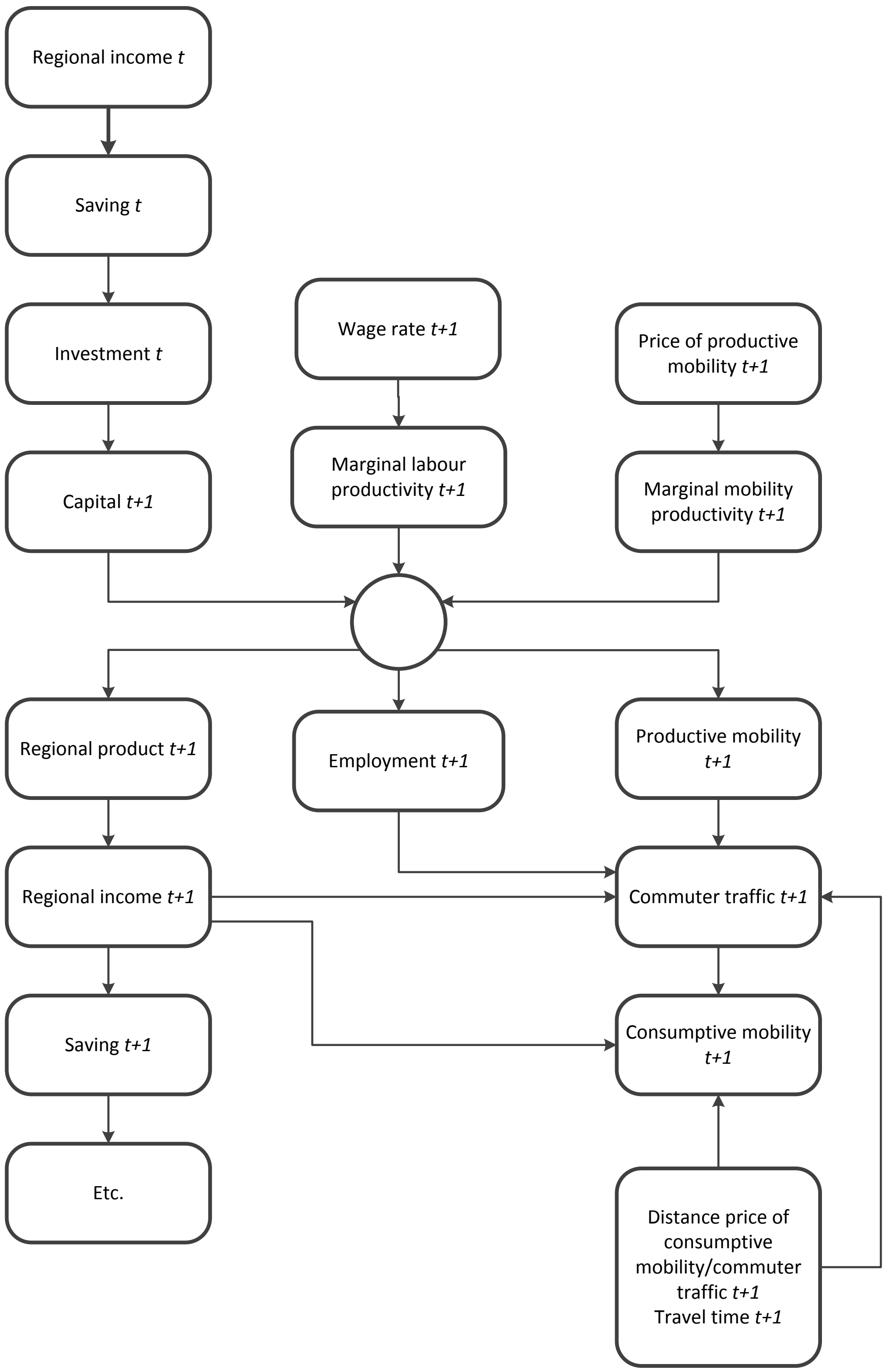
ANNEXES

1 NUMBER OF REPORTED DISASTERS (IFRC, 2006)

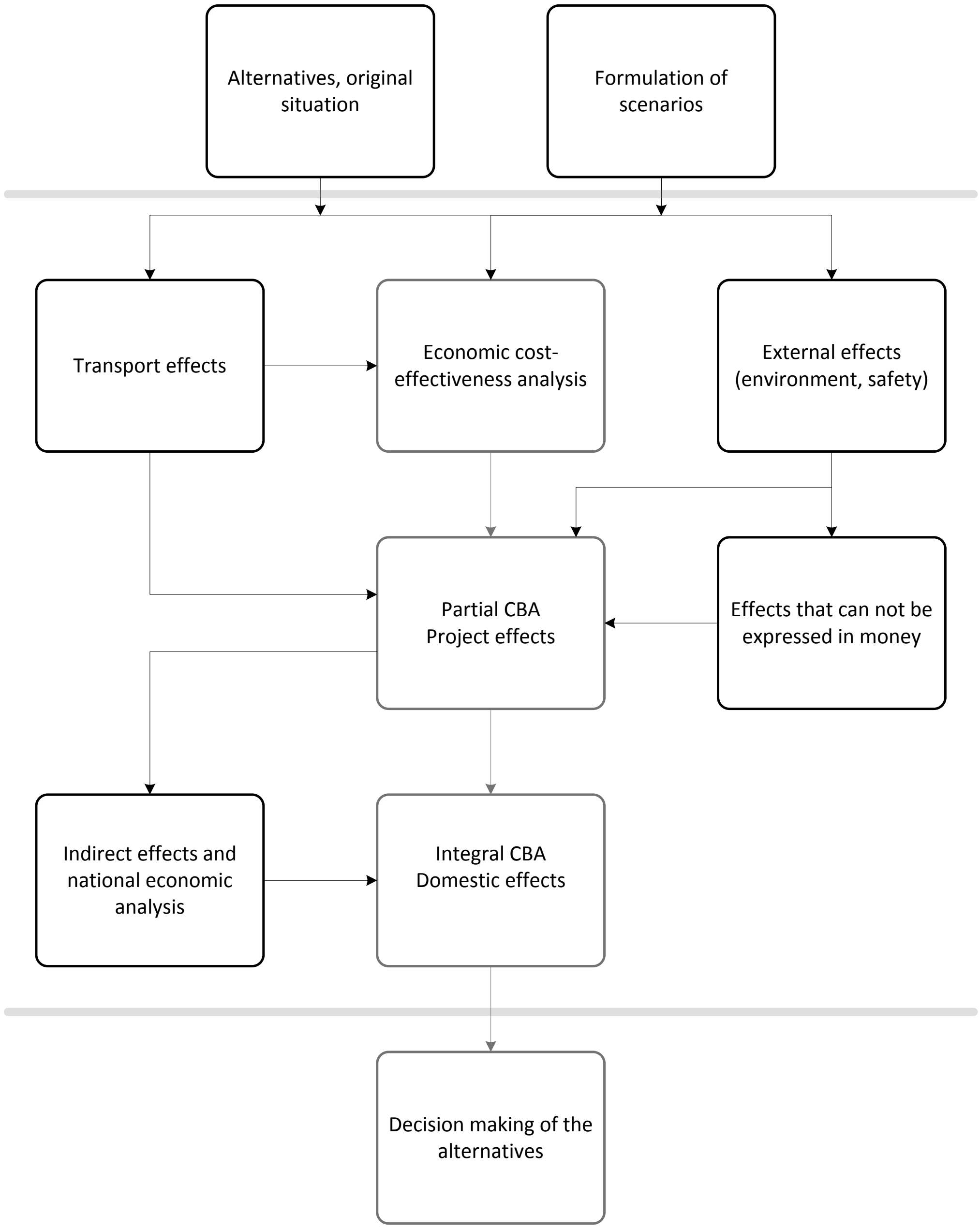
The number of reported disasters and the amount of estimated damage

Disaster type	**Number of reported disasters 1996-2005**	**Amount of estimated damage in millions of US dollars (2005**
Avalanches/landslides	191	1,382
Droughts/famines	300	29,156
Earthquakes/tsunamis	297	113,181
Extreme temperatures	168	16,197
Floods	1,310	208,434
Forest/scrub fires	158	29,186
Other natural disasters	25	142
Volcanic eruptions	50	59
Windstorms	917	319,208
total	**3416**	**716,945**

