Towards a Theoretical Foundation for Disaster-Related Management Systems: A System Dynamics Approach

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Towards a Theoretical Foundation for Disaster-Related Management Systems
A System Dynamics Approach

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Dissertation submitted in partial fulfilment of a Philosophiae Doctor degree in Civil Engineering

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Reykjavík, February 2016
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Theory for Disaster-Related Management Systems
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Bibliographic information:
Sólveig Thorvalsdóttir, 2015, Towards a theoretical foundation for disaster-related management systems: a system dynamics approach, PhD dissertation, Faculty of Civil and Environmental Engineering, University of Iceland, 201 pp.


Printing: Háskólaprent
Reykjavík, Iceland, February 2016
To my father,

Dr. Thorvaldur Veigar Gudmundsson, M.D.

When I was 10 years old my father told me I could do anything I wanted to.
I believed him then, and I still believe him.

Blue skies
Abstract
This doctoral study provides a theoretical foundation for disaster-related management systems dealing with natural disasters. The three main components of a management system are an organization, its objectives, and the procedures needed to meet these objectives. The term organization in this study refers to entities that deal with societal disruptions from a broad-based perspective, such as ministries and governmental institutions, which collaborate with and coordinate numerous and diverse stakeholders. The study theoretically derives disaster-related objectives and procedures associated with this perspective.

The research has four aims: (1) to develop a disaster-related goal and core objectives to reach it; (2) to outline dynamic relationships between the core disaster-related objectives; (3) to design a method for the core objectives to be in accordance with the S.M.A.R.T. criteria (specific, measureable, assignable, realistic, and time-related); and (4) to create links between stakeholders’ daily objectives and disaster-related objectives. The term disaster-function is introduced to denote a management function aimed to reach a disaster-related objective. The term disaster-function management denotes the management of all the disaster functions. The results are a set of management tools for addressing disaster-related problems from a broad-based perspective. The concept and tools of disaster-function management strengthen the link between disaster-related management and conventional project management, easing the application of project management tools in disaster-related management.

The theoretical basis of the work is comprised of management, engineering, and disaster-related, methodology and principles. The principle of management–by–objectives, the S.M.A.R.T. criteria, and the sustainable livelihood framework are used to characterize good management. Loss estimation methodology is used to incorporate a risk-based approach into the procedures developed in this study. A system dynamics approach is used to clarify relationships between objectives and provides variables for connecting engineering information with the objectives. The original disaster life cycle is the point of departure for developing disaster-related objectives.

The study uses the following circumstances as sources for management and engineering data for developing ideas and examples: (i) the 2010 Eyjafjallajökull volcanic eruption in South Iceland; (ii) the 2010 Haiti earthquake; and (iii) current conditions within the Kárahnjúkar Power Plant in East Iceland that create a low, but complicated risk of a small-scale disaster: dam failure due to seismic activity or due to volcanic eruption under the Vatnajökull glacier causing increased water discharge in the river above the dam, and leading to floods in farmlands below.
Útráttur


Rannsóknin nefn þjóður markmið: (1) skilgreina tilgang og grunnmarkmið stjórnunarkerfa fyrir náttúruhamfari í byggð; (2) útlista tímaða tengsl á milli grunnmarkmiðanna; (3) hanna aðferð til að láta grunnmarkmiðin vera í samremi við S.M.A.R.T. skilyrðin (e. specific, measureable, assignable, realistic, and time-related); og (4) búa til tengingar á milli daglegra markmiða hagsmunaaðila og grunnmarkmiðanna. Hugtaki viðlagastjórnun er skilgreint hér sem stjórnunarkerfi fyrir náttúruhamfarir í byggð sem byggir á ofangreindum markmiðum. Niðurstöður eru stjórnunarkaðir fyrir viðlagastjórnun. Þækin styrkja tengslin á milli viðlagastjórnunar og hefðbundinnar verkefnastjórnunar og auðvelda innleiðingu verkefnastjórnunar inn í stjórnunarkerfi sem fást við náttúruhamfarir í byggð.

Rannsóknin byggir á fræðisviðum stjórnunar og verkfræði, og svo reglug og venjum sem tengjast viðbúnaði og viðbrögðum við náttúruhamfórum. Meginreglan um markmiðastjórnun (e. management-by-objectives), S.M.A.R.T. skilyrðin, og stjórnunarrammí fyrir sjálfbæra þróun (e. sustainable livelihood framework) eru notuð til að skilgreina góða stjórnun. Fræði járdaskjálfta-verkfræði um að áætlja tjón og tap (loss estimation methodology) eru notuð til að innleiða aðferðir áhættustýringer inn í aðferðirnar sem í þessari rannsókn eru þróaðar. Kvik-kerfa nálgun er notuð til að greina og skýra tímaða tengsl markmiðanna og kemur með skilgreiningar á breytum sem nýttar eru til að tengja saman markmið viðlagastjórnunar og verkfræðilegar upplýsingar. Hin upprunalega hringrás náttúruhamfara í byggð (the original disaster life cycle) er notuð sem útgangspunktur til að skilgreina markmið viðlagastjórnunar.

Rannsóknin notar eftirfarandi aðstæður til að afla verkfræðilegra og stjórnunarlegra upplýsinga: (i) Eldgosið í Eyjafjallajökli 2010; (ii) járðaskjalftann á Haiti 2010; og (iii) aðstæður við Kárahnjukavirkjun sem skapa litla en flókna áhættu varðandi náttúruhamfarir í byggð: stíflurof í virkjuninni af vóldum járhreiðinga eða af aukun vatnsrennsli í anni í kjölfar eldgoss undir Vatnajökli, sem leiðir til flóða á landbúnaðarsvæðum.
List of Publications

This dissertation is based on the work presented in papers published in or submitted to International Scientific Indexing (ISI) journals.


Preface

I am the last of a long line of privileged people who completed a Ph.D. under the guidance of Prof. Ragnar Sighjörnsson. It was Ragnar who initiated the work presented herein when he called me into his office one day in 2008 and told me that it was time for me to earn my PhD. My two wonderful professors at Johns Hopkins University, Dr. Nick Jones and Dr. Bob Scanlan, had already planted the idea in my brain when they encouraged me to stay on after completing my masters, but I wasn’t ready then. When Ragnar started talking about it, I gave it serious thought and decided, yes, I was ready. At the time, I was working in Pakistan training people in urban search and rescue. I finished my contract in January 2010, got an office at the Earthquake Engineering Research Centre in Selfoss and started coursework in February that year. I told Ragnar that I didn’t want to do conventional earthquake engineering. I wanted to use my background in civil engineering, structural dynamics, earthquake engineering, project management, disaster management, civil protection, loss estimation, urban search and rescue, and international disaster coordination with the United Nations and Red Cross to focus on the most fundamental, overarching aspects of management in regards to activities before, during, and after natural disasters (whatever they are) and on how to incorporate engineering data systematically into this big picture. He said OK. And so the quest began. The first steps were not easy. The only common ground the literature provided regarding disasters was on disaster cycles in all variations. Ragnar eventually said, write a paper about the cycle. A whole paper only on the cycle, I replied very surprised. Yes. That was the turning point of this work. We eventually replaced the cycle phases with objectives, which opened up new directions for the research and was a simple, but powerful, alteration on how to address disasters. While a simple idea, it was a scientific challenge. It took two years to write the paper on objectives and get it published. It now provides the platform that the rest of the work is built on. This is just one example of where Ragnar’s insight provided clarity to my confusion.

I was once asked why I decided to do my PhD at the Earthquake Engineering Research Centre in Selfoss. Before I could answer, Ragnar jumped in and said it was because I had built a house 4 km down the road from the Centre and I couldn’t be bothered to go anywhere else and laughed. While it is indeed true that uprooting your life to travel to a far away place to go to school is enough once in a lifetime, it also just so happened I had a world-renowned expert close to my home. Even if I had searched the world over I would never have found a doctoral advisor more perfect for me than Ragnar.

Ragnar died on the 15th of July 2015. I felt his absence deeply during the last step of this wonderfully enlightening journey.
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Glossary

**Comprehensive disaster management:** Managing the four basic phases of the original disaster life cycle: mitigation, preparedness, response, and recovery (NGA, 1979).

**Building damage functions:** The probabilities of structural and non-structural damage calculated using building damage functions lie at the heart of loss estimation. Building damage functions are used for estimating the probability of discrete states of structural and non-structural damage to buildings (Kircher et al., 1997).

**Causal loop diagram:** Influence diagrams representing feedback loops and how the feedback loops interconnect to create the system. (Ahmad and Simonovic, 2000).

**Damage probability matrix:** A matrix describing the conditional probabilities of sustaining different degrees of damage at given levels of ground motion (Singhal and Kiremidjian, 1996) by using discrete damage states vs. discrete intensity values (ATC, 1985).

**Disaster:** A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceed the ability of the affected community or society to cope using its own resources (UNISDR, 2009).

**Disaster life cycle:** Mitigation, preparedness, response, recovery (NGA, 1979).

**Disaster-related management:** Any and all management activities regarding any and all aspects of a disaster, whether it is in anticipation of, during, or after a serious disruption of the community has taken place (Thorvaldsdóttir and Sigbjörnsson, 2014).

**Disaster risk:** A set of plausible scenarios leading to an accident (or disaster), the likelihoods of unwanted events within the scenarios, the consequences of the events and a description of uncertainty (Montewka et al., 2014), where potential effects are loss of lives, health, livelihoods, assets and services, which could occur to a particular community or society over some specified future period (UNISDR, 2009).

**Disaster risk management:** The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster (UNISDR, 2009).

**Disaster risk reduction:** The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events (UNISDR, 2009). This definition
includes disaster preparedness, which does not reduce the risk of the event happening, but has an effect on the course of events during the event.

**Disaster risk reduction plan:** A document prepared by an authority, sector, organization or enterprise that sets out goals and specific objectives for reducing disaster risks, together with related actions to accomplish these objectives (UNISDR, 2009).

**Disaster function:** A management function guided by a disaster-related objective (Thorvaldsdóttir and Sigbjörnsson, 2014).

**Disaster-function management:** Management of disaster functions that cover all disaster-related objectives (Thorvaldsdóttir and Sigbjörnsson, 2014).

**Disaster management:** This term is intentionally not used due to lack of definition.

**Emergency management:** The organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular, preparedness, response and initial recovery steps (UNISDR, 2009).

**Emergency services:** Services of specialized agencies that have specific responsibilities and objectives for serving and protecting people and property in emergency situations (UNISDR, 2009).

**Exposure:** People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses (UNISDR 2009).

**Exposed elements:** See Exposure.

**Elements at risk:** See Exposure.

**Fragility functions (curves):** Functions describing the conditional probabilities of sustaining different degrees of damage at given levels of ground motion (Singhal and Kiremidjan, 1996). Fragility functions predict the probabilities of reaching or exceeding specific damage states for a given level of peak hazard or response (Kircher et al., 1997).

**Hazard:** A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2009).

**Impact:** The collision of a natural process with an object that results in damages to the object that may lead to cascading damages and other consequences to that object or other objects, and cause disruption to a community.

**Impact operations:** Operations in response to imminent or actual impact of the natural process with the elements at risk (Thorvaldsdóttir and Sigbjörnsson, 2014). As a generalization, impact operations include disaster operations other than rescue, relief and recovery operations.

**Loss estimation methodology:** Engineering methodology to estimate damages and losses for a given set of exposures, circumstances (e.g. earthquake at night) and hazard levels.

**Mitigation:** Any and all activities that measureably reduce disaster risk. This
includes preventing identified risk (stopping identified risk from happening) and avoiding identified risk (moving away from the risk), which both eliminate risk. Mitigation measures can address any risk component.

**Natural hazard:** Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2009).

**Natural process:** Environmental process or phenomenon. Can cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2009).

**Natural disaster:** A disaster involving natural processes.

**Objects:** See Exposure.

**Operations:** Activities associated with reacting to an increased level of natural process that threatens or has led to impact, up until normality is renewed. Operations are devided into impact, rescue, relief and recovery operations.

**Preparedness:** Preparedness activities are necessary to the extent that mitigation measures have not, or cannot, prevent disasters (NGA, 1979). Preparedness activities include developing contingency plans for impact, rescue, relief and recovery operations. Other examples are installing warning systems, compiling resource inventories, conducting training exercises, and stockpiling vital food and medical supplies.

**Perspective:** The term perspective is important to this thesis and commonly used. A perspective is “the ability to see all the relevant data in a meaningful relationship” (The Free Dictionary, 2014), providing context for addressing problems and presenting solutions.

