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Cascading effects
What are they, and how do they affect society?

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Executive Summary

This lesson is based on the CascEff deliverable "A report on the role of the media in the information flows that emerge during crisis situations" (Reilly and Atanasova 2016[D3.4]). It reorganises the content of that document for individual users, instructors, educators, and educational institutions that wish to engage in a learning session about the news media during crisis situations with cascading effects. It helps learners to consider and understand main areas of change in communication dynamics and information flows during crises, in order to influence the behaviour of disaster-affected populations and improve disaster management in general.

Therefore, the general aim of the first lesson is to help learners to understand the roles and dynamics of mediated communication related to disasters, and to reflect on how institutions and organisations can approach the news media for a successful management of crises. By the end of the course, students should be able to:

1) explain the role of news media in information flows that emerge during stages of cascading disasters, and in particular:
2) describe the positive and negative effects of news media coverage upon the behaviour of citizens and communities that are vulnerable to cascading disasters;
3) explain how social media can supplement pre-existing media strategies deployed during stages of disasters;
4) identify the information flows between key stakeholders (including professional journalists, emergency managers and members of the public), that can inform a collaborative model of decision-making in pre and post disaster stages, and help build situational awareness during crisis situations.

In order to achieve these aims, this lesson explores the role of traditional media in disasters in general, and its changes over time, and it links to issues of citizen engagement and the role of emotions during crises. The lesson also explores the role of traditional media during the different stages of a disaster, and within the wider informative flows that can shape communication at those times. Therefore, this part of the lesson also links to issues related to social media. It then explains the importance of context in evaluating media role, by focusing on three case studies and analysing their information flows and media role (Floods in England, Project X Haren, Pukkelpop). The conclusive part of the lesson brings together the issues considered in the form of a summative discussion of main areas of change in media and emergency management.

1 Cascading effects – what are they and how do they affect society?

1.1 Introduction

Many systems in society that provide us with fundamental functions and services, such as power supply, transportation, health care and communication systems, have become increasingly interconnected. While this growing dependency between different societal functions has given rise to more efficient services, it has also introduced new types of vulnerabilities. In particular, these mutual dependencies (also called interdependencies) between different systems mean that a failure in one system may cascade to other systems, giving rise to overall consequences which may be more severe than those associated with the initially affected system alone. In order to improve the emergency response to incidents involving cascading effects, knowledge and understanding of the way cascading effects propagate between different systems in society, and how these types of events give rise to negative consequences, are crucial. This lesson summarises findings drawn from analyses of past events involving cascading effects and the intended learning outcomes (ILOs) are:

- to increase understanding about what cascading effects are;
- to give an overview of how past events involving cascading effects can be studied (through document analysis);
- to increase understanding about what can be learned about past events involving cascading effects, and specifically, how cascading effects can affect society.

In the first section, cascading effects are conceptually described. In the following sections, knowledge gained by analysing 40 previous large-scale events around the world that involved cascading effects are presented. Finally, conclusions drawn from these analyses are presented.

1.2 What are cascading effects?

Broadly speaking, cascading effects are the effects arising when an incident affecting one system or function in society propagates to another system or function, due to a dependency between them. More specifically, cascading effects are here defined in the following way.

Cascading effects refer to the impacts of an initiating event where:

1. System dependencies lead to impacts propagating to other systems, and;
2. The combined impacts of the propagated event are of greater consequences than the root impacts, and;
3. Multiple stakeholders and/or responders are involved.

A simple example can be used to explain the main features of this definition. First of all, an initiating event of some sort must occur that affects one or several systems. This initiating event may for example be a fire in a power station. While this event in itself may result in direct economic consequences and impacts on the power system, it does not per se give rise to cascading effects unless other systems or functions are affected by the degraded function of the power system. However, when the fire in the power station in the end causes failures in railway transport, it is clear that cascading effects have occurred. This is due to the existence of a dependency between the power system and the railway system (first part of the definition), here in form of the railway systems dependence of the power system for its traction power. The combined impacts of the consequences arising in the two systems are clearly greater than the impacts of the initial fire itself, for example resulting in trains not arriving on time, etc. (second part of the definition). Finally, in order to manage this type of event, it is not sufficient with first responders extinguishing the fire, but also infrastructure providers' ability to manage the consequences arising in the power system and the transport system. In this way, multiple stakeholders and responders are involved, which is highlighted in the definition above (third part of the definition). This example can be presented in a more generic form by using Figure 1.1 below.

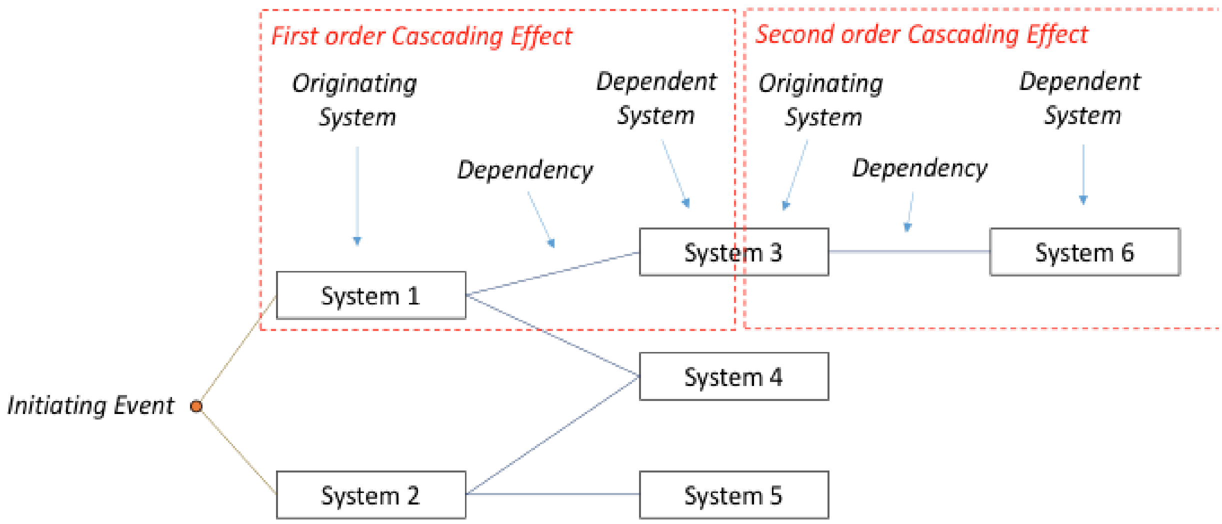

Figure 1.1. Conceptual model of the propagation of effects between systems in an incident that involves cascading effects.