2 MOBILEC MODEL

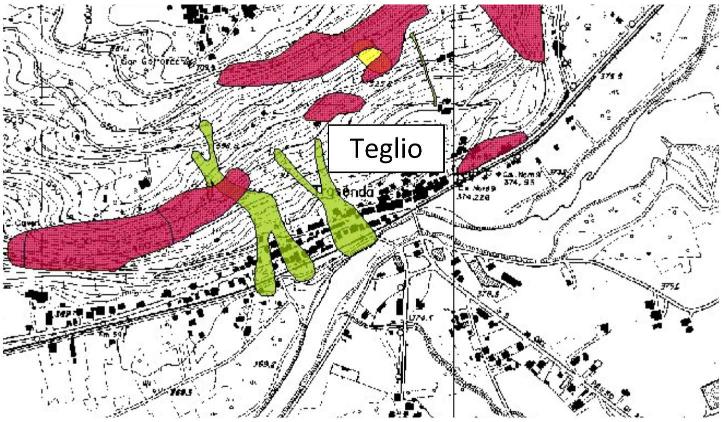


3 COST-BENEFIT ANALYSIS

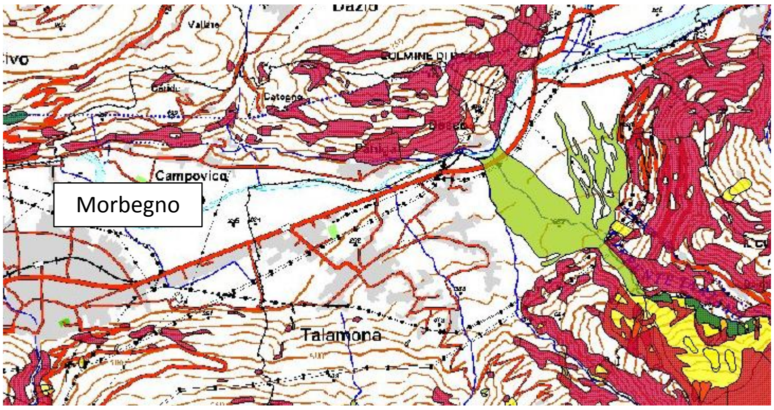


4 THE VULNERABLE LOCATIONS IN THE VALLEY.

1 The junction at Teglio



2 The road between Morbegno and Sondrio

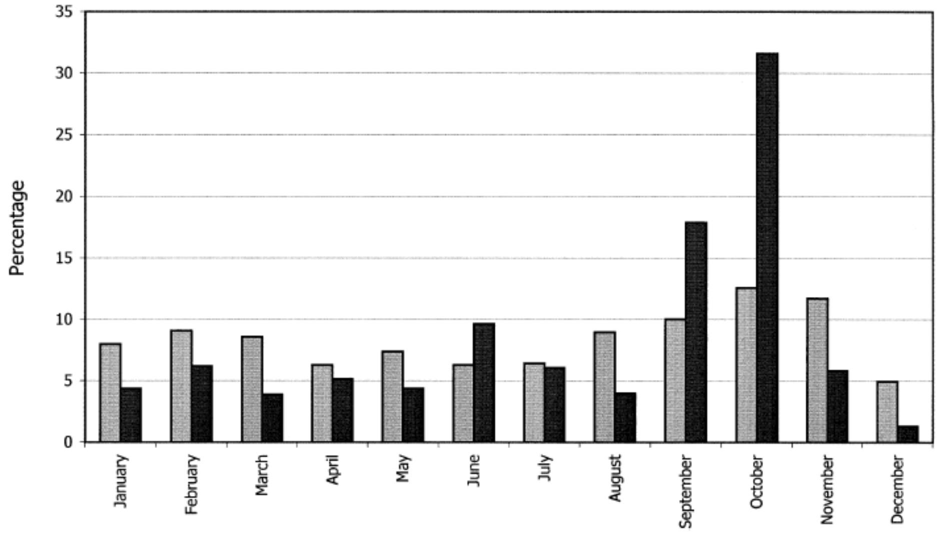


Green: fast flow (debris)

Red: vulnerable area for rock fall/toppling

5 MONTHLY DISTRIBUTION OF LANDSLIDE EVENTS

The monthly distribution of landslide events that resulted in dead or missing people in Italy from 1410 to 1999. Grey: number of events; Black: deaths or missing people.



6 THE INPUT-OUTPUT TABLE OF SONDRIO

The Input-Output table of Sondrio in 2000 in million Euros

		Purchasing sector						Final demand		
		agriculture	manufacturing	construction	tourism	services	**total**	consumption	export	total production
Selling sector	agriculture	5,6	74,3	16,2	14,6	1,6	112,4	38,5	32,8	183,6
	manufacturing	4,1	554,0	135,7	93,3	155,9	943,0	421,0	397,6	1761,6
	construction	1,1	56,5	128,5	11,5	61,9	259,6	62,3	0,0	321,9
	tourism	0,0	7,1	3,0	0,6	19,6	30,5	174,6	0,0	205,1
	services	7,2	388,5	99,4	58,7	792,1	1345,9	1695,0	81,8	3122,7
	total	18,1	1080,5	382,8	178,7	1031,2	**2691,2**	***2391,5***	***512,1***	
	import	22,4	223,2	74,1	41,0	67,9	***428,6***	92,1		
	labour	10,9	338,6	102,2	95,9	777,5	***1325,1***			
	total consumption	51,4	1642,3	559,2	315,6	1876,6				

7 SHARE OF THE REGIONS IN THE ACTIVITIES

Import and export (percentages)

		Activity				
		Agriculture	Manufacturing	Construction	Tourism	Services
Centroid	I	90	75	90		90
	II		20		80	
	III				20	
	IV	10	5	10		10
total		**100**	**100**	**100**	**100**	**100**