**Recovery, recovery operations:** Recovery operations continue until the society is no longer suffering disruption. Their purpose is to return life to normal or improved levels, for example through clean-up, reconstruction of building, rehabilitation of people, insurance payout processes, redevelopment loans, and legal assistance.

**Relief, relief operations:** Any direct and indirect operations with the overall objective of providing temporary assistance (Thorvaldsdóttir and Sigbjörnsson, 2014).

**Rescue, rescue operations:** Any direct and indirect operations that have the overall objective of saving lives (Thorvaldsdóttir and Sigbjörnsson, 2014).

**Residual risk:** The risk that remains in unmanaged form even when effective disaster risk reduction measures are in place and for which emergency response and recovery capacities must be maintained (UNISDR, 2009).

**Response:** The term response is mostly avoided due to multiple meanings, such as: impact operations rescue and short-term relief, rescue and relief, rescue, relief and recovery, and building response to an earthquake.

**Risk:** A set encompassing the following: a set of plausible scenarios leading to an accident, the likelihoods of unwanted events within the scenarios, the
consequences of the events, and description of uncertainty provided by Montewka et al (2014).

**S.M.A.R.T. criteria**: Specific, measureable, assignable, realistic, and time-related criteria for objectives (Doran, 1981).

**Stakeholder**: An entity owning a system, benefitting from a system, or acting within a system (Checkland and Poulter, 2010).

**Stock and flow diagram**: Diagrams depicting how levels and rates are interconnected to produce feedback loops and how the feedback loops interconnect to create the system (Ahmad and Simonovic, 2000).

**System dynamics (SD)**: Jay W. Forrester’s foundation of system dynamics incorporates computing technology, computer simulation, strategic decision-making, and the role of feedback in complex systems (Richardson, 2011). The SD approach is based on the theory of feedback processes that provide users with an understanding of the dynamic behaviour of systems (Ahmad and Simonovic, 2000). A feedback system is influenced by its own past behaviour through a closed-loop structure that brings results from past actions of the system back to control future actions. The feedback loop is the basic structure within the system. Levels (stock variables) and rates (flow variables) are fundamental variables within a feedback loop.

**System dynamics variables, connecting variables**: Connecting variables are used to establish the relationship among other variables in a SD model. They carry information from one element in a model to another element. Information can be a quantity, a constant, an algebraic relationship, or a graphical relationship (Ahmad and Simonovic, 2000).

**System dynamics variables, converting variables**: Converting variables transform input into output. Converters can accept input in the form of algebraic relationships, graphs, and tables (Ahmad and Simonovic, 2000).

**System dynamics variables, flow variables**: Flow in system dynamics modelling represents activities that fill and drain stocks (Ahmad and Simonovic, 2000). Flow variables (rates) tell how fast the stocks variables (levels) are changing.

**System dynamics variables, stock variables**: Stocks are used in system dynamics modelling to represent anything that accumulates (Ahmad and Simonovic, 2000). Stock variables (level) describe the condition of the system at any particular time.

**Vulnerability**: The characteristics and circumstances of a community, system or asset, making it susceptible to the damaging effects of a hazard. It describes conditions of objects and their susceptibility to damage (UNISDR, 2009).

**Vulnerability function**: Mathematical function, e.g., fragility function and Damage Probability Matrix, describing probabilities of damage states as a function of hazard intensity.
# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCV</td>
<td>Connecting variable</td>
</tr>
<tr>
<td>CLD</td>
<td>Causal loop diagram</td>
</tr>
<tr>
<td>DF</td>
<td>Disaster function</td>
</tr>
<tr>
<td>DFA</td>
<td>Disaster-function activities</td>
</tr>
<tr>
<td>DFM</td>
<td>Disaster-function management</td>
</tr>
<tr>
<td>DID</td>
<td>Damage, injury, and disruption</td>
</tr>
<tr>
<td>DL</td>
<td>Disrupted loop</td>
</tr>
<tr>
<td>DPM</td>
<td>Damage probability matrix</td>
</tr>
<tr>
<td>EXV</td>
<td>Excitation variable</td>
</tr>
<tr>
<td>FBL</td>
<td>Feedback loop</td>
</tr>
<tr>
<td>FLV</td>
<td>Flow variable</td>
</tr>
<tr>
<td>IL</td>
<td>Improvement loop</td>
</tr>
<tr>
<td>MMI</td>
<td>Modified Mercalli intensity</td>
</tr>
<tr>
<td>NL</td>
<td>Normal loop</td>
</tr>
<tr>
<td>OBJ</td>
<td>Objective</td>
</tr>
<tr>
<td>NR</td>
<td>Natural resource</td>
</tr>
<tr>
<td>PGA</td>
<td>Peak ground acceleration</td>
</tr>
<tr>
<td>SD</td>
<td>System dynamics</td>
</tr>
<tr>
<td>SDA</td>
<td>System dynamics approach</td>
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<td>SFD</td>
<td>Stock and flow diagram</td>
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<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>UNISDR</td>
<td>United Nations International Strategy for Disaster Reduction</td>
</tr>
<tr>
<td>UNOCHA</td>
<td>United Nations Office for the Coordination of Humanitarian Affairs</td>
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</tbody>
</table>
Acknowledgement

A PhD project is a collaborative effort and there are many people to thank. First and foremost, I gratefully acknowledge the collaboration with the late dr. Ragnar Sigbjörnsson. Without his initiative, guidance, and support, this dissertation would not exist. I sincerely thank Dr. Rajesh Rupakhety, who has helped me on this last leg of the journey through administrative affairs necessary to submit my dissertation to the University of Iceland and for constructive comments on previous drafts. Dr. Óli Grétar Sveinsson, I thank for his contribution to this work and staying with it through the years. Dr. Guðmundur Freyr Þorarsson, I thank you for being so supportive. Dr. Kurt Petersen, from Lund University, Sweden, was a significant influence at the beginning of the work and provided me with much food for thought and scholarly advice. I am also grateful to Dr. Hirokazu Tatano for the opportunity given to me by Kyoto University to spend three months at the Disaster Prevention Research Institute in 2012-3. I thank Dr. Nick Jones for his never-ending encouragement and for whatever he wrote in his reference letter.

I would like to acknowledge Mr. Erlendur Birgisson, my rescue mate from the Icelandic International Urban Search and Rescue team, who was a co-author on the Haiti paper. I greatly appreciate the work of the anonymous reviewers who provided sound feedback and in every case that improved the papers. Daniel Teague and Randi Whitney Stebbins, I thank for proofreading manuscripts.

The Earthquake Engineering Research Centre in Selfoss is a special place. While Ragnar has been the brain of the centre, Elinborg is the heart. Elinborg, takk fyrir alla vináttuna í gegnum árin. I also want to thank Rajesh, Simon and Benedikt for making the Centre feel like the family that it is for this fisherman’s wife. And Puja, you are a wonderful addition for us, who are Rajesh’s Icelandic family. Thanks for all the help with the graphics. To all the PhD candidates at the Centre, I wish you the best of luck.

Ragnar gave me the opportunity to teach his course named Natural Catastrophes and to further develop it. I have taught the course five times since 2010. I am grateful to Ragnar and the University of Iceland for this opportunity to discuss ideas with graduate students, which helped me to develop various ideas on the topic of disaster-related management.

In 2011, the Ministry of Foreign Affairs, Crises Response Unit offered me an opportunity to work in Palestine for the United Nations in the field of disaster management. Working as a consult in my research field while working towards a PhD was of great value and had a practical impact for disaster risk management in Palestine. I have worked on disaster risk management projects in Palestine every year since and still have projects there. I thank my friends at the MFA, UNDP, UNOCHA, The PAL-DRM team, Palestinian Civil Defence, and other Palestinian partners for the many discussions on disaster-related topics and how to design the best disaster related management system for the West Bank and Gaza Strip.
I gratefully acknowledge the research grants from the University of Iceland’s Eimskip Fund and the South Iceland Science Fund and the financial support from Kyoto University. The co-support provided by the EU Civil Protection Financial Instrument, in the framework of the European project Urban Disaster Prevention Strategies using Macro-seismic Fields and Fault Sources (Acronym: UPStrat-MAFA, Grant Agreement No. 23031/2011/613486/SUB/A5) is also gratefully acknowledged.

Rainrace Consultancy ehf., I thank for financial support and for patiently waiting on the sidelines.

Last, but by no means least, I thank my husband, family and friends, who have had to tolerate listening to me going on and on (and on) about the details that I was dealing with at the time and the many times that I have been absent from gatherings and events. I love and appreciate all of you so very much.
1 Introduction

1.1 General Intent

This doctoral dissertation is on the topic of disaster-related activities and associated management systems, with a focus on, but not limited to, natural disasters. Disaster-related management can be seen from many perspectives. The focus herein is on higher-level management. The intent is to study disaster-related activities from a broad-based perspective and provide management tools for big-picture, disaster-related management systems.

The work was motivated by the ever-present threat of natural disasters and the lack of theoretically derived disaster-related management tools for higher-level entities. The number and scale of natural disasters and their increasing impact within recent years have resulted in massive loss of life and long-term negative social, economic and environmental consequences for vulnerable societies throughout the world, in particular in developing countries (UNGA, 2005). Recent disasters, such as floods due to Hurricane Katrina in the USA in 2005, earthquakes in New Zealand in 2010, and Japan in 2011, and the 2010 Eyjafjallajökull volcanic eruption in Iceland, have shown that no society can ignore the threat of extreme natural processes or their effects. The problem of disasters is a relevant and important issue of worldwide concern.

A management system is an organization, objectives and procedures used by the organization to reach the objectives (ISO, 2015). Doran (1981) emphasized that the establishment of objectives and the development of their respective action plans are the most critical steps in a company’s management process. He argued that when top- and middle-level management are indecisive, or set inadequate objectives, errors in judgment would compound themselves throughout the entire organization. The author argues that the same applies to companies and societies as a whole with respect to disasters if higher-level personnel set inadequate disaster-related objectives, the company or society will suffer negative consequences. The development of higher-level management tools for disaster-related activities must, therefore, be based on specific disaster-related objectives. The notion of specific disaster-related objectives frames disaster-related problems as management problems. Determining sensible disaster-related objectives underpins the development of the management tools presented herein.

Higher-level entities need to understand the scope of disaster-related problems from their broad-based perspective, that thin, wide management layer that envelopes the entire spectrum of management activities. An overarching perspective is an important concept, but not easy to define. However, failing to define the scope of disaster-related management leaves those managing disaster-related activities at higher levels, such as ministerial levels, especially the levels of prime ministers and presidents, without clear boundaries for their management projects. A definition of an overarching perspective is concluded from the research herein.
This work has a footing in civil engineering. Civil engineering focuses on the functionality of the physical aspects of society, such as buildings, bridges, roads, harbours, water systems, waste management systems, and energy systems. Structures are designed for live, dead, and environmental loading. Specialized disciplines within civil engineering, such as earthquake engineering, focus on detailed aspects of a hazardous, natural environment to provide safety to the inhabitants and reduce financial loss to owners. The notions of environmental risk and associated damage, financial loss, and disruption of service are integral parts of civil engineering. A civil engineering perspective makes damage to physical components caused by natural processes, and the overall damaging process, the nuclei of natural disaster related problems.

Successful disaster-related management from a broad-based perspective, as indeed from any perspective, requires specific management tools. The lack of higher-level, disaster-related management tools and the author’s conviction that theoretically derived, risk damage based management tools can clarify disaster-related problems and solutions for higher-level personnel and guide them in coordinating higher-level, disaster-related activities inspired the quest described in this dissertation.

### 1.2 Research Aims

To contribute to a theoretical foundation for disaster-related management systems, the research fulfils four aims.

**Research aim #1:** To develop a disaster-related goal and core objectives to reach the goal.

The International Organization for Standardization describes a management system as a set of procedures an organization follows in order to meet its objectives (ISO, 2015). A disaster-related management system is, therefore, a system designed to meet specific, disaster-related objectives. The first research aim is to develop a disaster-related goal and objectives.

The disaster-related goal developed within this research aim builds on the following definition of a disaster (UNISDR, 2009): “A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources”, discussed in Section 2.1.

Applying a systems approach, and using the original disaster life cycle as the point of departure, led to eight objectives that arguably constitute the most fundamental, or core, objectives to reach a disaster related goal (Thorvaldsdottir and Sigbjörnsson, 2015a) and are outlined in Section 2.1.