In Figure 1.1, it can be seen that an initiating event may affect one or several systems (System 1 and System 2). These are referred to as the originating systems. This event could be, for example, a natural event such as an earthquake, an accidental event such as an explosion, or an internal system failure such as malfunctioning of a technical component Due to dependencies to other systems, cascading effects may arise when impacts arise in other systems (Systems 3, 4, and 5). Returning to the example above, the initiating event may be a fire in a power station happening in the Power system (the originating system called System 1 in the figure). Cascading effects arise due to a dependency between the Power system and the Railway system (the dependent system called System 3 in the figure). If this impacted system gives rise to additional impacts to other system, there is a continuation of the cascading effect. The first resulting effects from directly impacted systems from the initiating event to dependent systems are defined as "first-order cascading effects". If this line of propagation continues, second, third, etc. order cascading effects arise.

Discussion points

- Can you think about any event that matches the definition of cascading effects?
- How did impact propagate from one system to another in this event?
- What was the initiating event?
- What stakeholders were involved in the response to the event?

Central to the above conceptual model is the ability to delineate systems and system boundaries. Here we are utilizing the categorization of different types of societal functions into sectors that exist in most countries, e.g. the health care sector or transport sector, to represent a system. These sectors are normally governed by governmental sector authorities and with their specific regulations. This way of defining systems, and associated boundaries, is a practical way of addressing the issue of what constitutes a system. Here we define a total of 22 different types of systems, which together should be considered to cover all types of necessary societal functions in a society. In Table 1.1 the full list of systems used in the CascEff study are given.

Table 1.1. System categories and how they are demarcated in the CascEff project.

Categories	No.	Description and exemplification
Power Supply	1	Activities and assets that ensure continuous supply of electric power from suppliers to customers, e.g. production, transmission and distribution of electric power.
Telecommunication	2	Activities and assets that ensure electronic communication of information over significant distances, e.g. landline and mobile phone systems, Internet, servers, etc.
Water supply	3	Activities and assets that ensure continuous supply of water from suppliers to customers, including pipes, pumps, water treatment plants, infiltration areas, etc.
Sewage	4	Activities and assets that collect and treat wastewater and day water, such as treatment plants, drain pipes, etc.
Oil and gas	5	Activities and assets that ensure continuous supply of oil and gas products, e.g. production, distribution and processing of oil and gas.
District heating	6	Activities and assets that ensure continuous supply of hot water for heating houses and premises, e.g. heating plants, pumping stations, water pipes.
Health care	7	Activities and assets that provide professional services to people in order to achieve or sustain mental and physical well-being and prevent illness and impaired health, e.g. emergency care, primary care, elderly care, child care, medicine distribution and production, disease control, etc.
Education	8	Activities and assets that contribute to a formalised transfer of knowledge, e.g. primary school, secondary school, universities, etc.
Road transportation	9	Activities and assets that enable transportation of people and goods on roads, e.g. road networks, bridges, tunnels, road maintenance activities, etc.
Rail transportation	10	Activities and assets that enable transportation of people and goods on railways, e.g. railway networks, subways, trams, signal systems, maintenance activities, etc.
Air transportation	11	Activities and assets that enable transportation of people and goods by airplane, e.g. airport operations, air traffic control, airspace security, etc.

Sea transportation	12	Activities and assets that enable transportation of people and goods by sea, lake and waterways, e.g. port operations, shipping industry, etc.
Agriculture	13	Activities and assets related to the cultivation of animals and plants in order to support e.g. food, biofuel and medical production, farming, livestock, etc.
Business and industry	14	Activities and assets that enable the production and exchange of goods and services to customers. Activities and assets covered in other categories are excluded here.
Media	15	Activities and assets that enable the dissemination of news and other information in society, e.g. radio, television, newspaper, social media, etc.
Financial	16	Activities and assets related to the continuous provision of economic services performed by the financial industry, e.g. insurance, cash availability, central banking system, credit cards, etc.
Governmental	17	Activities and assets that enable the provision of governmental/public services at local, regional and national levels, e.g. municipal government, county administration and national agencies. Activities and assets that are covered in other system categories are not included here.
Emergency response	18	Activities and assets that are necessary to respond to acute events where human life and health, environment or property is threatened, e.g. rescue services (land, sea, etc.), police, ambulances, emergency care, national guard, etc.
The public	19	People in a society or a community and their ability to live a normal life where they have continuous access to the services that characterise a modern society
Environment	20	Flora (i.e. all types of plants), fauna (all type of animals) and the ecosystems which they inhabit, e.g. sea, ocean, forest, etc.
Political	21	The political leadership on local, regional and national level
Food supply	22	Activities and assets that are necessary to produce and distribute food to people, e.g. food producers, wholesaler, food inspections

In the conceptual model presented in Figure 1.1, a number of concepts are introduced. These concepts deserve further explanation, and can be applied to the systems presented in Table 1.1, see textbox below.

Discussion points

- Think about the event you discussed above – what systems from Table 1.1 were affected by this event?
- How many orders of cascading effects did the event include?

Defining key terms

Initiating event (initiator) - the first in a sequence of natural (e.g. flood), accidental (e.g. fire) or intentional (e.g. bombing) events that may affect one or several systems.

Originating system - a system from which a failure propagates to another system.

Dependent system - a system which is negatively affected by a failure in another system.

Impacted system - a system which is negatively affected by either an initiating event, or an event affecting an originating system.

Dependency - mechanism whereby a state change in one system can affect the state of another system.

Interdependency - a mutual dependency between two systems, i.e. system A is dependent on system B and vice versa.

Incident - a chain of events affecting multiple systems.

Cascade order - the number of stages in a propagation from a directly impacted system to a particular system that is impacted indirectly.

Impact - the extent to which a system is affected due to an initiating event or due to a dependency.

Conditions - circumstances that can enable, prevent, aggravate or mitigate dependencies and impacts.

2 Studying past events involving cascading effects

As mentioned in the introduction, an important way of improving the response to incidents involving cascading effects is to learn from such events that have occurred in the past, which is facilitated by using a structured approach for collecting and analysing data. This section briefly describes the method used for collecting and analysing data from past events involving cascading effects in order to facilitate understanding of the results. Data is here collected from written material in terms of official reports, investigations or media reports. However, the approach can prove fruitful for guiding and providing structure for also gathering and analysing data from other sources such as interview studies or surveys.

The method is based on the key concepts and the conceptual model described in the previous sections. The purpose of the method is to enable systematic descriptions of key characteristics of cascading effects in past events among a broad variety of societal actors constituting the different systems. Further, the method also supports describing circumstances that affected how the cascading effect developed, termed mitigating or aggravating conditions. These types of conditions play an important role as they enable the extrapolation and generalization of the findings from one context to another, which is important in order for knowledge of past events to be useful as decision support in future events. These descriptive accounts can then be used to analyse cascading effects, both by analysing individual events involving cascading effects and by analysing general patterns across different events. The results from such analyses can then e.g. be used for predictive analyses and/or integrated in decision support tools.