Business, shopping and working motive (percentages)

	agriculture	manufacturing	construction	tourism	services	consumption/ wages
Chiavenna	7	8	6	**12**	4	8
Piantedo	7	**41**	**16**	1	**19**	**13**
Morbegno	8	**13**	**12**	7	4	**11**
Chiesa in Valmalenco	2	3	6	**47**	3	7
Sondrio	**20**	7	**14**	1	9	**12**
Teglio	**11**	5	7	4	11	7
Aprica	9	1	**14**	0	**18**	**10**
Tirano	**26**	11	12	7	**23**	**16**
Grosio	4	7	5	3	1	**9**
Bormio	6	3	10	**16**	8	7
Total	**100**	**100**	**100**	**100**	**100**	**100**

8 TRIP GENERATION LONG-RUN EQUILIBRIUM

*1000 Euro	production					attraction				
Centroid	*work*	*business*	*shopping*	*import*	*export*	*work*	*business*	*shopping*	*import*	*export*
Chiavenna	0	40	0	0	0	42	98	230	18	0
Piantedo	696	3343	1499	0	904	1463	4027	2400	584	0
Morbegno	545	739	1175	0	258	278	1105	309	187	0
Ch. in Valmalenco	0	157	0		0	165	383	902	70	
Sondrio	636	597	1371		128	83	344	195	75	
Teglio	0	230	0		67	6	18	79	12	
Aprica	535	1236	1154		66	708	1177	1435	106	
Tirano	804	1954	1733		246	830	1173	1969	99	
Grosio	415	0	893		0	0	0	0	0	
Bormio	0	157	0		0	56	130	307	24	
I				864						1339
II				212						218
III				22						0
IV				76						113
total	**3630**	**8454**	**7826**	**1174**	**1670**	**3630**	**8454**	**7826**	**1174**	**1670**

The colours of total trip ends for a motive in the table with the trip ends match with the interaction matrix need to match the totals of the interaction matrix that is represented below.

1000 Euro/day (August)				
INTERMEDIATE			FINAL DEMAND	
	1 ... 10	**TOTAL**	**Consumption (shop) C**	**Export X**
1 ... 10				
TOTAL		**8454**	**7826**	**1670**
Wages (work) W		**3630**		
Import M		**1174**		

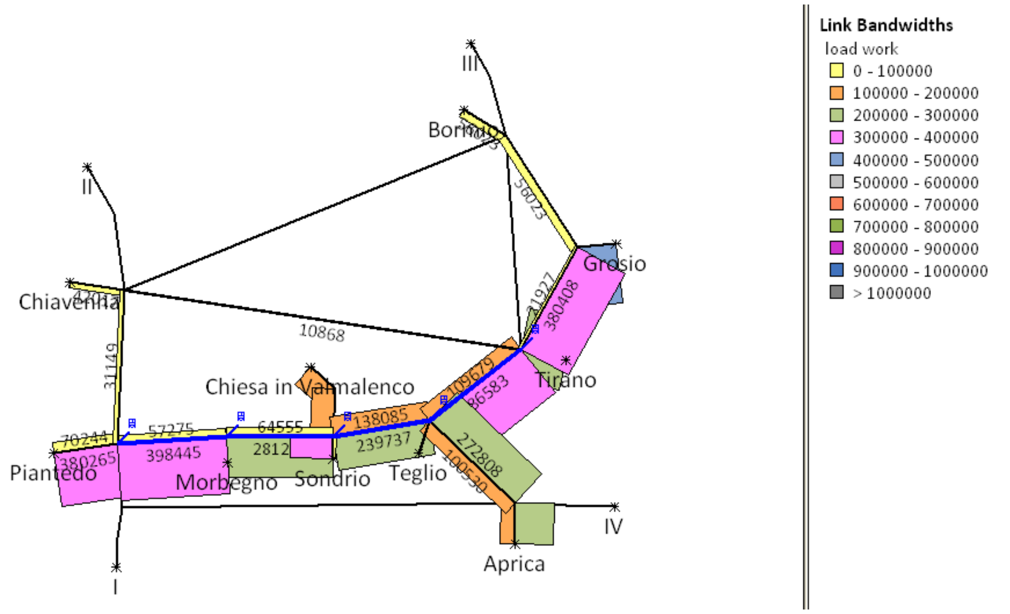
9 INTERACTION MATRIX OF LONG-RUN EQUILIBRIUM

1000 Euro/day													
INTERMEDIATE PRODUCTION/CONSUMPTION												FINAL DEMAND	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Σ**	**C**	**X**
1	0	19	5	2	2	0	6	6	0	1	***40***	*0*	*0*
2	39	1592	437	152	136	7	465	464	0	52	***3.343***	*1.499*	*904*
3	9	352	97	34	30	2	103	103	0	11	***739***	*1.175*	*258*
4	2	75	21	7	6	0	22	22	0	2	***157***	*0*	*0*
5	7	284	78	27	24	1	83	83	0	9	***596***	*1.371*	*128*
6	3	110	30	10	9	0	32	32	0	4	***230***	*0*	*67*
7	14	589	162	56	50	3	172	171	0	19	***1.236***	*1.154*	*66*
8	23	931	255	89	79	4	272	271	0	30	***1.954***	*1.733*	*246*
9	0	0	0	0	0	0	0	0	0	0	***0***	*893*	*0*
10	2	75	21	7	6	0	22	22	0	2	***157***	*0*	*0*
Σ	***98***	***4.027***	***1.105***	***383***	***344***	***18***	***1.177***	***1.173***	***0***	***130***	**8.454**	**7.826**	**1.670**
W	*0*	*696*	*545*	*0*	*636*	*0*	*535*	*804*	*415*	*0*	**3.630**		
M	*18*	*584*	*187*	*70*	*75*	*12*	*106*	*99*	*0*	*24*	**1.174**		