**Research aim #2:** To outline the dynamic relationship between disaster-related objectives.

As a result of research aim #1, disaster-related objectives can be summarized as
follows: to understand disaster risk, measurably mitigate it, prepare for future events associated with any residual unmitigated risk, intervene in damaging processes and react to life-threatening situations, recover from the impact, provide temporary relief until recovery is accomplished, and learn from the operations in order to improve the system used to meet the objectives. The statement highlights a dynamic relationship between the objectives. Understanding this dynamic relationship between the objectives is necessary when managing activities to meet the objectives. Understanding this relationship is the subject of research aim #2.

For the purpose of outlining the dynamic relationship, each objective is expanded into basic activities needed to meet the objective. The dynamic relationships between all these activities is analysed using a system dynamics approach. The relationships are first depicted on a causal loop diagrams (CLD). The arrows in the CLD indicate projects needed to be complete to meet the objectives. The dynamic relationships are converted into stock and flow variables and presented in stock and flow diagrams (SFD), the first step of a modelling process. Loss estimation methodology is used to characterize the components of risk. This process is outlined in Section 2.2. Engineering and management data from the circumstances at the Kárahnjúka Power Plant in East Iceland was used to develop the concept.

Research aim #3: To develop a method to make disaster-related objectives specific, measurable, assignable, realistic, and time-related within a disaster-related management system.

Doran (1981) offered S.M.A.R.T. (specific, measurable, assignable, realistic and time-related) criteria as a guide for writing meaningful objectives. The third research aim is to develop a method to apply the S.M.A.R.T. criteria to the disaster-related objectives. A simple generalization of the criteria is presented in Section 2.3, using the outcome of research aims #1 and #2. An application of research aim #4 led to the creation of a flowchart that inserts the S.M.A.R.T. objectives into disaster-related procedures, explained in Section 3.2.4. In addition to engineering and management data used for research aims #2 and #4, data from the Haiti earthquake was used to develop the flowchart.

Research aim #4: To develop a framework depicting the key components for maintaining a well-functioning society and coping with disasters.

The fourth research aim is based on the assumption that a disaster is a deviation from normal, daily life to some level of disruption. Disaster operations will eventually lead back to routine, daily life again, either as it was or in a new form. This places a disruption in context with daily life by stating that a disruption is a varying degree of separation from daily life. The form that the disruption takes can vary. Two examples are demonstrated in Fig. 1.1, a variation in degree of intensity (defined here as the number of elements involved) or complexity (defined here at the number of types of elements of involved). Fig. 1.1 shows four data points. Airborne volcanic ash from the 2010 Eyjafjallajökull volcanic eruption caused worldwide disruption to the travel
industry and its passengers, but the disruption itself was relatively simple; people could not travel (low complexity, high intensity). Meanwhile, ash inundated a small farming community of less than 10 farms next to the volcano. This caused complex disruption affecting virtually every aspect of the human and animal lives of the affected population (high complexity, low intensity). An earthquake in a non-urban area that involves internal earth dam failure could cause flooding limited to the vicinity of the river banks, possibly ruining only fields and pastures (low-complexity, low-intensity). The disruption in the capital region caused by the 2010 earthquake in Haiti is an example of a high-complexity, high-intensity event.

Reducing the disruption complexity and/or intensity in these events brings the situation closer to daily life. Since daily life activities are where a disruption starts and are part of the overall management goal (the well functioning society of a daily life is being sought), understanding the objectives and management of daily life activities is an important aspect of understanding how to manage disaster functions.

![Figure 1.1. Daily life conditions seamlessly linked to disruption intensity and complexity.](image)

This last research aim is to develop a framework that finds commonality between management components for daily life and disruptions to daily life to create a management link between daily and disrupted life. The management components of a sustainable livelihood are used to represent the former and the results from research aim #1 are used to represent the latter. The daily-disaster framework is introduced in Section 2.4 as a contextual framework depicting the objectives from a daily perspective as well as a disaster perspective. Key management components that need to be taken into consideration in order to ensure that disaster-related management is in sync with daily management are also included. Engineering and management data from the 2010 Eyjafjallajökull volcanic eruption is used to develop the framework.
1.3 Dissertation Organization

This dissertation is divided into three parts. Part I contains the following chapters:

- Chapter 1 introduces the work by presenting the factors motivating this work, the four research aims, the dissertation organization, the scientific papers and manuscript that the work is based on, and provides an overview of background literature.
- Chapter 2 explains the development of a theory-based, disaster-related management system. Each subchapter deals with one of the research aims discussed in Section 1.2.
- Chapter 3 presents cases in which the tools developed in Chapter 2 are applied.
- Chapter 4 presents a discussion of the work, a summary of the key results, conclusions, and suggestions for further research.

Part II presents scientific papers based on this work. Three ISI papers have been published based on the research presented in this dissertation. The manuscript of another ISI paper is under review. The papers contribute to the development of the theoretical foundation for disaster-related management systems presented herein and are source papers for tool application. The papers are listed below and their links to the chapters of Part I is mentioned. The papers are presented in full as appendices.

   a) Chapter 2.1: The development of disaster-related objectives

2. Thorvaldsdóttir S, Sigbjörnsson R (2015a) Conceptualizing societal safety systems using a system dynamics approach. Safety Science (under review). The subchapters related to it are
   a) Chapter 2.2.2: Using a systems approach to develop a management system to reach disaster-related objectives
   b) Chapter 3.2.2: Paper is a source for application

   a) Chapter 2.4.3: Using the Sustainable Livelihood framework for analysing disaster-related activities
   b) Chapter 3.2.1: Paper is a source for application
4. Thorvaldsdóttir S, Birgisson E, Sigmundsson R (2011) Interactive on-site and remote damage assessment for urban search and rescue. Earthquake Spectra, 27(S1):S239–S250. The chapters related to it is
   a) Chapter 3.2.3: Paper is a source for application

1.4 Background Literature

The background literature relevant to the present work comprises three subjects: disaster-related, management, and engineering literature. Fig. 1.2 summarises the main definitions, frameworks, principles and methodologies used from each subject.

![Figure 1.2](image)

**Figure 1.2.** Management, engineering and disaster-related literature and principles that collectively form the basis of this work.

### 1.4.1 Disaster-Related Literature

#### UNISDR Terminology

The United Nations International Secretariat for Disaster Reduction was established as a follow-up to the United Nations International Strategy for Disaster Reduction (UNISDR), which was implemented in the last decade of the 20th century. In 2009, UNISDR (2009) published definitions of several key terms related to disasters “to promote a common understanding and usage of disaster risk reduction concepts and to assist the disaster risk reduction efforts of authorities, practitioners and the public.” Various definitions are used from this publication (see Glossary).

#### Disaster Life Cycle

In 1978, following a series of studies on contemporary disasters, the U.S. National Governors’ Association published a report that introduced the Disaster Life Cycle (Fig. 1.3) containing four phases of the life of a disaster: (1) mitigation, (2) preparedness, (3) response, and (4) recovery (NGA, 1979; Neal, 1997; Rubin, 2009). These four phases were termed comprehensive emergency management (CEM).
Disaster Planning Guides

Planning guides from well-established entities, such as the International Federation of the Red Cross and Red Crescent Societies (IFRC, 2007) and the International Search and Rescue Advisory Group (INSARAG, 2012), provide information to determine basic, disaster-related activities (Fig. 1.4) and shore up general knowledge about these activities.

![Figure 1.3](image1.png)

**Figure 1.3.** The four phases of the original disaster life cycle (NGA, 1979), which begins with mitigation and ends with recovery. The red spot denotes a disaster.

![Figure 1.4](image2.png)

**Figure 1.4.** Planning guides provide information on disaster-related activities, such as guides from the International Search and Rescue Advisory Group and the Red Cross.
1.4.2 Management Principles

Management Systems
The International Organization for Standardization describes a management system as a set of procedures an organization follows in order to meet its objectives (ISO, 2015).

Management by Objectives
Peter Drucker introduced the concept of management by objectives in 1954 (Drucker, 1954). Classical management theory states that management by objectives, as a concept, is an integrated management system to manage an organization by aligning the entire managerial effort with specific performance goals (Ghuman, 2010).

Management Functions
Classical management theory also offers the concept of management functions. Typical management functions include planning, logistics, operations, and finance. The US military uses these management functions for joint operations between the army, navy, air force and marines (Air War College, 2012). They add management functions that are specifically relevant to their goals and objectives, such as intelligence and civil-military operations. Emergency services have also taken up management functions within their incident command system, which uses the planning, logistics, operations, finance, and command functions.

S.M.A.R.T. Objectives
George T. Doran (1981) suggested the S.M.A.R.T. criteria for writing effective objectives in a management article, entitled “There’s a S.M.A.R.T. Way to Write Management’s Goals and Objectives.” The acronym is explained in Table 1.1. S.M.A.R.T. criteria are not a checklist. They are tools to get results and to be applied as best suited for the implementers (Doran, 1981). Not all levels of management put the same effort into all objectives and not every objective follows all five criteria.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
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<tbody>
<tr>
<td>Specific</td>
<td>Target a specific area for improvement</td>
</tr>
<tr>
<td>Measurable</td>
<td>Quantify, or at least suggest, an indicator of progress</td>
</tr>
<tr>
<td>Assignable</td>
<td>Specify who will do it</td>
</tr>
<tr>
<td>Realistic</td>
<td>State what results can realistically be achieved, given available resources</td>
</tr>
<tr>
<td>Time-related</td>
<td>Specify when the result(s) can be achieved</td>
</tr>
</tbody>
</table>

Sustainable Livelihood Framework
The sustainable livelihood framework (SLF), (DFID, 1999) characterises a
livelihood perspective. The SLF “presents the main factors that affect people’s livelihoods and typical relationships between these” (DFID, 1999). The “aim is to help stakeholders with different perspectives to engage in structured and coherent debate about the many factors that affect livelihoods, their relative importance and the way in which they interact” (DFID, 1999). The framework captures how people’s decisions on their livelihood are influenced by regulatory opportunities and restrictions that are produced by transforming structures and processes, and the vulnerability context within which people live. The SLF consists of five, main components (see Fig. 1.5), depicting five, main management aspects of a sustainable livelihood:

1. Livelihood assets (human, natural, physical, financial and societal) that are needed to achieve a positive livelihood outcome.
2. Vulnerability context, such as shocks (including natural disasters), monetary trends and changing seasons.
3. Transformation structures, processes and policies affecting the assets.
4. Strategies to reach these goals.
5. Outcomes of livelihoods.

The SLF connects the perspectives of numerous actors related to livelihood. The framework creates a general livelihood perspective. The SLF defines actors by types of organizations “that set and implement policy and legislation, deliver services, purchase, and trade and perform all manner of other functions that affect livelihoods” (DFID, 1999), (see Table 3.14). Guide sheets are available on how to use the framework (DFID, 1999).

![Sustainable Livelihood Framework](image)

**Figure 1.5.** The sustainable livelihood framework (adapted from DFID, 1999) depicting the five basic components of good management for sustainable livelihoods.
1.4.3 Engineering Methodology

Loss Estimation Methodology

Loss estimation methodology is used to forecast the destructive impact of a natural disaster (Thorvaldsdottir, 1991). Losses for disaster-related management purposes are estimated for a given area, e.g. for a given jurisdiction or country, or for a given hazard, e.g. for a known faulting system. A loss estimate requires a probabilistic or deterministic quantification of the expected hazard (such as a PGA or MMI map for an earthquake), an inventory of structure types exposed to the hazard (exposure), and a model describing the relationship between hazard level and damage level (vulnerability function) for each structure type.

Vulnerability models are based on the assumption that a causal relationship, in the probabilistic sense, can be established through physical modelling or empirical data between hazard intensity (often characterized in terms of PGA or MMI) and expected damage (often described by a damage factor, which is the ratio of repair cost to replacement cost). Such relationships can be continuous functions describing probabilities of exceedance of a certain level of damage conditioned on a measure of hazard, called fragility curves, damage curves, or vulnerability functions. The relationships can also be described as a discrete probability distribution, wherein probabilities of discrete damage states are conditioned on intensities of hazard, often developed from histograms. Relationships can be represented in a two-dimensional matrix, commonly known as the damage probability matrix (DPM).

According to Malik (1986), DPMs were first described by Martel in 1964 and then further developed by Whitman, Reed and Hong, who published a paper titled “Earthquake damage probability matrices”, (Whitman, 1974), at the fifth world conference in earthquake engineering. Table 1.2 is an example of a DPM used for estimating earthquake-induced damage to buildings (ATC, 1985). In this example, the DPM is a collection of damage distribution models for a range of seven intensity intervals (seven rightmost columns in Table 1.2). It is common practice to present both a quantitative description of the damage states, see Table 1.2, and an associated qualitative description, see Table 1.3.

Table 1.2. Example of a Damage Probability Matrix (ATC, 1985).