The method consists of carrying out three different steps with respect to the identification of cascading effects. The three main steps of the method are:

Step 1 – Identify Impacted Systems

Step 2 – Describe Dependency Impacts

Step 3 – Describe System Impacts.

Each step of the method is briefly described in the following sections. It should be noted, however, that the three steps are typically performed using an iterative approach, meaning that when an impacted system has been identified (Step 1) this is followed by describing Dependency (Step 2) and System Impacts (Step 3) for this system before returning to Step 1 and identifying additional impacted systems.

2.1 Step 1 – Identify impacted systems

The first step of the method constitutes identifying systems that have been impacted, either by the initiating event or through dependencies to one or several originating systems, which have been impacted in an earlier cascade order. In addition, systems that could have been impacted due to some specific and traceable conditions are also identified, i.e. keeping track of potential effects.

A single system may be influenced several times as it can be affected in several different stages of an event. For example, a certain system could be affected directly by the initiating event; but also indirectly through cascading effects due to a dependency to another system. The impacts might also be very diverse, for example a system may be struck by one type of impact on short-term but another type of impact on long-term, or having one type of impact locally and another type of impact nationally. Hence, when there are different dependencies leading to different impacts for a given system, Dependency and System impacts (Steps 2-3) will be described several times for that system. In practice, this step (and the following) are conducted for each system.

2.2 Step 2 – Describe Dependency Impacts

The second step of the method is to describe the Dependency Impact for each impacted system with the purpose to get an understanding of how, and to what extent, a system is exposed to strain when a system on which it depends has been impacted. If there are multiple dependencies that affect a system, as is the case for system 4 in Figure 1.2 (which for example would be the case when a combined failure in both rail and road transportation gives rise to a severe impact on fuel distribution), the dependency impacts are described separately. The impact is described from four different perspectives.

Dependency consequences are used to describe the type of and the magnitude of the consequences due to the dependency (or dependencies). **Dependency characteristics** contribute to the understanding of the nature and mechanism of the dependencies. This in turn may be important for decision-making at a strategic level when considering how to respond to or manage events that involve or may involve cascading effects. **Dependency conditions** are Conditions that significantly either aggravate or mitigate impacts in order to be able to generalise the information gathered and to extrapolate it to other contexts. For example, if the same event would occur during another time of the year; is it likely that it will lead to similar types of impacts or will it be more or less serious? **Dependency Impact Level** is a measure of the extent of the dependency impact. It is, admittedly, to some extent a rough judgment made by the analyst, but it is argued to be useful when subsequently analysing and modelling cascading effects. For example, in order to get a sense of whether a relatively small system impact in one system gives rise to very large subsequent dependency impacts on other systems; or whether a rather small dependency impact may give rise to large system impacts for some systems.

2.3 Step 3 – Describe System Impacts

The third step of the method is to describe the System Impact for each impacted system which refers to effects on the impacted system due to one or several Dependency Impacts and taking the impacted system's inherent coping capacity into consideration. The difference between Dependency Impacts and System Impacts is that the Dependency Impact describes the direct exposure, e.g. two water pumps in the water distribution system were flooded due to a failure in the power system. System Impact, then, describes how the system subsequently is impacted by this exposure, e.g. the water distribution system was redundant which only led to some minor issues with low water pressure, or on the other extreme, that it led to complete system collapse. Similar to Step 2, the impact is described from four different perspectives.

System consequences are used to describe the type of and the magnitude of the system consequences. This is done using the same consequence categories and procedure as described for characterising dependency consequences.

System consequence characteristics describe aspects of the consequences that contribute to a better understanding of the nature of the system impacts.

In addition to conditions that affect the Dependency Impacts, there are also **System conditions** that can aggravate or mitigate the System Impacts, i.e. circumstances that, if they change, would give rise to different System Impacts although the Dependency Impacts were the same. For example, looking at the water distribution example again, the system impacts due failure of two water pumps could be larger if there was a high demand on the water distribution system at the time of the failure occurrence (e.g. summertime, during hours of high industrial production, etc.).

The **System Impact Level** is a measure of the impacts on what the system aims to accomplish, i.e. related to the descriptions of the systems as presented in Table 1.1. The System Impact Level will, similar to the estimation of the Dependency Impact Level, generally be a rough judgment made by the analyst, but it is considered to be useful when subsequently analysing and modelling cascading effects.

2.4 Which past events involving cascading events can be interesting to learn from?

The method briefly outlined above (and more thoroughly described in CascEff Deliverable D2.1 and D2.2) has been used by researchers in the CascEff project to analyse large-scale past events around the world involving cascading effects. The events were selected with the aim of obtaining a great variety of cascading effects in terms of many different types of dependencies, systems, initiating events, etc. These events are presented in Table 1.2, and results from analyses of these events are presented in Chapter 1.5.

Table 1.1 List of selected case studies.

No.	Short name	Continent	Country	Year	Initiating event
1	Auckland	Oceania	New Zealand	1998	Power outage
2	Tieto	Europe	Sweden	2011	IT-event
3	UK floods	Europe	UK	2007	Flooding
4	Enschede	Europe	Netherlands	2000	Explosion
5	London bombings	Europe	UK	2005	Terrorism
6	Mont Blanc	Europe	Switzerland; France	1999	Fire
7	Sandy	North America	US; Canada; Jamaica; Haiti; Dominican Republic; Bahamas; Cuba; Puerto Rico; Bermuda	2012	Hurricane
8	Eyjafjallagökull	Europe	Island	2010	Volcano eruption
9	Malmö floods	Europe	Sweden	2014	Flooding
10	Myyrmanni bombing	Europe	Finland	2002	Terrorism
11	Kista blackout	Europe	Sweden	2001	Power outage
12	Östersund	Europe	Sweden	2010-2011	Contaminated water supply
13	Baltimore	North America	USA	2001	Tunnel Fire
14	L'Aquila	Europe	Italy	2009	Earthquake
15	European blackout	Europe	Germany; France; Belgium; Netherlands; Italy; Spain	2006	Power outage
16	Ice storm North America	North America	Canada; USA	1998	Ice storm
17	Philadelphia strike	North America	USA	2009	Strike
18	Russian heat wave	Asia	Russia	2010	Heat wave
19	Colorado floods	North America	USA	2013	Flooding
20	Buenos Aires blackout	South America	Argentina	1999	Power outage
21	Los Frailos Tailings	Europe	Spain	1998	Dam rupture
22	Greece Wild Fire	Europe	Greece	2006	Wildfire
23	Earthquake Umbria and Marche	Europe	Italy	1997	Earthquake
24	New Mexico cold snap	North America	USA	2011	Cold snap
25	UK fuel crisis	Europe	UK	2000	Fuel shortage
26	Darwin blackout	Oceania	Australia	2014	Blackout