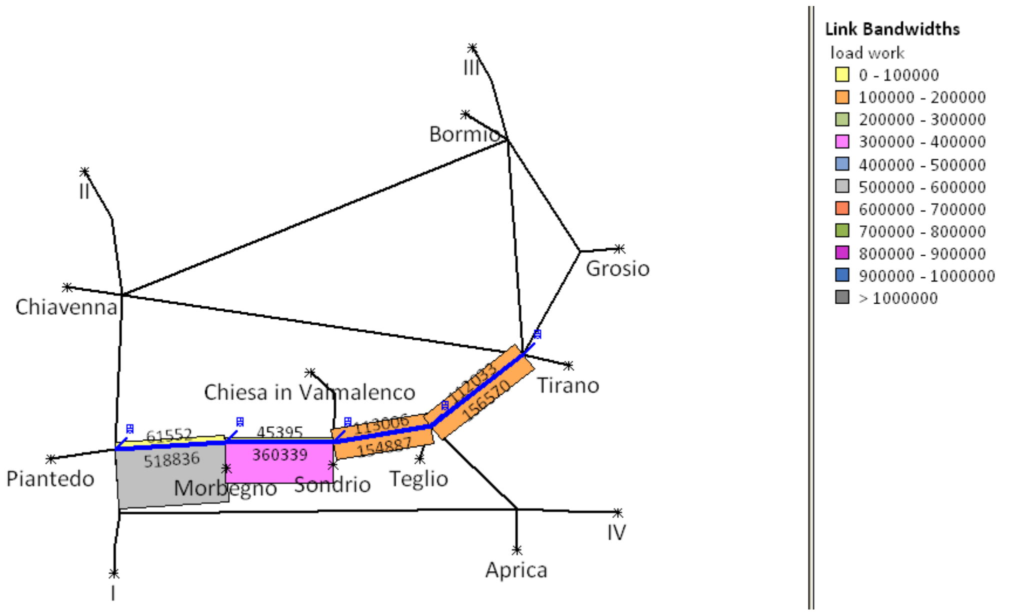
10 Trip assignment long-run equilibrium

Working motive

Trips made by car

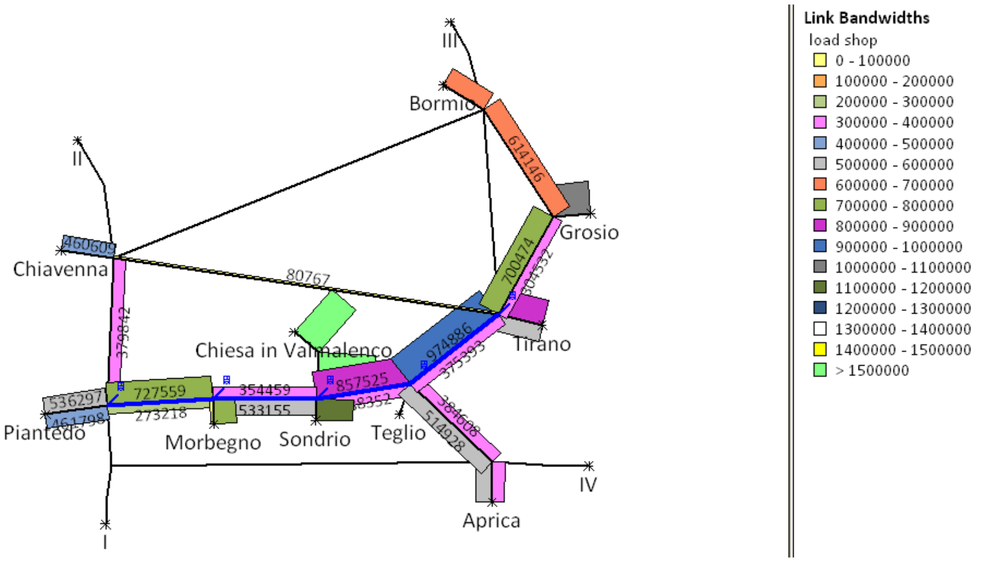


Trips made by train

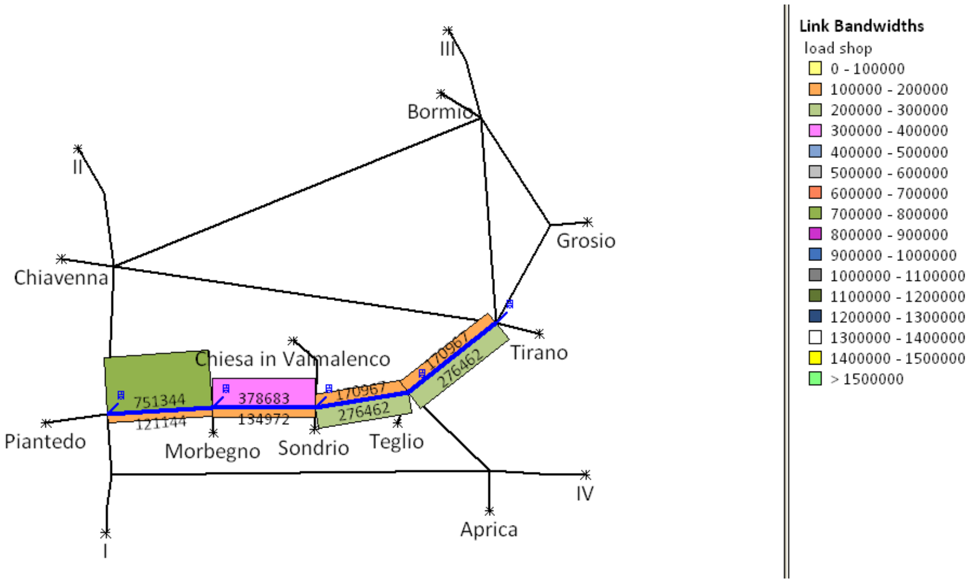


Shopping motive

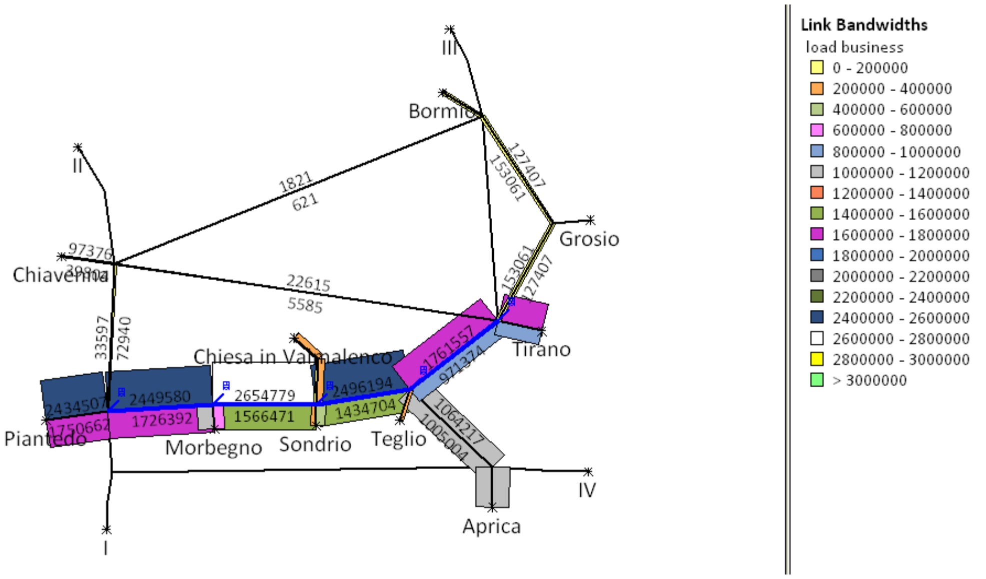
Trips made by car



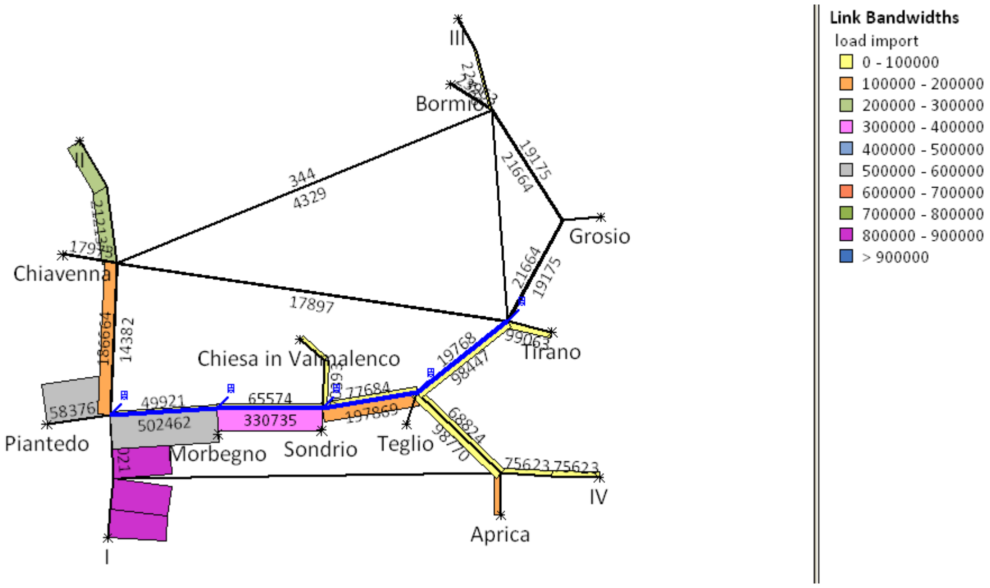
Trips made by train



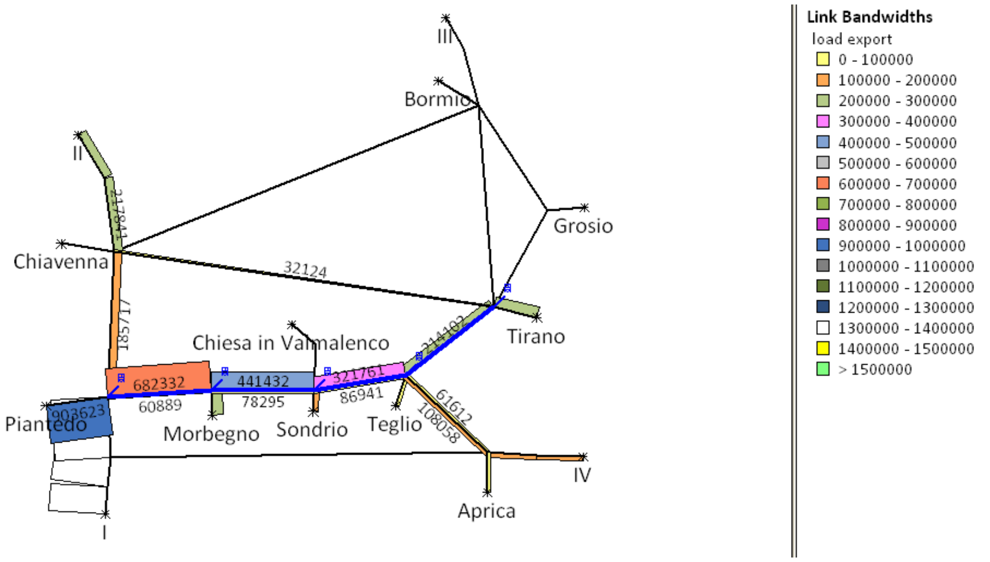
Business motive



Import



Export


III
Bormio
II
Grosio
Chiavenna
32124
Tirano
Chiesa in Valmalenco
682332
441432
321761
60889