<table>
<thead>
<tr>
<th>Damage State</th>
<th>Damage Factor Range (%)</th>
<th>Central Damage Factor (%)</th>
<th>Probabilities of exceedance (in %) for different PGA ranges (PGA in % g, where g is acceleration due to gravity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
<td>0</td>
<td>95 49 30 14 3 1 0.4</td>
</tr>
<tr>
<td>Slight</td>
<td>0-1</td>
<td>0.5</td>
<td>3 38 40 30 10 3 0.6</td>
</tr>
<tr>
<td>Light</td>
<td>1-10</td>
<td>5</td>
<td>1.5 8 16 24 30 10 1</td>
</tr>
<tr>
<td>Moderate</td>
<td>10-30</td>
<td>20</td>
<td>0.4 2 8 16 26 30 3</td>
</tr>
<tr>
<td>Heavy</td>
<td>30-60</td>
<td>45</td>
<td>0.1 1.5 3 10 18 30 18</td>
</tr>
<tr>
<td>Major</td>
<td>60-100</td>
<td>80</td>
<td>0 1 2 4 10 18 39</td>
</tr>
<tr>
<td>Destroyed</td>
<td>100</td>
<td>100</td>
<td>0 0.5 1 2 3 8 38</td>
</tr>
</tbody>
</table>
Table 1.3. Damage States in Damage Probability Matrices (ATC, 1985).

<table>
<thead>
<tr>
<th>Sn.</th>
<th>Damage State</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>No damage</td>
</tr>
<tr>
<td>2</td>
<td>Slight</td>
<td>Limited localized minor damage not requiring repair</td>
</tr>
<tr>
<td>3</td>
<td>Light</td>
<td>Significant localized damage of some components generally not requiring repair</td>
</tr>
<tr>
<td>4</td>
<td>Moderate</td>
<td>Significant localized damage of many components warranting repair</td>
</tr>
<tr>
<td>5</td>
<td>Heavy</td>
<td>Extensive damage requiring major repairs</td>
</tr>
<tr>
<td>6</td>
<td>Major</td>
<td>Major widespread damage. Facility may be razed, demolished or repaired</td>
</tr>
<tr>
<td>7</td>
<td>Destroyed</td>
<td>Total destruction of the majority of the facility</td>
</tr>
</tbody>
</table>

From a thorough literature review (Thorvaldsdóttir, 1991), it is evident that a significant amount of research has gone into developing models for regional loss estimation for earthquakes (Jones et al., 1995). Much of the earlier development work was motivated by the insurance and reinsurance industry due to a need for suitable earthquake insurance. This industry is still one of the leading contributors to research. Loss estimations also lay the grounds for emergency response plans, retrofitting (Kirkham et al., 2014) and rehabilitation after an earthquake (Kreimer, 1991). More recent efforts in loss estimation methodology include special publications of scientific literature, such as Earthquake Spectra Theme Issue (1997), Natural Hazards Review Special Issue (2006), and Earthquake Spectra Theme Issue (2011). Earthquake engineering conferences commonly have special sessions on loss estimation.

Loss Estimation is the basis for many, well-known computer models for estimating losses, such as EPEDAT (Eguchi et al., 1997) and Hazus (www.fema.gov/hazus). Hazus is the US Federal Emergency Management Agency’s methodology for estimating potential losses in disasters. It is a nationally applicable, standardized methodology with models for estimating potential losses from earthquakes, floods and hurricanes. It is used worldwide. Potential loss estimates analysed in Hazus include the following:

- **Physical damage** to residential and commercial buildings, schools, critical facilities and infrastructure.
- **Economic loss**, including lost jobs, business interruptions, repair and reconstruction costs.
- **Social impacts**, including estimates of shelter requirements, displaced households and population exposed, in scenarios, to floods, earthquakes and hurricanes.

Examples of collaboration on loss estimation include The Global Earthquake Model (www.globalquakemodel.org), an international forum to develop, use and share tools and resources for transparent assessment of earthquake risk and Syner-G, a European collaborative research project focusing on systemic seismic vulnerability and risk analysis of buildings, lifelines and infrastructure (www.vce.at/SYNER-G/files/project/proj-overview.html).
DPMs provide planning detail by depicting how many buildings are expected to fall into each damage state. DPMs constructed from damaging earthquakes are available for many regions, such as Southern California following the 1994 Northridge earthquake (Eguchi et al., 1997), South Iceland following the June 2000 earthquakes (Thorvaldsdóttir, 2006), and Athens following the 1999 Athens earthquake (Eleftheriadou and Karabinis, 2011), to name a few.

Different building types have different levels of vulnerability and will, therefore, respond differently to the same level of intensity. To capture the variations in vulnerability, separate DPMs and fragility curves are constructed based on additional properties that influence the vulnerability of the system, such as height, material, age and soil conditions. However, the more detailed vulnerability models require more detailed damage data from past earthquakes, which may not be available. A major drawback of damage predictions has been that they usually do not present the uncertainty involved, although users generally prefer being provided with a precise estimate (Whitman, 1986; Malik et al., 1986). This issue of precision is still important. Collaboration between users and developers during a study provides users with more insight into uncertainty.

Collecting and compiling data to populate inventory databases is the most time-consuming and costly part of any loss study (Thorvaldsdóttir, 1991). Whitman (1986) pointed out that, in principle, it is possible to prepare a very complete inventory of attributes and location data, but that in reality, some sort of compromise is necessary between the level of detail in the data and the effort to collect the data. This is still a valid statement, despite an increase in digitization of building data.

Loss estimates can be the basis for additional information used for planning in the form of cascading disruptive effects during and following the initial impact, making services, networks and urban facilities unavailable during the system failure and recovery processes. Methodologies, such as the disruption index (DI), have been developed to estimate the dysfunction of urban systems on a broad level (Ferreira et al., 2014; Oliveira, 2012).

Systems approach

A systems approach is efficient for finding solutions to complex disaster management problems (Simonovic, 2011; Gillespie, 2004). The systems approach is concerned with good design, i.e., it is a logical and systematic approach to problem solving in which assumptions, goals, objectives, and criteria are clearly defined and specified (Simonovic, 2011). The utility of a systems approach is derived from a critical examination of the simplifying assumptions (Ryan, 2008). Ryan defines a systems approach with the following points:

1. System area is an idealization.
2. Systems have multiple components.
3. The components are interdependent.
4. Systems are organized.
5. Systems have emergent properties.
6. Systems have boundaries.
7. Systems are enduring.
8. Systems affect and are affected by their environment (open system).
9. Systems exhibit feedback (closed system).
10. Systems have non-trivial behaviour (as a result of 8 and 9, above).

Complex systems
The term complex implies multiple components organized in a non-aggregative arrangement and interdependence (Ryan, 2008). The commonest way to quantify complexity is by the amount of information it takes to describe a system (Ryan, 2008). Complex systems tend to evolve over time and have subsystems, which may pursue their own goal (Khisty and Mohaddadi, 2001).

Norman and Kuras (2006) define a complex system as follows:

1. Its structure and behaviour are not deductible, nor may they be inferred from the structure and behaviour of its component parts.
2. Its elements can change in response to pressures from neighbouring elements.
3. It has a large number of useful potential arrangements of its elements.
4. It continually increases its own complexity given a steady influx of energy (raw resources).
5. Independent change agents characterise it.

While complex system models consist of unique individual agents capable of learning, planning and symbolic reasoning, capturing the micro-diversity of a system, system dynamics models capture the aggregate flow of quantitative parameters (Ryan, 2008).

Systems Engineering
Ryan (2008) presents the histories of systems movement and systems engineering. He further states that the history of systems engineering is quite separate from the systems movement (Ryan, 2008). In the conventional systems engineering approach, the project is recursively broken into subparts and put together. Selecting and coordinating the subprojects is the domain of the systems engineer (Bar-Yam, 2005). Ryan (2008) explains that the need for systems engineering arose from problems in the design and implementation of solutions to large-scale engineering challenges spanning multiple engineering disciplines. Large-scale engineering projects that require a multi-disciplinary team of engineers also require a lead engineer whose focus is on how to integrate engineers and their different contributions. Management concerns are, therefore, considered as significant as technical challenges for a systems engineer.

Systems Engineer
A systems engineer requires both engineering and management-governed approaches (Sousa-Poza 2104). In an engineering role, the systems engineer draws on his or her expertise to articulate and derive a robust and credible propositional solution for the problem that is justified by knowledge in and of a field, as well as the understanding of how such a propositional solution may be
realised. In a management role, the systems engineer draws on their intuition, artistry, empathy, and technical skills honed through participation in a situation and systematic observation to efficaciously get things done, while recognising that no ideal or optimal solution or decision can be known in advance. Furthermore, the systems engineer must be aware that the design activity and realisation activity can occur concurrently, calling for changes to the design even as components start being integrated into a system.

**Complex Systems Engineering – Evolutionary Engineering**

Critics of conventional systems engineering state that it lacks the ability to deal with the complex dynamic systems of today (Bar-Yam, 2003; Norman and Kuras, 2006; Pennock and Wade, 2015). Norman and Kuras (2006) suggest an augmentation of systems engineering. They call it complex systems engineering (CSE). They state that CSE is not new or renewed attention to detail, but rather attention to overall coherence (Norman & Kuras, 2006). The original approach emphasizes design and how to integrate fundamental system attributes by design. Whereas the augmentation emphasizes process, potentially recognizing the evolutionary nature through which complex assemblies are often realized (Sousa-Poza, 2014). “Evolutionary engineering processes” is another term used for the augmented approach, emphasizing multiple, parallel, development processes and the variety of possibilities and subsystems and how they act together in a process of innovation (Bar-Yam, 2003). Evolutionary engineering processes focus on creating an environment and processes, rather than a product, in which continuous innovation can occur (Bar-Yam, 2003).

**System Dynamics**

System dynamics is a methodology to understand the behaviour and dynamics of complex systems over time (Forrester, 1998; Goh and Love, 2012). Jay W. Forrester, an electrical and computer engineer at Massachusetts Institute of Technology, applied his background in computer sciences and engineering to the development of computer modelling and analysis of social systems leading to the field of system dynamics. System dynamics arose from seeking a better understanding of management (Forrester, 1998). Forrester proposed that system dynamics could transform management from an art to a science where companies, economies, and all social systems should be modelled as accumulations and rates of flow threaded together by information feedback loops involving delays and nonlinear relationships (Forrester, 1961; Lane, 2007). Initially, the purpose was to learn about their modes of behaviour and understand the underlying causal mechanisms for the purpose of organisational redesign.

Forrester presented the original statement of the foundations of system dynamics. It emphasized four threads: computing technology, computer simulation, strategic decision-making, and the role of feedback in complex systems (Richardson, 2011). Forrester developed a structure for system dynamics using a four-tiered structural hierarchy (Richardson, 2011):

1. Closed system boundary (i.e., dynamic behaviour arises internally)
2. Feedback loops as the basic structural elements within the boundary
3. Level (state) variables representing accumulations within the feedback loops
4. Rate (flow) variables representing activity within the feedback loops.

In 1998, Forrester wrote:

“For the last 30 years, I have been developing a field known as system dynamics. System dynamics combines theory, methods, and philosophy for analyzing the behavior of systems. … Applications have now expanded to environmental change, politics, economic behavior, medicine, engineering, and other fields. System dynamics shows how things change through time.”

System dynamics has been used for a variety of purposes – in particular for flood management and policy analysis. See, for example, Ahmed and Simonovic (2000; 2004), Simonovic and Ahmed (2005), Deegan (2007), Simonovic (2011) and Lehman (2011). It has also been used for accident control (Leveson, 2011; 2015; Goh et al., 2010), finding solutions for complex disaster management problems (Simonovic, 2011; Gillespie, 2004; Patwardhan and Sharma 2005), modelling patterns of breakdown in human and organizational processes in accidents (Kontogiannis, 2012), and formalizing causal interdependencies between technical, organizational and human safety factors (Bouloiz et al., 2013).

The purpose of a fully developed system dynamics model is to show how changes in one, or more, variable affects others. Most system dynamics models are created in four stages (Albin, 1997): conceptualization, formulation, testing, and implementation. The steps associated with these four stages are outlined below.

1. CONCEPTUALIZATION
   a. Define the purpose of the model.
   b. Define the model boundary and identify key variables.
   c. Describe the behaviour or draw the reference modes of the key variables.
   d. Diagram the basic mechanisms, the feedback loops, of the system.

2. FORMULATION
   a. Convert feedback diagrams to level and rate equations.
   b. Estimate and select parameter values.

3. TESTING
   a. Simulate the model and test the dynamic hypothesis.
   b. Test the model’s assumptions.
   c. Test model behaviour and sensitivity to perturbations.