No.	Short name	Continent	Country	Year	Initiating event
27	Oslo blackout	Europe	Norway	2007	Power outage
28	Warrnambool exchange fire	Oceania	Australia	2012	Fire
29	Philadelphia pipe rupture	North America	USA	2013	Water pipe rupture
30	Boston pipe rupture	North America	USA	2010	Water pipe rupture
31	Pinatubo eruption	Asia	Philippines	1991	Volcano eruption
32	Puyehue eruption	South America	Argentina	2011	Volcano eruption
33	Maui pipeline outage	Oceania	New Zealand	2011	Landslide
34	Kyrill	Europe	German; Poland; Austria; Czech Republic	2007	Storm
35	European heatwave	Europe	France; UK; Netherlands; Portugal; Spain; Italy; Germany; Switzerland; Austria	2003	Heatwave
36	Buncefield fire	Europe	UK	2005	Fire
37	Chinese milk scandal	Asia	China	2008	Food contamination
38	Balkan flooding	Europe	Serbia; Croatia; Bosnia and Herzegovina	2014	Flooding
39	Catalonia droughts	Europe	Spain	2007-2009	Drought
40	Varanus Island explosion	Oceania	Australia	2008	Explosion

3 Learnings on cascading effects from past events

This section presents the results from analyses of the 40 past events involving cascading effects presented in Table 1.2. It should be noted that further insights can be drawn by employing other methods to analyse the data or be utilized for predictive modelling efforts, however here we aim at giving an exemplification of type of insights that can be gained at a more general level and the type of collected data. In this section, we present some summarised information about the data and examples of insights that can be gained.

Discussion points

- Think about the event you discussed above: what information would be valuable in order to improve the capacity to manage a similar event in the future?

3.1 Between which systems do cascading effects occur?

From the detailed analysis of the 40 events involving cascading effects, propagation of effects from one system to another were identified 428 times. About half of these are from an initiating event to a first order impacts and the rest cascading effects of different orders between systems.

In Figure 1.4, all Originators (Initiating event or Originating system) are given on the y-axis and Dependencies (Impacted system) are given on the x-axis. The size of the circle represents the relative frequency of cascading effects between the systems. From the figure, it is clear that the two most frequent cascading effects in the analysed events are Power supply to Business & Industry and Power supply to Public. It can also be noted that Power supply is often represented as an originating system (since this system is represented many times along the row corresponding to the Power supply on the y-axis) and seldom as a dependent system (since this system is represented only a relatively few times along the column corresponding to the Power supply on the x-axis). Further, the Public is often represented as a dependent system (i.e. the public is impacted in most of the events) but it is also shown that quite frequently behaviour of the Public has an impact on the functioning of other systems (such as overloading telecommunication towers in the case of emergencies). From Figure 1.4 it can also be concluded that many cascading effects are *not* represented in the data in the database, which can be explained by the fact that either there are no such relationships between real-life systems, or a sufficient number of cases has not been analysed to identify them.

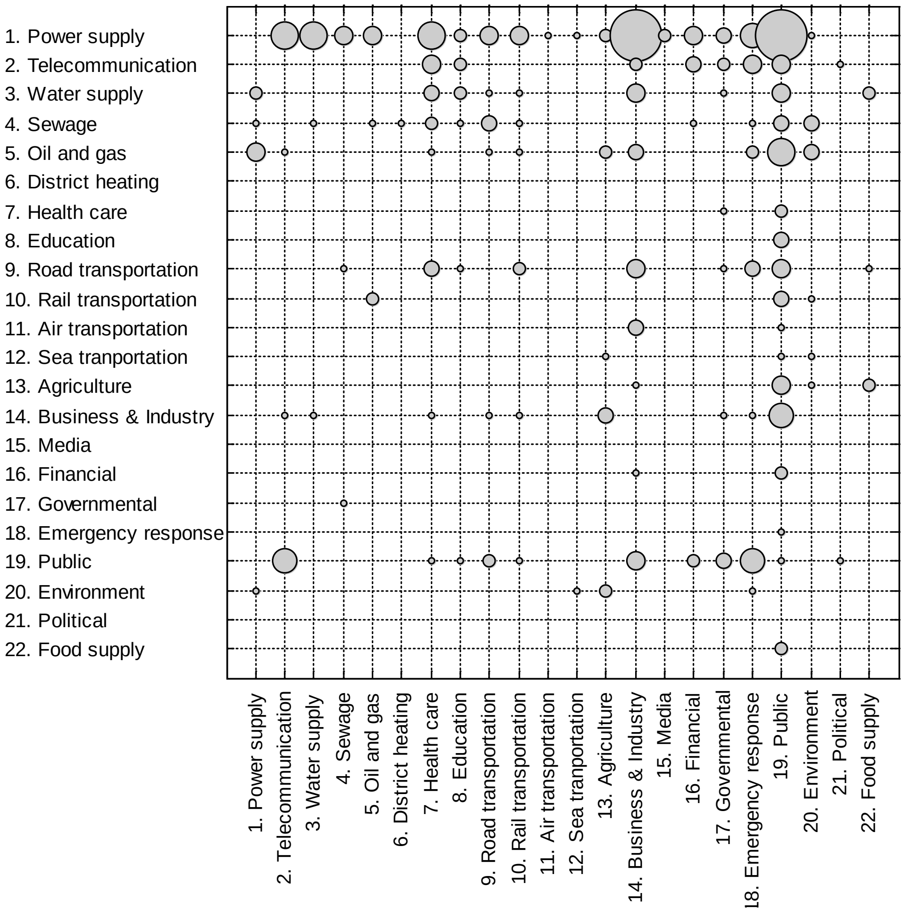

Figure 1.1 Illustration of which systems cascading effects occur between. Originators (i.e. Initiating events or Originating systems) are shown on the y-axis and the Dependencies (i.e. Impacted systems) on the x-axis. A large circle represents a frequent cascading effect, while a small circle represents an infrequent cascading effect.

3.2 Which systems are most frequently originating and dependent systems, respectively?

In Figure 1.5, the number of times each system is represented as an originating and dependent system, respectively, is illustrated. As described above, the Power supply system is the most frequent originating system while the Public was the most frequent dependent system. It can also be concluded that several of the systems are rarely represented among the 40 studied events, such as District heating, Air transportation and Sea transportation.