78295
86941
903623
Piantedo
Morbegno
Sondrio
Teglio
61612
108058
IV
Aprica
I
Link Bandwidths
load export
0 - 100000
100000 - 200000
200000 - 300000
300000 - 400000
400000 - 500000
500000 - 600000
600000 - 700000
700000 - 800000
800000 - 900000
900000 - 1000000
1000000 - 1100000
1100000 - 1200000
1200000 - 1300000
1300000 - 1400000
1400000 - 1500000
> 1500000

11 DISTANCES BETWEEN THE SUB REGIONS

Distance d_{ij} between zone *i* and *j* (in km)

	1	2	3	4	5	6	7	8	9	10
1	-	27,6	39,5	79,6	64,2	84,8	105,1	94,2	109,2	131,0
2	27,6	-	11,9	52,0	36,6	57,2	77,5	66,6	81,6	106,9
3	39,5	11,9	-	40,1	24,7	45,3	65,6	54,7	69,7	95,0
4	79,6	52,0	40,1	-	15,4	36,0	56,3	45,4	60,4	85,7
5	64,2	36,6	24,7	15,4	-	20,6	40,9	30,0	45,0	70,3
6	84,8	57,2	45,3	36,0	20,6	-	20,3	9,4	24,4	49,7
7	105,1	77,5	65,6	56,3	40,9	20,3	-	29,7	44,7	70,0
8	94,2	66,6	54,7	45,4	30,0	9,4	29,7	-	15,0	40,3
9	109,2	81,6	69,7	60,4	45,0	24,4	44,7	15,0	-	25,3
10	131,0	106,9	95,0	85,7	70,3	49,7	70,0	40,3	25,3	-

12 DISTANCES BETWEEN THE SUB REGIONS AFTER THE EVENT

Distance d_{ij} between zone *i* and *j* (in km)