4. IMPLEMENTATION
   a. Test the model’s response to different policies.
   b. Translate study insights into an accessible form.

Model conceptualization, i.e. conceptualization of a problem, is the most important activity in the development of a system dynamics model (Luna-Reyes, 2003). It is the most creative part of the modelling process and requires careful consideration. The discipline of system dynamics has long been based on building fully-specified,
quantitative models of strategic problems (Coyle, 2000). However, there is value in rigorous and disciplined approaches to system descriptions that might be precursors to simulations (Wolstenholme and Coyle, 1983; Coyle, 2000).

A system dynamics approach uses causal loop diagrams (CLD) and stock and flow diagrams (SFD) to conceptualize the basic mechanisms of systems in the form of feedback loops. The feedback loops explain the relationships between the variables. Causal loop diagrams are influence diagrams and have their origin in control engineering (Wolstenholme and Coyle, 1983). Ahmad and Simonovic (2000) explain that CLD’s represent simplified versions of systems to be modelled by depicting influence links, or arrows, between elements within a system. A link is positive when a change in one element causes the same direction of change in the other (both increase or both decrease), indicated by a “+” near the arrowhead in the CLD. A negative link depicts opposing behaviour (an increase/decrease in one component causes a decrease/increase in the other), indicated by a “-” near the arrowhead in the CLD. Feedback loops are formed from two, or more, links. If all arrows are positive then the loop is positive (indicated by a plus sign inside the loop), creating a reinforcing loop. If both positive and negative arrows can be found in the loop, then the loop is negative (indicated by a minus sign inside the loop), creating a balanced loop that seeks equilibrium.

Stock and flow diagrams use stock variables to describe the state of the system at any given moment and flow variables to describe the rate of change in stock variables. Stocks are defined in a variety of ways, depending on the system in question. Examples include the water level in reservoirs (Ahmed and Simonovic, 2000) or the amount of waste at waste disposal sites (Chaerul et al., 2008). Connecting variables (constants, algebraic or graphical relationships) carry information from one element to another. See, for example, Ahmad and Simonovic (2000). System dynamics models are then developed based on SFDs. The models are constructed based on mathematical equations describing the relationships between the variables developed. The variables are solved numerically via simulation, usually with high-level graphical computer programs (Chaerul et al., 2008). Various types of software are available for creating and running SD models, such as Vensim®PLE (Vensim, 2015), Insight Maker (Insightmaker, 2015), and Stella (ISEE, 2105). As noted above, formalizing the system into level and rate equations is the next step after conceptualization.

Figs. 1.6 (Fig. 8, Albin, 1997) and 1.7 (Fig. 7, Albin, 1997) demonstrate the difference between a causal loop diagram (Fig. 1.6) and a stock and flow diagram (Fig. 1.7). Both figures depict the basic mechanism of a company. The arrows in the CLD depict influence. The boxes in the SFD represent stocks, the valves are flows, and the circles are connecting variables (connotations are those used in the Stella software). Both show the cause and effect relationship between inventory and profit that are influenced by various factors. CLDs are simpler and the SFDs are more complex, more informative, and more time consuming to create (Albin, 1997). For example, the CLD shows that shipments affect inventory negatively (more shipments, less inventory). The SFD shows that shipment is a flow variable,
which, when flowing (valve open), moves items from the inventory out of the system. Another difference between the diagrams is that the SFD requires the variable increase-in-attractiveness between delivery-delay and attractiveness-of-firm to create a flow variable that increases the stock of attractiveness-of-firm. Designing a SFD requires thought in creating variables, where a CLD focuses on influence. A modeller may choose to create one or both types of diagrams when conceptualizing the basic mechanism of the system (Albin, 1997).

Figure 1.6. An example of a Casual Loop Diagram: The basic mechanism of a company, i.e., influence factors on inventory and profit (Albin, 1997).

Figure 1.7. An example of a stock and flow diagram. The basic mechanism of a company, i.e., influence factors on inventory and profit (Albin, 1997).
Soft Systems Methodology Definition of Stakeholders

The soft systems methodology (SSM) is an approach to tackling problematic, messy situations (Checkland and Poulter, 2006). These are complex, ill-structured problems of the real world and, thus, much less tidy than the ones posed by natural and physical sciences (Khisty and Mohaddadi, 2001) where the system evolves through learning processes. Soft systems methodology involves:

1. A world-view making the system meaningful
2. Transformation processes that convert input into output
3. External constraints of the system
4. Stakeholders.

The SSM purposely brings human activity systems into a systems approach by making stakeholders part of a system. Stakeholders are grouped into (Checkland and Poulter, 2010):

1. System owners
2. System customers
2 Disaster-Related Management System Methodology

2.1 Disaster-Related Goal and Objectives

Research aim 1: To develop a disaster-related goal and core objectives to reach it.

A goal for disaster-related activities is obtained by rephrasing the UNISDR definition of a disaster in Section 1.2 to:

Have a well-functioning community or society with a low risk of serious disruptions to the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts and to cope with such events using a society’s own resources if they occur.

Core objectives to reach this goal are developed through an expansion of the four phases of the disaster life cycle (NGA, 1979): mitigation, preparedness, response and recovery. The development process is a systems approach. It is an extrapolation of the process used by Coetzee and Van Niekerk (2012) to present the transformation of linear disaster phases (system input) to a normative disaster management cycle (system output), see Fig. 2.1a.

a) Coetzee and Van Niekerk

Original system: Linear disaster phases

Transformation process

Transformed system: Cyclic disaster phases

b) DFM objective development

Original system: 4 cyclic disaster phases: mitigation, preparedness, response and recovery

Transformation process

Transformed system: Eight Disaster Function Management objectives

Thorvalsdóttir and Sighjörnsson, 2014

Figure 2.1. a) The systems approach used by Coetzee and Van Niekerk (2012) to outline the transformation process from a linear to cyclic disaster phases. b) The systems approach used here to outline the transformation process from a cyclic phase system to an objective approach to disaster-related management. The arrow between a) and b) shows how the two approaches are connected.
While Coetzee and Van Niekerk (2012) derived a transformation system to explain the development between a linear system (input) and cyclic system (output), here a transformation was derived that explains the development from a cyclic system (input) to using objectives (output). In other words, Coetzee’s and Van Niekerk’s output is our input. See the arrow between Fig. 2.1 a) and b). The cyclic system used as input is the four cyclic phases of the original disaster life cycle. The objectives used as output are eight objectives derived from the following theoretical argument (Thorvaldsdóttir and Sigbjörnsson 2014), which was developed in context with the disaster-related goal above:

“Disaster-related activities aim to understand disaster risk in order to measurably mitigate disaster risk, to prepare for future events associated with any residual unmitigated risk, to intervene in damaging processes and react to life-threatening situations, to recover from the impact, to provide temporary relief until recovery is accomplished and, finally, learn from the operations in order to improve the system used to meet the objectives.”

From this statement, the eight disaster-related objectives listed in Table 2.1 are derived.

Table 2.1. Disaster-related objectives (Thorvaldsdóttir and Sigbjörnsson, 2014).

<table>
<thead>
<tr>
<th>Sn.</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>To understand disaster risk, its components and context</td>
</tr>
<tr>
<td>2.</td>
<td>To measurably reduce known disaster risk</td>
</tr>
<tr>
<td>3.</td>
<td>To prepare future operations for dealing with future disasters</td>
</tr>
<tr>
<td>4.</td>
<td>To react to damaging processes (including threatening natural processes, collision of natural processes with elements at risk (i.e., impact) and damage sequences*</td>
</tr>
<tr>
<td>5.</td>
<td>To save the lives of those caught in damaging or otherwise injurious processes</td>
</tr>
<tr>
<td>6.</td>
<td>To provide temporary relief of suffering to those affected</td>
</tr>
<tr>
<td>7.</td>
<td>To implement non-temporary measures to return a community to normalcy</td>
</tr>
<tr>
<td>8.</td>
<td>To systematically learn from recent events and implement changes</td>
</tr>
</tbody>
</table>

*See Table 2.13, second column, for main stages of damaging processes

The transformation process from the four sequential disaster phases (mitigation, preparedness, response and recovery) to the eight objectives explains how the objectives are developed. The transformation process involves seven changes to the phases, which are summarised in Table 2.2.

A general literature survey yielded a collection of 20 different models outlining various aspects of disaster-related activities (Table 2.3). The model name and reference are listed in the second column of Table 2.3. The activities within each model were analysed and summarized according to the eight disaster-related objectives (Table 2.1). The summaries are presented in the third column in Table 2.3. In some cases, activities in the models were split in order to match the disaster-function management objectives. For example, nrs. 8.-10. are all
goals that are part of the Hyogo framework for action, but each goal relates to
different disaster-related objectives. Also, risk reduction is split into risk
analysis and mitigation. None of the models included activities in all eight of
the core functions. Collectively, they cover all eight functions, which verifies
that each of the core objectives has been addressed in the literature and is a
valid disaster-related objectives.

Table 2.2. Changes made to the original four disaster phases to develop the eight
disaster-related objectives (Thorvaldsdóttir and Sighjörnsson, 2014).

<table>
<thead>
<tr>
<th>Sn.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Add disaster risk analysis</td>
</tr>
<tr>
<td>2.</td>
<td>Clarify terminology regarding mitigation and preparedness</td>
</tr>
<tr>
<td>3.</td>
<td>Separate rescue and relief operations within response</td>
</tr>
<tr>
<td>4.</td>
<td>Expand impact operations within response</td>
</tr>
<tr>
<td>5.</td>
<td>Plan recovery operations prior to the event</td>
</tr>
<tr>
<td>6.</td>
<td>Expand the definition of preparedness to include preparing for impact, rescue, relief, and recovery operations, and rename it operational preparedness</td>
</tr>
<tr>
<td>7.</td>
<td>Add systematic learning from recent events</td>
</tr>
</tbody>
</table>

Table 2.3. Examples of models that include one or more disaster-related objective

<table>
<thead>
<tr>
<th>Sn.</th>
<th>Models</th>
<th>Activities incorporated into models</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dam-Break Flood Emergency Management System Adapted from UNDRO 1991 (Rodrigues et al., 2001)</td>
<td>Risk mitigation (prevention, preparedness, response (relief) and recovery (reconstruction))</td>
</tr>
<tr>
<td>2.</td>
<td>Comprehensive emergency management (McEntire et al., 2002)</td>
<td>Mainly preparedness and response</td>
</tr>
<tr>
<td>3.</td>
<td>Disaster-resistant community (McEntire et al., 2002)</td>
<td>Mitigation</td>
</tr>
<tr>
<td>4.</td>
<td>Disaster-resilient community (McEntire et al., 2002)</td>
<td>Recovery and, to a lesser extent, mitigation</td>
</tr>
<tr>
<td>5.</td>
<td>Invulnerable development/Comprehensive vulnerability management (McEntire et al., 2002)</td>
<td>Mitigation, preparedness, response and recovery</td>
</tr>
<tr>
<td>6.</td>
<td>Sustainable development and sustainable hazards mitigation (McEntire et al., 2002)</td>
<td>Mitigation and recovery</td>
</tr>
<tr>
<td>8.</td>
<td>Hyogo framework for action goal #1 (UNISDR, 2005)</td>
<td>Disaster prevention, mitigation, vulnerability reduction, preparedness, and integration of disaster risk considerations into sustainable development policies, planning and programming at all levels</td>
</tr>
<tr>
<td>Sn.</td>
<td>Models</td>
<td>Activities incorporated into models</td>
</tr>
<tr>
<td>-----</td>
<td>-----------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>9</td>
<td>Hyogo framework for action goal #2 (UNISDR, 2005)</td>
<td>Developing and strengthening of institutions, mechanisms and capacities at all levels</td>
</tr>
<tr>
<td>10</td>
<td>Hyogo framework for action goal #3 (UNISDR, 2005)</td>
<td>Emergency preparedness, response, and recovery programmed into the reconstruction of affected communities; incorporation of risk reduction approaches</td>
</tr>
<tr>
<td>11</td>
<td>Top-level working processes (goals) for disaster management (Köhler and Wacher, 2006)</td>
<td>Mitigation, preparedness, response, recovery</td>
</tr>
<tr>
<td>12</td>
<td>Spatial modelling in risk management (Mora and Keipi, 2006)</td>
<td>Risk identification, mitigation, risk transfer/retention, and preparedness</td>
</tr>
<tr>
<td>13</td>
<td>Introduction to International Disaster Management (Coopla, 2007)</td>
<td>Mitigation, preparedness, response, recovery</td>
</tr>
<tr>
<td>14</td>
<td>Concept and components of a disaster risk management master plan model (Wenzel et al., 2007)</td>
<td>Disaster risk assessment, response and recovery, preparedness and awareness, mitigation and prevention, and institutional building</td>
</tr>
<tr>
<td>15</td>
<td>Learning from disasters (Poliwoda, 2007)</td>
<td>Learning evolutions</td>
</tr>
<tr>
<td>16</td>
<td>Disaster management framework for urban floods (Price and Vojinovic, 2008)</td>
<td>Pre-disaster/preparation phase (risk analysis, actions, awareness), during disaster/supporting phase (warning, evacuation, services), post-disaster/restoration phase (damage assessment, reconstruction, mitigation)</td>
</tr>
<tr>
<td>17</td>
<td>Scenario based study on information flow and collaboration patterns in disaster management (Sagun et al., 2009)</td>
<td>Pre-, during and post-disaster</td>
</tr>
<tr>
<td>18</td>
<td>Phases in disaster management (Janssen et al., 2010)</td>
<td>Prevention, early signals, response (intervention), recovery, after-crisis care, and evaluation</td>
</tr>
<tr>
<td>19</td>
<td>Disaster risk reduction within climate change (Birkmann, 2010)</td>
<td>Mitigation, preparedness, response, recovery</td>
</tr>
<tr>
<td>20</td>
<td>Disaster-management cycle (Wisner and Adams, 2002)</td>
<td>Sustainable development (prevention and preparedness), disaster impact, and humanitarian action (response and rehabilitation)</td>
</tr>
</tbody>
</table>