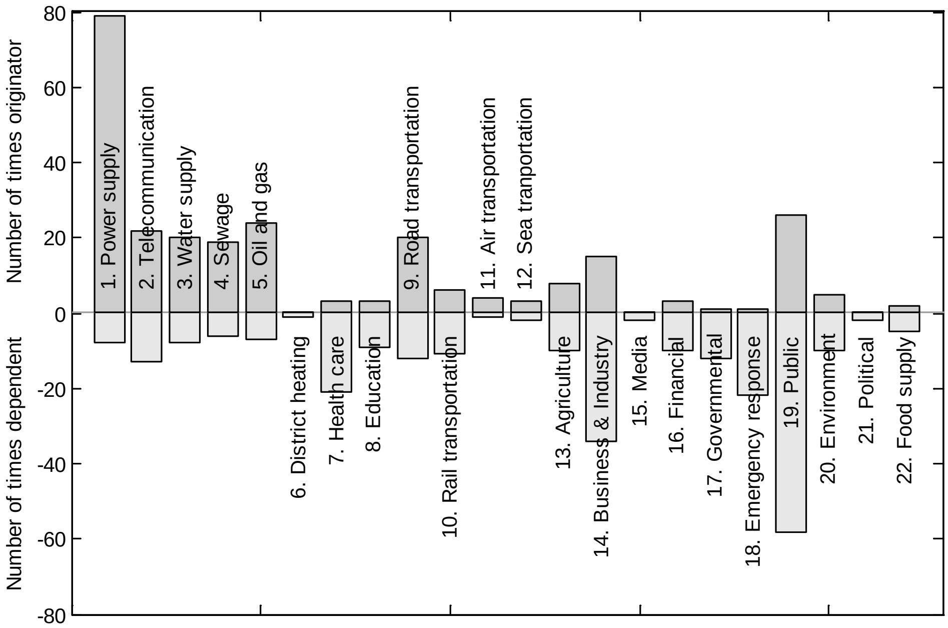

Figure 1.2 Number of times each system was represented as an originating and dependent system, respectively. System name located above or below middle line depending on if it is mainly an originating or a dependent system.

3.3 How many systems are involved in the same event and what cascade order?

In Figure 1.6 (top), the number of systems involved in the 40 studied events is plotted against the maximum cascade order for the event. From this analysis, there appears to be a moderate positive correlation between the variables, i.e. in events with a large number of systems involved it is likely that they will also have higher order of cascading effects. In Figure 1.6 (bottom left), the number of systems involved in the 40 events is plotted against the total event duration (shown in days on a logarithmic scale). From this figure, it seems that there is no clear correlation between the number of systems involved in the event and the duration, which means that it does not necessarily take longer to recover from an event with cascading effects even if many systems are involved. In Figure 1.6 (bottom right), the cascade order is plotted against the total event duration. Neither does this figure show any clear correlation, i.e. it does not seem that a higher order of cascading effects leads to a longer recovery time.

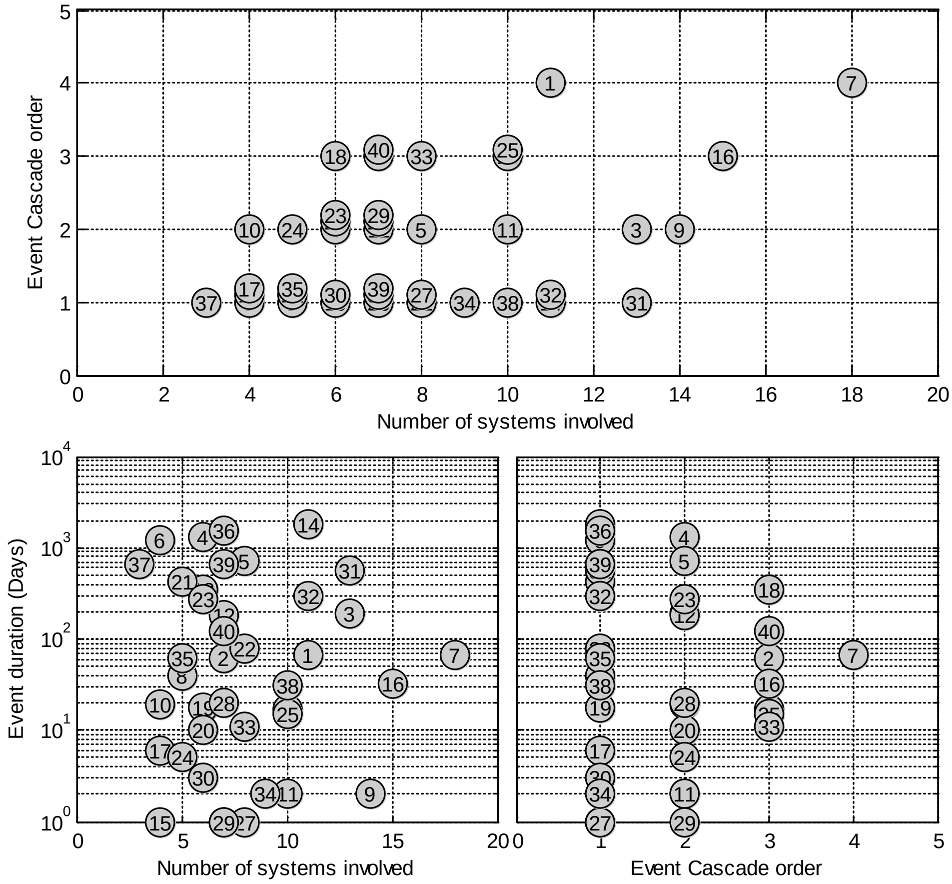

Figure 1.3 Top: Number of systems involved vs. cascade order for the 40 studied events. Bottom left: Number of systems involved vs. event duration (days). Bottom right: Cascade order vs. event duration (days).

3.4 How often are the systems involved, and what is the duration of the impacts?

In Figure 1.7, the grey bars show the number of times each system has been represented in the analysed events. As can be seen from this figure, some systems are more frequently represented than others. For example, the systems Business & Industry and Public are the most frequent ones, while the systems District heating, Media and Political are only represented a few times. The blue lines in Figure 1.7 illustrate the system impact duration (in days on a logarithmic scale). From this analysis, it can be concluded that many systems have a mean value of impact duration around the range of one to a few hundred days (e.g. the systems Oil and gas, Education, Road transportation, Rail transportation, Agriculture, Business & Industry), while there are a few systems with a significantly shorter system impact durations, ranging between approximately 1-10 days (e.g. Air transportation, Sea transportation, and Media). These results hence give interesting and important insight on different systems ability to recover from disturbances, i.e. an indication of their resilience.