Scenario 1

	1	2	3	4	5	6	7	8	9	10
1	-	27,6	39,5	150,4	135,0	114,4	134,7	105,0	120,0	131,0
2	27,6	-	11,9	178,0	162,6	142,0	162,3	132,6	147,6	158,6
3	39,5	11,9	-	189,9	174,5	153,9	174,2	144,5	159,5	170,5
4	150,4	178,0	189,9	-	15,4	36,0	56,3	45,4	60,4	85,7
5	135,0	162,6	174,5	15,4	-	20,6	40,9	30,0	45,0	70,3
6	114,4	142,0	153,9	36,0	20,6	-	20,3	9,4	24,4	49,7
7	134,7	162,3	174,2	56,3	40,9	20,3	-	29,7	44,7	70,0
8	105,0	132,6	144,5	45,4	30,0	9,4	29,7	-	15,0	40,3
9	120,0	147,6	159,5	60,4	45,0	24,4	44,7	15,0	-	25,3
10	131,0	158,6	170,5	85,7	70,3	49,7	70,0	40,3	25,3	-

Scenario 2

	1	2	3	4	5	6	7	8	9	10
1	-	27,6	39,5	79,6	64,2	239,9	219,6	105,0	120,0	131,0
2	27,6	-	11,9	52,0	36,6	212,3	192,0	132,6	147,6	158,6
3	39,5	11,9	-	40,1	24,7	224,2	203,9	144,5	159,5	170,5
4	79,6	52,0	40,1	-	15,4	264,3	244,0	184,6	199,6	210,6
5	64,2	36,6	24,7	15,4	-	248,9	228,6	169,2	184,2	195,2
6	239,9	212,3	224,2	264,3	248,9	-	20,3	344,9	359,9	370,9
7	219,6	192,0	203,9	244,0	228,6	20,3	-	324,6	339,6	350,6
8	105,0	132,6	144,5	184,6	169,2	344,9	324,6	-	15,0	40,3
9	120,0	147,6	159,5	199,6	184,2	359,9	339,6	15,0	-	25,3
10	131,0	158,6	170,5	210,6	195,2	370,9	350,6	40,3	25,3	-

13 RATIO LENGTH OF THE O-D MATRIX

Scenario 1

Ratio length of route in long-run equilibrium/scenario 1

		Destination									
		1	2	3	4	5	6	7	8	9	10
Origin	1					>2					
	2				>2	>2	>2	>2	>2		
	3				>2	>2	>2	>2	>2	>2	
	4		>2	>2							
	5	>2	>2	>2							
	6		>2	>2							
	7		>2	>2							
	8		>2	>2							
	9			>2							
	10										

Scenario 2

Ratio length of route in long-run equilibrium/scenario 2

		Destination									
		1	2	3	4	5	6	7	8	9	10
Origin	1						>2	>2			
	2						>2	>2	>2		
	3						>2	>2	>2	>2	
	4						>2	>2	>2	>2	>2
	5						>2	>2	>2	>2	>2
	6	>2	>2	>2	>2	>2			>2	>2	>2
	7	>2	>2	>2	>2	>2			>2	>2	>2
	8		>2	>2	>2	>2	>2	>2	>2		
	9			>2	>2	>2	>2	>2			
	10				>2	>2	>2	>2			

14 O/D MATRIX WORK MOTIVE

Scenario 1

		Destination										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**total**
Origin	**1**	0	13	8	0	0	0	3	5	6	0	**35**
	2	0	564	395	0	0	0	0	0	50	0	**1009**
	3	0	72	80	0	0	0	0	0	0	0	**151**
	4	0	0	0	0	79	0	14	27	25	0	**145**
	5	0	0	0	0	39	0	3	20	6	0	**68**
	6	0	0	0	0	1	0	0	3	1	0	**5**
	7	0	0	0	0	52	0	435	109	90	0	**686**
	8	0	0	0	0	119	0	42	427	191	0	**779**
	9	0	0	0	0	0	0	0	0	0	0	**0**
	10	0	1	1	0	4	0	4	12	34	0	**56**
	total	**0**	**649**	**484**	**0**	**294**	**0**	**502**	**603**	**403**	**0**	**2934**

Scenario 2

		Destination										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**total**
Origin	**1**	0	13	8	0	7	0	0	6	6	0	**40**
	2	0	564	395	0	263	0	0	0	91	0	**1312**
	3	0	72	80	0	72	0	0	0	0	0	**223**
	4	0	8	12	0	79	0	0	0	0	0	**99**
	5	0	6	9	0	43	0	0	0	0	0	**58**
	6	0	0	0	0	0	0	0	0	0	0	**0**
	7	0	0	0	0	0	0	435	0	0	0	**435**
	8	0	0	0	0	0	0	0	0	191	0	**191**
	9	0	0	0	0	0	0	0	0	0	0	**0**
	10	0	1	2	0	0	0	0	12	34	0	**50**
	total	**0**	**664**	**505**	**0**	**464**	**0**	**435**	**18**	**322**	**0**	**2408**