### 2.2 Dynamic Relationship between Disaster-Related Objectives

**Research aim 2:** To outline the dynamic relationship between disaster-related objectives.

A system dynamics approach is used to clarify the relationship between the objectives through the following steps:

1. The system environment is defined from a civil engineering perspective to provide context for further development of the system.
2. Activities that contribute to each of the eight disaster-related objectives are defined, thus characterizing the eight disaster functions.
3. Each disaster function is defined as a single feedback loop system where the transformation involves completing projects towards the associated objective.
4. The eight single feedback loops systems are combined into a single complex system through a causal loop diagram.
5. Feedback loops that exist within the complex system are identified.
6. Excitation variables are identified for the complex system, based on the system environment presented in step 1.
7. A list of projects is compiled that summarizes the tasks to be completed based on the causal loop diagram. The tasks are either within a disaster function or due to the dynamic relationship between the disaster functions.
8. Additional stock and flow variables are defined as needed for creating a logical progression of information within the complex system stock and flow diagram.
9. Develop stock and flow diagrams that depict the relationship between the disaster-related objectives based on the causal loop diagram and the project list. This completes the conceptualization stage for a SD model.

2.2.1 System Environment

From a civil engineering perspective, the basic components of a natural disaster can be described in three parts: (i) objects and assets (exposure), in particular the built environment, (ii) natural processes, such as seismicity, volcanic eruptions and river flow, and (iii) the damages natural processes cause to the exposure leading to disruption within a society. The exposure and the natural processes constitute the environment that provides the context for the disaster-related management system addressed in this study. The context can be seen from three circumstances: future, on-going, and past events.

Characterizing a future, unwanted event, i.e. a disaster scenario, includes (Montewka, 2014):

1. A set of plausible scenarios of damage and disruption
2. The likelihood of such scenarios
3. The consequences of the damage and disruption
4. Description of uncertainty.

The discipline of civil engineering provides methodologies, such as earthquake engineering and loss estimation, to address the above list. Gradually or suddenly, a risk turns into an actual event.

Characterizing an on-going event includes:

1. The behaviour of the natural processes
2. The direct threat to exposed elements
3. Impact (collision) and damage sequences

Field assessments are required to determine the actual processes, damages and consequences that are happening on the ground. Eventually, the natural processes subside and return to their normal fluctuation level and damaging processes come to a halt.
Characterizing a past event includes:

1. Identifying possible missed precursors
2. Detailing the natural process behaviour
3. Detailing the impact and damaging processes
4. Detailing the consequence chains.

The above description is not intended to be exhaustive. It is intended to be sufficient to provide context to the remaining subchapters.

2.2.2 Disaster Function Activity

Classical management theory provides the notion of management functions. Examples of general management functions are planning, logistics, and operations. The management of a function is guided by a goal or an objective. The purpose of a disaster-related management function, termed disaster function, is to manage activities so that a disaster-related objective is met. This section provides generalized activities that contribute to each of the objectives (and need to be managed within a disaster function), taking into account the context of the system environment described in chapter 2.2.1. The activities are listed in Tables 2.4-2.11.

Activities around the first objective describe the system environment and set the stage for the remaining objectives. The basic tasks of loss estimation projects are used as a guide to generalize the activities towards the first objective. For the second objective of mitigating risk, a standard engineering approach is employed, such as addressing building codes, land use planning, and building content. Objectives 3-7 are developed using general knowledge about disaster response activities and supported by available contingency planning guides for disasters. The tasks for objective 4 are those that need to be performed in response to imminent or actual impact (collision) of the natural process with the elements at risk (see Table 2.13 on stages of damaging process). As a generalization, impact operations include disaster operations other than rescue, relief and recovery operations. Activities for the last objective are determined using the basic idea of learning from the past to improve the procedures for meeting the first seven objectives.

The lists are not intended to be exhaustive. It is intended to be a realistic representation of disaster-related tasks that are sufficiently broad in detail to demonstrate the dynamic relationship between objectives using a system dynamics approach.
### Table 2.4.  *Disaster Risk Analysis Function, DF1 (Thorvaldsdóttir and Sigbjörnsson, 2015a).*

<table>
<thead>
<tr>
<th>DF#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF1.1</td>
<td>Develop natural process parameters, such as peak values, temporal changes, geographical variations and probabilities of occurrence (hazard analysis through historic and real time recording of hazards).</td>
</tr>
<tr>
<td>DF1.2</td>
<td>Classify, characterize and inventory objects exposed to a hazard, such as structures, people and services.</td>
</tr>
<tr>
<td>DF1.3</td>
<td>Develop damage models and determine vulnerability factors.</td>
</tr>
<tr>
<td>DF1.4</td>
<td>Develop probabilistic or deterministic scenarios, consisting of direct damages, losses and human impact, and cascading damages and consequences, such as loss of function and service disruptions, from a human, material, economic or environmental perspective.</td>
</tr>
</tbody>
</table>

### Table 2.5.  *Mitigation Function, DF2 (Thorvaldsdóttir and Sigbjörnsson, 2015a).*

<table>
<thead>
<tr>
<th>DF#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF2.1</td>
<td>Identify opportunities for reducing risk through land-use planning, building codes, retrofitting, construction inspection, public education in making homes and work places safer, financial insurance, securing building content, and other structural, non-structural, and non-building related measures.</td>
</tr>
<tr>
<td>DF2.2</td>
<td>Analyse each option, based on cost, estimated time of completion, resources required, effectiveness (as in level of risk reduced), benefits per beneficiary, and other relevant aspects.</td>
</tr>
<tr>
<td>DF2.3</td>
<td>Compare benefits of different options and different combinations of options, and select an option or a combination.</td>
</tr>
<tr>
<td>DF2.4</td>
<td>Implement and monitor actual reduced risk and re-evaluate choice against anticipated reduction.</td>
</tr>
</tbody>
</table>

### Table 2.6.  *Operations Preparedness Functions, DF3 (Thorvaldsdóttir and Sigbjörnsson, 2015a).*

<table>
<thead>
<tr>
<th>DF#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF3.1</td>
<td>Develop standard operating procedures for assessment and coordination for impact, rescue, relief, and recovery operations.</td>
</tr>
<tr>
<td>DF3.2</td>
<td>Establish facilities, communications networks, and procure equipment.</td>
</tr>
<tr>
<td>DF3.3</td>
<td>Write contingency plans based on DF1.4 scenario.</td>
</tr>
<tr>
<td>DF3.4</td>
<td>Train personnel and test plans.</td>
</tr>
</tbody>
</table>
Table 2.7.  **Impact Operations Function, DF4 (Thorvalsdóttir and Sigbjörnsson, 2015a).**

<table>
<thead>
<tr>
<th>DF#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF4.1</td>
<td>Monitor natural processes and damaging processes, diagnose current situation and forecast possible turn of events, and convert existing impact contingency plan into an operations plan.</td>
</tr>
<tr>
<td>DF4.2</td>
<td>Protect population to avoid the need for rescue operations through warnings, directives, closing off areas, and evacuations, to the greatest extent possible.</td>
</tr>
<tr>
<td>DF4.3</td>
<td>Protect property by redirecting natural processes, such as sandbagging, digging diversion trenches, cooling lava and control of reservoir spillways.</td>
</tr>
<tr>
<td>DF4.4</td>
<td>Halt or reduce on-going damaging process by intervening, such as stopping leaking gas lines, putting out fires, and avoiding potential explosions.</td>
</tr>
</tbody>
</table>

Table 2.8.  **Rescue Operations Function, DF5 (Thorvalsdóttir and Sigbjörnsson, 2015a).**

<table>
<thead>
<tr>
<th>DF#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF5.1</td>
<td>Perform reconnaissance missions to gain an overview and convert rescue contingency plan to an operations plan.</td>
</tr>
<tr>
<td>DF5.2</td>
<td>Search for, locate, access, medically assist people and ensure their safety.</td>
</tr>
<tr>
<td>DF5.3</td>
<td>Transport victims and hand them and information about them over to medical facilities or other parties.</td>
</tr>
<tr>
<td>DF5.4</td>
<td>Perform support operations, such as crowd control and closing off of hazardous areas.</td>
</tr>
</tbody>
</table>

Table 2.9.  **Relief Operations Function, DF6 (Thorvalsdóttir and Sigbjörnsson, 2015a).**

<table>
<thead>
<tr>
<th>DF#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF6.1</td>
<td>Perform needs assessments to get an overview and convert relief contingency plan to an operations plan.</td>
</tr>
<tr>
<td>DF6.2</td>
<td>Sustain life and provide temporary relief through providing for basic needs, such as shelter, water, food, cooking facilities, heat, clothing, fuel, physical and mental health, and financial assistance.</td>
</tr>
<tr>
<td>DF6.3</td>
<td>Make temporary repairs to homes, roads and bridges, etc.</td>
</tr>
<tr>
<td>DF6.4</td>
<td>Make temporary repairs for temporary renewals of services, such as intermittent power supply.</td>
</tr>
<tr>
<td>DF6.5</td>
<td>Perform support operations, such as crowd control and closing off of hazardous areas.</td>
</tr>
</tbody>
</table>
Table 2.10. Recovery Operations Function, DF7 (Thorvaldsdóttir and Sighþórsson, 2015a).

<table>
<thead>
<tr>
<th>DF#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF7.1</td>
<td>Perform a situation assessment to get an overview and convert contingency plan to an operations plan.</td>
</tr>
<tr>
<td>DF7.2</td>
<td>Restoration processes: remove rubble and clean up the affected area, reunite family members and bury the deceased, fully restore services and reconstruct the physical environment.</td>
</tr>
<tr>
<td>DF7.3</td>
<td>Reform processes: renew urban planning and revise building codes.</td>
</tr>
<tr>
<td>DF7.4</td>
<td>Re-establish livelihoods, and support the physical and mental rehabilitation of people, their hope and eagerness for the future.</td>
</tr>
</tbody>
</table>

Table 2.11. Systematic Learning Function, DF8 (Thorvaldsdóttir and Sighþórsson, 2015a).

<table>
<thead>
<tr>
<th>DF#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF8.1</td>
<td>Have guidelines available for performing systematic learning, both identifying lessons and implementing remedies prior to the next event.</td>
</tr>
<tr>
<td>DF8.2</td>
<td>Review existing knowledge and methods to develop disaster scenarios (DF1). Based on the actual event, evaluate the need for changes and make them.</td>
</tr>
<tr>
<td>DF8.3</td>
<td>Review existing knowledge and methods, determine mitigating options and implement them (DF2), based on the actual event. Evaluate the need for changes and make them.</td>
</tr>
<tr>
<td>DF8.4</td>
<td>Determine the effectiveness and efficiency of the operations (DF4-7), relative to the actual damaging process and consequences and use the results to review existing procedures, training, facilities, and equipment, based on the evaluation of the current system (DF3). Identify necessary changes in operational procedures and make them.</td>
</tr>
</tbody>
</table>

Various activities within different functions are similar, but have different objectives. For example, both DF#1 and DF#4 need to record hazard activity. DF#1 does it to calculate risk, DF#4 does it to warn of an imminent risk that calls for reaction. The term monitor is used in DF#4 to place an emphasis on the need to keep alert, which is not of the same importance in DF#1. Another example is the activity of learning. When recovery takes place, in order to better rebuild, there needs to be a learning process on how to rebuild better. This learning process in recovery operations is different to the learning process in DF#8. The latter is a review of the system and procedures of each DF and asks, for example, how successful the process was to ensure that recovery is focused on better rebuilding. Many activities are cross-cutting in that they relate to many functions, for example, communication, developing new technology, or gender issues.