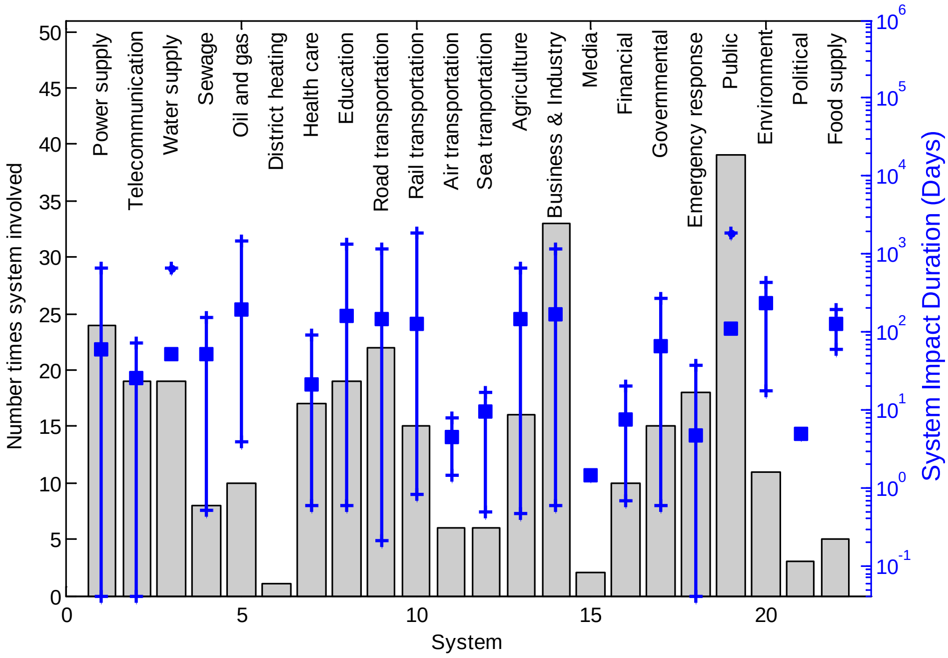

Figure 1.4 Number of times each system has been represented in the data (grey bars and left y-axis). System impact duration in days with mean value (square) and min/max values (+) (blue lines and right y-axis), note logarithmic scale.

3.5 What coping capacity do the systems have?

In Figure 1.8 the assessment of the dependency impact level is compared with the system impact level for each system. This comparison is made in order to gain insights about the coping capacity of each system in relation to the disruption to the system they depend upon. For some systems, the dependency impact level leads to a higher system impact level, which means that these systems seem to be more sensitive to disruptions with respect to the system they depend upon (e.g. Rail transportation, Sea transportation, and Media). For other systems, the relationship seems to be the opposite, i.e. they are more resilient than the system they depend upon as the average system impact level is lower than the dependency impact (e.g. Water supply, Health care, and Education). There are also some examples of systems that seem rather neutral to disturbances in the systems they depend upon, since the average system impact level is more or less the same as the dependency impact level (e.g. Power supply, Telecommunication, and Sewage). From these results it can be concluded that the coping capacity for different systems may vary considerably, meaning that some systems are less affected by disruptions than others.

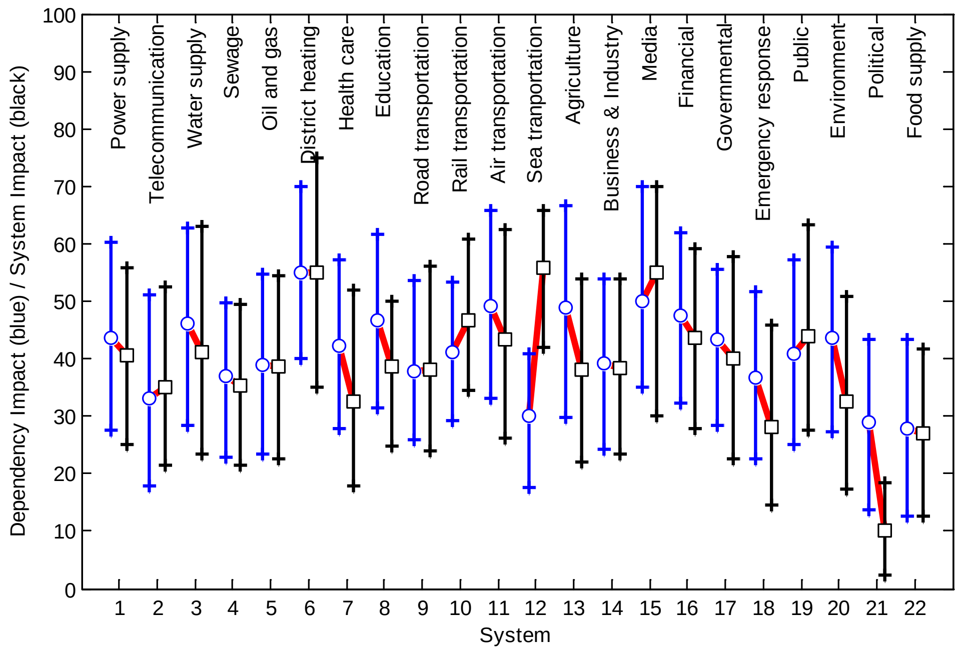

Figure 1.5 Average Dependency Impact Level (blue line) and System Impact Level (black line) for each system. For each system, the most likely estimations of Dependency Impact and System Impact are connected with a red line in order to facilitate interpretation.

3.6 How long time does it take from the initiating event to impacts in the different systems?

Figure 1.9 shows the time delay between when the initiating event started and when a specific system was affected. The figure clearly shows that many systems are impacted more or less instantaneously (see e.g. the systems Public and Environment), or within one day (see e.g. the systems Power supply and Telecommunication). It can also be noted that the system Oil and gas stands out considerably by having a significantly longer time delay than the other systems. This hence gives insights into the "window of opportunity" for taking mediating actions with respect to an initiating event happening and the time to when systems starts getting affected, which is extremely short for most systems in accordance with the data.