2.2.3 Disaster Function as Single Feedback Loop

Each of the eight disaster functions is defined as a single feedback loop system (Fig. 2.2). The transformation process is defined as activities associated with the completion of projects, i.e., a management process in line with the origin of system dynamics. A source creates a need for new projects according to an inflow rate (rate of new projects). The transformation process completes projects at an outflow rate. The difference between the inflow and outflow rates
is the level of incomplete projects (the stock level). The finished projects are placed into the environment. The environment provides feedback to the source, creating the need for new or adapted projects. Defining the environment within the system creates a closed loop system.

Input and output control factors affect the input and output flow rates. The control factors are variables that define the rate of project accomplishment, such as risk awareness, political interest, funding, resources available, and level of education of disaster managers. Input and output control factors can be in the form of feedback loops to set gauges for control, for example, to set time limits, monitor quality assurance, insert level of acceptable risk into the system, and many others.

![Diagram](image)

Thorvaldsdóttir and Sighjörnsson, 2015a

**Figure 2.2. A disaster function presented as a single feedback-loop system.**

### 2.2.4 Causal Loop Diagram

A dynamic, disaster-related management system is created by integrating the single loop feedback systems. The system boundary is determined by answering Forrester’s (1998) question: “Where is the boundary that encompasses the smallest number of components, within which the dynamic behaviour under study is generated?” In this study, these are the eight core objectives addressed in Research aim #1. Therefore, eight, single-loop feedback systems are within the integrated system, incorporating the eight disaster functions. A causal loop diagram is used to depict the relationship between the objectives/functions (Fig. 2.3). The CLD was drawn based on how changes in one disaster function affect other functions. The arrows indicate projects needed to be completed to meet the objectives. These projects can be due to changes in the originating function leading to changes in the second function, one function feeding information to another function, or other influences that require action. The CLD does not portray influences between DFs if no activity is involved, because such influence does not call for action within the system and is not relevant to a management system. The activities listed in Tables 2.4-2.12 were
used as a basis of logic. The resulting causes and effects among the disaster-functions are described in narrative form in Table 2.12.

The arrows are positive when an increase in the original disaster-function results in an increase in the influenced disaster-function and negative when an increase or decrease in the original disaster-function has an opposite effect in the influenced disaster function. An arrow will be positive or negative depending on how the information in Tables 2.4-2.12 is used to define how the disaster functions influence each other. For example, line 13 focuses on the longer the recovery time (increase in time and effort), where another modeller may focus on the shorter the recovery time (decrease in time and effort).

Table 2.12. *Cause and effect relations between disaster functions used to draw the casual loop diagram of Figure 2.3 (Thorvaldsdóttir and Sighjörnsson, 2015a).*

<table>
<thead>
<tr>
<th>Narrative</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Increasing knowledge of risk processes (1+) improves range of possibilities to mitigate risk (2+). Positive</td>
</tr>
<tr>
<td>2.</td>
<td>The more risk mitigated (2+), the lower risk becomes (1-). Negative</td>
</tr>
<tr>
<td>3.</td>
<td>The more risk mitigated (2+), the less need for contingency plans (3-). Negative</td>
</tr>
<tr>
<td>4.</td>
<td>Increasing knowledge of risk processes (1+) improves the ability to create relevant and objective contingency plans (3+). Positive</td>
</tr>
<tr>
<td>5.</td>
<td>The clearer the objective of a plan (3+), the clearer the required type of risk information needed (1+). Positive</td>
</tr>
<tr>
<td>6.</td>
<td>The better the contingency plans (3+), the less time will be spent on developing operational plans during an event (4-, 5-, 6-, 7-). Negative</td>
</tr>
<tr>
<td>7.</td>
<td>The more effective the impact operations (4+), the less lives are threatened and the less need for rescue (5-). Negative</td>
</tr>
<tr>
<td>8.</td>
<td>The more effective the impact operations (4+), the less need for temporary relief (6-). Negative</td>
</tr>
<tr>
<td>9.</td>
<td>The more effective the impact operations (4+), the less damage and the less need for recovery (7-). Negative</td>
</tr>
<tr>
<td>10.</td>
<td>The more people rescued (5+), the more need for temporary relief (6+). Positive</td>
</tr>
<tr>
<td>11.</td>
<td>The more people who are rescued (5+), the greater the need for rehabilitation (7+). Positive</td>
</tr>
<tr>
<td>12.</td>
<td>The better temporary relief considers recovery aspects (6+), the less new issues arise during the recovery time (7-). Negative</td>
</tr>
<tr>
<td>13.</td>
<td>The longer the recovery time (7+), the more attention is needed to temporary relief (6+). Positive</td>
</tr>
<tr>
<td>14.</td>
<td>The more operations were needed (4+, 5+, 6+, 7+), the greater the need to learn from them and improve (8+). Positive</td>
</tr>
<tr>
<td>15.</td>
<td>The better the lessons are identified (8+), the better the changes to pre-operation activities will be (1+, 2+, 3+). Positive</td>
</tr>
<tr>
<td>16.</td>
<td>The more precisely the information about past disasters is generated as part of a risk analysis objective (1+), the more likely that forecasting during impact operations will be beneficial (4+). Positive</td>
</tr>
<tr>
<td>17.</td>
<td>The more knowledge generated during activities to mitigate risk about building codes (2+), the less effort required to reach recovery objectives (7-). Negative</td>
</tr>
</tbody>
</table>
2.2.5 Complex System Feedback Loops

Feedback loops within a CLD show how information is fed back into the original disaster function in order to improve the information from that function. The CLD (Figure 2.3) depicts eight stocks and three feedback loops:

1. Normal Loop: objectives 1, 2 and 3 correspond to a normal, functioning society, living with the threat of possible damaging processes, and thus a risk of a disrupted society.
2. Disrupted Loop: objectives 4, 5, 6 and 7 correspond to on-going damaging processes and a disrupted society.
3. Changing Loop: objective 8 and loops 1 and 2 correspond to a recovered society, intending to learn from the event experience and change the functioning of society.

The normal loop (Fig. 2.4) represents feedback amongst risk analysers, mitigators, and operations preparedness planners – the three pre-operations disaster-functions pertaining to lines 1-6 in Table 2.12. For example, risk analysers may identify a flood threat and inform mitigators. However, the mitigators require specific information, so mitigators give feedback to the analysers if the risk needs further analysis from the mitigation perspective. The same goes for the preparedness planners. Risk analysers inform planners, who give analysers feedback to ensure that the risk information is relevant to preparedness activities. Once the mitigation efforts are completed, information about the resulting situation is sent to the analysers to update risk information and to planners to adapt the preparedness plans to the lowered risk level.
The disrupted loop (Fig. 2.5) represents feedback amongst the four operations functions, pertaining to lines 7 to 12 in Table 2.12. For example, a flood event may start with a weather forecast leading to impact operations, such as warnings about increased rain and river flooding, increased monitoring of weather forecasts and river discharge, sandbagging to contain rivers, digging trenches to redirect rivers, and telling people to evacuate. Successful impact operations reduce the need for other operations. When highly effective, there is no need for rescue operations. However, if impact operations are not performed or are unsuccessful, rescue operations may be required. The more people who are evacuate or rescued, the more need there will be for temporary activities, like shelters. The more successful the impact operations are, the less recovery effort is needed for uniting families, burials, urban planning, reconstruction, rehabilitation, etc. The relationship between rescue and recovery will depend on the size of the event. For example, all the people aboard a sunken ferry may require rescue, while only a small portion of the affected population may need rescuing in a large earthquake. The relationship between relief and recovery is strong, since relief is necessary until recovery is complete.

The improvement loop (Fig. 2.6) captures the entire CLD and links the earlier-mentioned loops into a single system (all lines in Table 2.12). It represents learning within a society that takes experience from the disrupted loop to improve the normal loop. The transformative activities in the improvement loop are those of the systematic learning function. It is a balanced loop because the more the society is disrupted, the more it needs to change. The more it changes, the better the society will function. The better the society functions, the less it will be disrupted. The improvement loop will provide a new and more resilient society.

Two arrows in Fig. 2.3 are between loops. See the last two lines in Table 2.12. The first is from risk analysis (1) to impact operations (4), and the second arrow is from mitigation (2) to recovery (7). The idea here is that projects aimed at risk analysis and mitigation produce significant information that can be used in impact operations and recovery, and such information sharing should be planned for.
Figure 2.5. Disrupted feedback loop: impact, rescue, relief and recovery functions.

Figure 2.6. Improvement feedback loop: Disrupted society, changing society and normal society.

The normal loop can theoretically exist on its own if no disaster ever occurs, but its sole purpose comes from the possibility of the disrupted loop being activated. The disrupted loop can be considered the core loop since its actions can exist as a system without the other two sectors. i.e., one can respond without any preparedness and without improving the system for possible future events. The activation of the disrupted loop also activates the improvement loop. The improvement loop can only function if a disruption has occurred. Therefore, not all objectives will be relevant at any given moment. Identifying which objectives are relevant and which loops should be active provides a metric to measure the functionality of information sharing between the disaster functions.
2.2.6 System Excitation

Exogenous variables stemming from the environment (natural and damaging processes) activate the system. Non-hazardous natural processes that have the potential to increase their fluctuation to a hazardous level activate the normal loop by calling for an analysis of the likelihood of occurrence, impact and consequences of the event. Natural processes that have reached a hazardous or damaging state and/or consequential damages activate the disrupted loop.

These variables directly affect two of the disaster functions (Fig. 2.7): risk analysis (1) and impact operations (4). Risk analysers monitor natural processes to understand and develop risk variables and probabilities, which in turn feed information to mitigation and operations preparedness functions, as explained in the normal loop. Impact operators monitor both natural and damaging processes and activate rescue, relief and recovery operations functions, as explained for the disrupted loop above, when a hazard reaches a threatening level and/or damages occur.

A natural process is, for the most part, unpredictable moment by moment and can increase, decrease or cease at any time. The corresponding damages react accordingly. Therefore, a turn of events is not related to predetermined phases, but creates varying combinations of damage processes and damage-injury-disruption (DID) states. Table 2.13 presents seven examples of combinations of different stages of damaging processes and DID states, activating different disaster functions.

While these exogenous variables activate the system, various endogenous variables keep the system active. For example, how system managers perceive risk, what is considered acceptable risk, what is the value of a human life, and what human and economic resources are available, are all factors that will affect if and how the system is kept active. Such factors are incorporated into the system as input and output control factors (see Chapter 2.2.3).
**Table 2.13. Damage process stages, DID, and DF (adapted from Thorvaldsdóttir and Sighjörnsson, 2014)**

<table>
<thead>
<tr>
<th>Sn.</th>
<th>Main stages of a damaging process</th>
<th>Damage-Injury-Disruption State</th>
<th>Relevant Disaster Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Normal hazard fluctuation: cause no alarm</td>
<td>Normal function of society</td>
<td>Disaster risk analysis. Mitigation and operations preparedness</td>
</tr>
<tr>
<td>2.</td>
<td>Precursors alert to possible further developments</td>
<td>No or minor damage</td>
<td>Imp ops* monitoring</td>
</tr>
<tr>
<td>3.</td>
<td>Precursors magnify, indicating a serious hazard</td>
<td>No or minor damage</td>
<td>Imp ops pre-damage activities</td>
</tr>
<tr>
<td>4.</td>
<td>Main event initiating damage sequences</td>
<td>Damage, injury and disruption</td>
<td>Imp ops, res ops*, rel ops*</td>
</tr>
<tr>
<td>5.</td>
<td>Secondary events: smaller events causing further damages</td>
<td>Additional damage to damaged elements and new damage</td>
<td>Imp ops, res ops, rel ops</td>
</tr>
<tr>
<td>6.</td>
<td>Tail end: natural processes die down and come to an end</td>
<td>Additional damage decreases and eventually ceases</td>
<td>Imp ops, res ops, rel ops</td>
</tr>
<tr>
<td>7.</td>
<td>Normal hazard fluctuation: cause no alarm</td>
<td>Stable state of damage, injury and disruption</td>
<td>Imp ops, res ops, rel ops, rec ops*</td>
</tr>
</tbody>
</table>

*Imp ops: impact operations; res ops: rescue operations; rel ops: relief operations; rec ops: recovery operations.