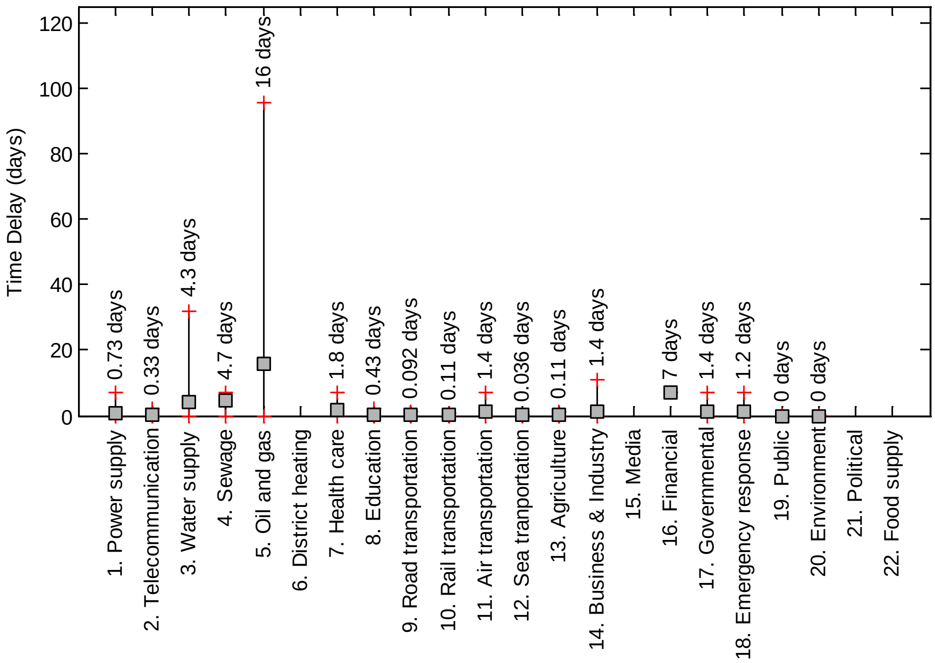

Figure 1.6 Time delay from the start of an initiating event to the start of a system impact. Square is mean value and crosses (+) minimum and maximum time delays found. The duration time given is the mean value.

3.7 How long time does it take for cascading effects to propagate?

Another interesting parameter relates to the speed of propagation from one system to another. In Figure 1.10, the time delay between when a specific system is affected in relation to when the systems it depends upon are firstly affected is given. This type of information can be used to signal "window of opportunities" for breaking chains of cascading effects and for which systems this might be possible. The figure reveals that for many systems there is very limited time delays between when the system they depend upon are affected and when effects arise in the system itself (similarly to Figure 1.9), e.g. for the systems Food supply, Sewage and Health care. This can be a result of a lack of, even possibility for, buffers in these systems. For some systems, effects occur within one day, e.g. Power supply and Rail transportations, while for some other systems there are time delays up to several days, e.g. Water supply, Road transportations and Agriculture. It can also be noted that when the public is affected, the time delay is on average slightly more than one day, e.g. meaning that mediating actions aimed at minimizing the direct impacts for the public due to failures in systems they depend upon should be deployed within a day.

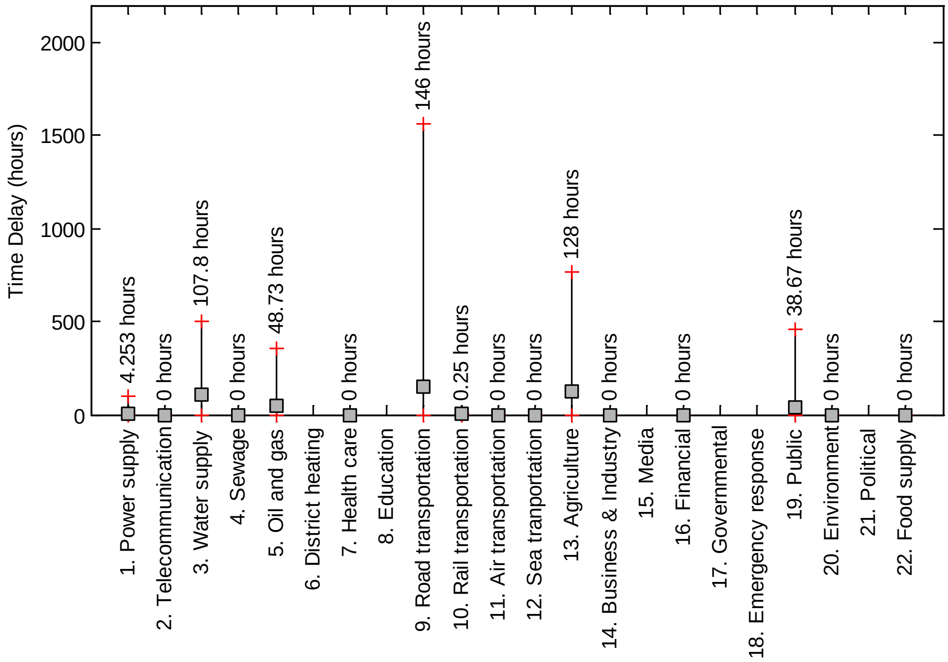

Figure 1.7 Time delay from when a specific system is affected in relation to when the systems they depend upon are affected. Square is mean value and crosses (+) minimum and maximum time delays found.

3.8 How large geographical areas are impacted as a result of different initiating events?

In Figure 1.11, the impacted geographical area for the systems for each type of initiating event is given. Weather-related initiating events like hurricanes and heat waves tend to, in general, impact a larger area while some initiating events like fires or volcano eruptions tend to, in general, impact a smaller area. The figure shows a rather large variation in impacted area between different cases of landslides, fires, physical terrorism and internal failures, while for e.g. volcano eruptions, heat waves and hurricanes, the variation is significantly smaller.

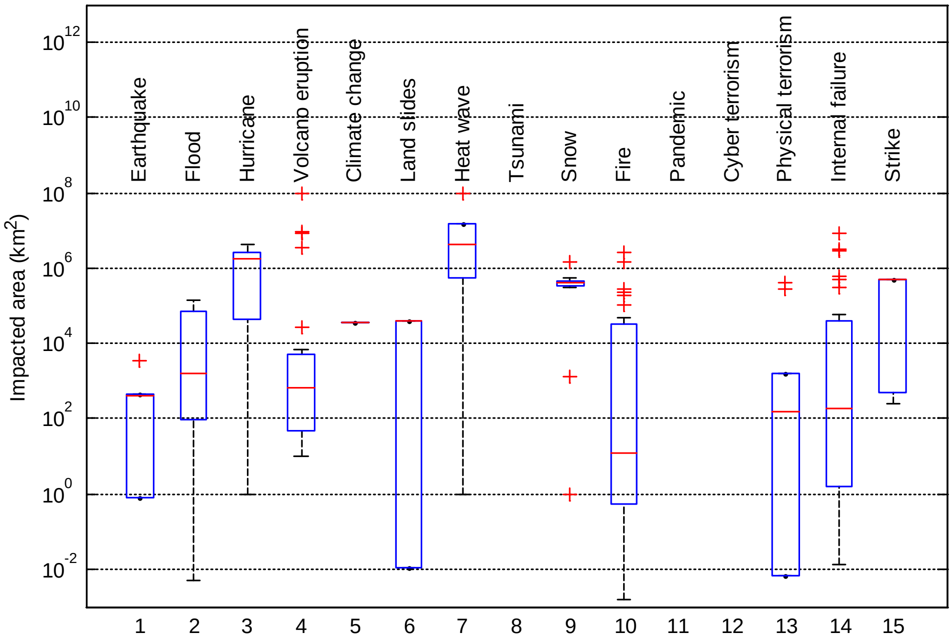

Figure 1.8 Impacted area for systems with respect to type of initiating event.

3.9 What conditions influence (mitigate or aggravate) cascading effects?

Figure 1.12 shows the number of times the different categories and values for conditions are mitigating or aggravating the impact. The most frequently mentioned mitigating condition category is coping capacity, mostly in terms of external resources but also in terms of buffers, structural integrity and preparedness plans. Other commonly mentioned mitigating conditions is the operational state (above normal capacity), and the timing of the event (time of day and weekends). The most mentioned aggravating condition is when the operational state is below normal capacity but also when the coping capacity (buffers and external resources) was below normal. Other commonly mentioned aggravating conditions are location (the event affected a metropolitan area), timing of the event (specifically the season) and weather. Also the cause of the event has been mentioned as an aggravating condition (if the event was intentional).

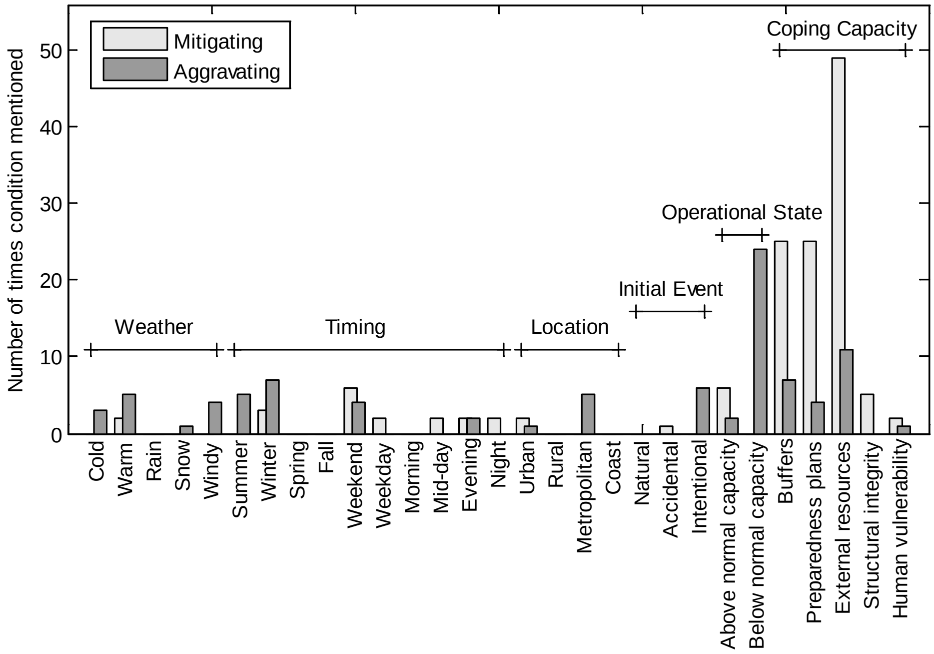

Figure 1.9 Number of times conditions are mentioned as mitigating or aggravating.

Discussion points

- How can the results presented in this chapter about cascading effects from previous events be used to improve the capacity to manage similar events in the future?
- What needs to be done to strengthen this capacity?

4 Concluding remarks

This lesson has presented conclusions about the nature, processes and patterns of cascading effects. The information was compiled through detailed case studies of 40 past events involving cascading effects, where data was gathered from existing written material in terms of scientific publications, official reports, investigations and media reports. The compiled data contains a significant amount of information from each of the 40 studied past events, including for example information about affected geographical area, time start, time end, cascade order, conditions, impact level, dependency type and dependency characteristics for each impacted system in the event. From the initial analyses of this data, interesting conclusions have been drawn, such as the frequency of propagation of cascading effects between different systems, the frequency of various systems as originating and impacted system, respectively, the duration, cascade order, impacted area, time delays, and much more. This information is highly relevant as a basis for increased understanding of the nature and of cascading effects and how to respond to these events. From the data analysed, it can be concluded that:

- Cascading effects most frequently occur from the system category Power supply to Business & Industry and from the system category Power supply to the Public. **Power supply is often represented as an originator and Public is often a dependent system** (i.e. an impacted system).
- In events with a **large number of systems involved it is likely that they will also have higher order of cascading effects** (although there is not a strong correlation). Further, it seems that there is no clear correlation between the number of systems involved in the event and the duration, which means that it does not necessarily take longer to recover from an event where many systems are involved.
- **Some systems are more frequently represented than others**, i.e. often involved irrespectively of the type of initiating event. For example, the systems Business & Industry and Public are the most frequent ones, while the systems District heating, Media and Political are only represented a few times – concluding that both the public and businesses and industries seems to be dependent on a number of other systems, in fact in some sense receiving systems of cascading effects, and a failure in anyone of these leads to consequences
- **Some systems seem to be more sensitive to disruptions with respect to the system they depend upon** (e.g. Rail transportation, Sea transportation, and Media). For other systems, the relationship seems to be **the opposite**, i.e. they are more resilient than the system they depend upon as the average system impact level is lower than the dependency impact (e.g. Water supply, Health care, and Education).
- **Many systems are impacted instantaneously** after the start of an initiating event (e.g. the systems Public and Environment), or within one day (e.g. the systems Power supply and Telecommunication) – leading to the conclusion that there is generally only a small time window of opportunity for taking action to remedy the effects of initiating events.
- For many systems, there is ve**ry limited time between when the system they depend upon are affected and when effects arise in the system itself**, e.g. for the systems Food supply, Sewage and Health care (i.e. might signal a lack of buffers for these systems). For some systems, effects occur within one day, e.g. Power supply and Rail transportations, while for some other systems there are time delays up to several

days, e.g. Water supply. This type of information can be used to signal "window of opportunities" for breaking chains of cascading effects and for which systems this might be possible.

- **Weather-related initiating events** like hurricanes and heat waves tend to, in general, impact a larger area while some initiating events like fires or volcano eruptions tend to, in general, impact a smaller area.
- **The most frequent mitigating condition category is coping capacity**, mostly in terms of external resources but also in terms of buffers, structural integrity and preparedness plans. Other commonly mitigating conditions is the operational state (above normal capacity), and the timing of the event (time of day and weekends). The most mentioned aggravating condition is when the operational state is below normal capacity but also when the coping capacity (buffers and external resources) was below normal.