### 2.2.7 Minimum Projects List

Two types of projects have been identified.

- Type I disaster function activity (Table 2.14, column 1): projects associated with performing the theorized disaster function activities in Tables 2.4-2.11
- Type II dynamic activity (Table 2.14, column 2): projects produced due to the dynamic relationships in Table 2.12

Type II projects take information produced by type I projects for one disaster function and send it to other disaster functions. The type II projects are defined by the arrows in Fig. 2.3 that point away from the numbered boxes. Column 3, Table 2.14, shows whether information flows within a feedback loop (FBL) or between loops. Movement between FBLs is information created in one loop for another loop, ready to be used when the receiving loop is activated.

The projects listed in Table 2.14 represent the minimum number of projects that need to be performed to address the core disaster-related objectives and define a minimum system boundary for a disaster-related management system.

### 2.2.8 Stock and Flow Diagrams

The SFDs presented herein constitute theoretically derived specifications for modelling the disaster-related management system in the study. The activities listed in Table 2.14, columns 1 and 2, are the initial building blocks for the SFD. The SFD was created using Vensim® PLE software. The software uses the
notation depicted in Figure 2.8. The cloud denotes entry into or exit from the system. Arrows denote connecting variables.

**Table 2.14.** Minimum projects list: Projects to be completed, as a minimum, to reach the disaster-related objectives (adapted from Thorvalsdóttir and Sighjörnsson, 2015a).

<table>
<thead>
<tr>
<th>Type I</th>
<th>Type II (Row # in Table 2.12 are in parenthesis)</th>
<th>FBL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF1.1-DF1.4</td>
<td>1. Send scenario information to mitigators (1)</td>
<td>NL</td>
</tr>
<tr>
<td></td>
<td>2. Send scenario information to preparedness planners (4)</td>
<td>NL</td>
</tr>
<tr>
<td></td>
<td>3. Send scenario information for impact operators (16)</td>
<td>BL</td>
</tr>
<tr>
<td>DF2.1-DF2.4</td>
<td>1. Send information on actual reduced risk to risk analysers (2)</td>
<td>NL</td>
</tr>
<tr>
<td></td>
<td>2. Send updates on reduced risk to preparedness planners (3)</td>
<td>NL</td>
</tr>
<tr>
<td></td>
<td>3. Have information ready to send when recovery operations are activated (17)</td>
<td>BL</td>
</tr>
<tr>
<td>DF3.1-DF3.4</td>
<td>1. Have plans, templates and information ready when impact operations are activated (6)</td>
<td>BL</td>
</tr>
<tr>
<td></td>
<td>2. Have plans, templates and information ready when rescue operations are activated (6)</td>
<td>BL</td>
</tr>
<tr>
<td></td>
<td>3. Have plans, templates and information ready when relief operations are activated (6)</td>
<td>BL</td>
</tr>
<tr>
<td></td>
<td>4. Have plans, templates and information ready when recovery operations are activated (6)</td>
<td>BL</td>
</tr>
<tr>
<td></td>
<td>5. Send feedback on the relevancy of the risk info to risk staff (5)</td>
<td>NL</td>
</tr>
<tr>
<td>DF4.1-DF4.4</td>
<td>1. Send real-time impact information to rescue operators (7)</td>
<td>DL</td>
</tr>
<tr>
<td></td>
<td>2. Send real-time impact information to relief operators (8)</td>
<td>DL</td>
</tr>
<tr>
<td></td>
<td>3. Send real-time impact information to recovery operators (9)</td>
<td>DL</td>
</tr>
<tr>
<td></td>
<td>4. Send information about impact operations to learning staff (14)</td>
<td>IL</td>
</tr>
<tr>
<td>DF5.1-DF5.4</td>
<td>1. Send real-time rescue information to relief operators (10)</td>
<td>DL</td>
</tr>
<tr>
<td></td>
<td>2. Send real-time rescue information to recovery operators (11)</td>
<td>DL</td>
</tr>
<tr>
<td></td>
<td>3. Send information about rescue ops to learning staff (14)</td>
<td>IL</td>
</tr>
<tr>
<td>DF6.1-DF6.5</td>
<td>1. Send real-time relief information to recovery operators (12)</td>
<td>DL</td>
</tr>
<tr>
<td></td>
<td>2. Send information about relief operations to learning staff (14)</td>
<td>IL</td>
</tr>
<tr>
<td>DF7.1-DF7.4</td>
<td>1. Send real-time recovery information to relief operators (13)</td>
<td>DL</td>
</tr>
<tr>
<td></td>
<td>2. Send information about recovery operations to learning staff (14)</td>
<td>IL</td>
</tr>
<tr>
<td>DF8.1-DF8.4</td>
<td>1. Send identified lessons to risk analysers (15)</td>
<td>IL</td>
</tr>
<tr>
<td></td>
<td>2. Send identified lessons to mitigators (15)</td>
<td>IL</td>
</tr>
<tr>
<td></td>
<td>3. Send identified lessons to preparedness planners (15)</td>
<td>IL</td>
</tr>
</tbody>
</table>

*FBL feedback loop; NL normal loop; DL disrupted loop; IL improvement loop; BL between loops*

In addition to the variables listed in Table 2.14, various stocks and variables have been defined in order to create a logical progression of information flow needed to create the SFD, mainly stocks that collect accomplished projects and variables that determine the need for projects. The variables defined for the development of the SFD are listed in Table 2.15. For the sake of presentation, the SFD for the disaster-related management system based on the eight disaster-related systems is presented in five figures, Figures 2.9-2.13.
Figure 2.8. Basic components of a stock and flow diagram using Vensim® PLE software.

Table 2.15. Stock and flow variables created in context with disaster-related objectives to draw stock and flow diagrams.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJ&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Objectives as stocks of a backlog of projects, where i is the objective number.</td>
</tr>
<tr>
<td>FLV&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Flow variables from stocks of backlog of projects to stocks of accomplished projects, where i is the objective number.</td>
</tr>
<tr>
<td>FLV&lt;sub&gt;ij&lt;/sub&gt;</td>
<td>Project information (Table 2.14, column 2) between stocks through flow variables, where i is the objective number and j is the activities number.</td>
</tr>
<tr>
<td>CCV&lt;sub&gt;ij&lt;/sub&gt;</td>
<td>Project information (Table 2.14, column 2) when not between stocks through connecting variables, where i is the objective number and j is the activity number.</td>
</tr>
<tr>
<td>DFA&lt;sub&gt;ij&lt;/sub&gt;</td>
<td>Disaster-function activities (Table 2.14, column 1), where i is the objective number and j is the activity number.</td>
</tr>
<tr>
<td>EXV&lt;sub&gt;h&lt;/sub&gt;</td>
<td>Excitation variable, where h depicts hazard.</td>
</tr>
<tr>
<td>EXV&lt;sub&gt;d&lt;/sub&gt;</td>
<td>Excitation variable, where d depicts damage.</td>
</tr>
<tr>
<td>FLV(EXV&lt;sub&gt;h&lt;/sub&gt;),</td>
<td>Flow variable influenced by the hazard excitation variable.</td>
</tr>
<tr>
<td>FLV(EXV&lt;sub&gt;d&lt;/sub&gt;)</td>
<td>Flow variable influenced by the damage excitation variable.</td>
</tr>
<tr>
<td>FLV(EXV&lt;sub&gt;h&lt;/sub&gt;, EXV&lt;sub&gt;d&lt;/sub&gt;)</td>
<td>Flow variable influenced by the excitation variables.</td>
</tr>
</tbody>
</table>

i=1-8 and j=1-4 except for when i=3, then j=1-5.

Fig. 2.9 presents the normal loop and information provided by the loop that is ready to be used during the activation of operations. Acceptable losses and the current state of the operations system are inserted into the normal loop to determine the need for mitigation and preparedness projects, respectively.

Figs. 2.10–2.12 present the disrupted loop and how it links to the normal and improvement loops.

Fig. 2.10 shows how information from the normal loop is used in projects in impact operations when excitation variables activate the disrupted loop. If the hazard level goes beyond what is acceptable, or if damages occur, the disrupted loop is activated. This figure shows how impact operations create information that activates rescue, relief, and recovery operations through connecting variables and creates a backlog for systematic learning projects.
Adapted from Thorvaldsdóttir and Sighjörnsson, 2015a

Figure 2.9. Stock and flow diagram for the normal loop. A continuation of FLV1.3 is in Fig. 2.10, and of FLV2.3 is in Fig. 2.11.
Adpated from Thorvaldsdóttir and Sigbjörnsson, 2015a

Figure 2.10. Stock and flow diagram for activation of impact operations. A continuation of CCV4.1-4.3 is in Fig. 2.11. A continuation of FLV4.1-4.3 is in Fig 2.12.
Fig. 2.11 shows how the connecting variables activate the conversion of the contingency plans, made ready by the normal loop, into operations plans. The plans then lead to rescue, relief and recovery operation activities. The figure shows how mitigation information produced in the normal loop is used in reform projects for recovery operations.

**Figure 2.11. Stock and flow Diagram for activation of the rescue, relief, and recovery operations. Continued from FLV2.3 in Fig. 2.11.**
Fig. 2.12 shows how rescue, relief and recovery activities feed into the flow out of each of the project backlogs and contribute to accomplishing the associated projects. Connecting variables between rescue, relief and recovery are shown. The completed projects then provide information for creating a project backlog for systematic learning.

Figure 2.12. Stock and flow diagram for impact, rescue, relief, and recovery operations. Continued from FLV4.1 - 4.3 in Fig 2.10. The continuation of DF8.1 is in Fig. 2.13.
Fig. 2.13 presents the objectives, activities, and variables in the improvement loop. It depicts how information is generated from the operations objectives to the normal loop through the learning process. This generates new activities in the normal loop since current working procedures need to be adjusted and improved according the lessons learned.

Figure 2.13. Stock and flow diagram for the improvement loop.

2.3 S.M.A.R.T. Disaster-Related Objectives

Research aim 3: To develop a method to incorporate specific, measurable, assignable, realistic, and time-related disaster-related objectives into disaster-related management activities.
The S.M.A.R.T. criteria are listed in the first two columns of Table 2.16. The last column describes how the S.M.A.R.T. criteria are adapted to disaster-related systems. The smarting is not a one-time thing, but develops along with the project. Doran (1981) assumes that a known group applies the objectives. However, in the case of developing a disaster-related system, stakeholders have yet to be identified or invited to the project.

Table 2.16.  S.M.A.R.T. criteria (Doran, 1981).

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
<th>Disaster-related</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific</td>
<td>Target a specific area for improvement</td>
<td>Target specific, disaster-related objectives to be improved</td>
</tr>
<tr>
<td>Measurable</td>
<td>Quantify, or at least suggest, an indicator of progress</td>
<td>Measure gap between the expected projects to be completed and the actual projects completed</td>
</tr>
<tr>
<td>Assignable</td>
<td>Specify who will do it</td>
<td>Assign stakeholders to projects</td>
</tr>
<tr>
<td>Realistic</td>
<td>State what results can realistically be achieved, given available resources</td>
<td>Ensure sufficient resources to complete the projects</td>
</tr>
<tr>
<td>Time-related</td>
<td>Specify when the result(s) can be achieved</td>
<td>Prioritize incomplete projects based on feedback loops</td>
</tr>
</tbody>
</table>

2.3.1 Specific
Making disaster-related objectives specific means adapting the objective to a given environment, i.e., to a given problem. The specifics state the boundaries and conditions for the objects, the natural process and their environment.

2.3.2 Measurable
Making a disaster-related objective measureable means creating a virtual, disaster-related system to use as a metric to measure the gap between the expected and actual projects, and measure the functionality of normal, disrupted and changing loops.

2.3.3 Assignable
Making disaster-related objectives assignable means ensuring that appropriate stakeholders have been identified and are available to take on the tasks needed to meet the objective. Stakeholder types should be taken into consideration: owners, customers (or beneficiaries), and actors.

2.3.4 Realistic
Making disaster-related objectives realistic means ensuring that there are sufficient resources ready and available to complete the tasks needed to meet the objective.

2.3.5 Time-Related
Making the objectives time-related means knowing the critical order in which the projects need to be completed in order to meet all the objectives. This order
is to be followed when deadlines are set for milestones. The arrows within the SFD in Figs. 2.9-2.13 indicate the required order.

2.4 Daily-Disaster Framework

Research aim 4: To develop a framework depicting the key components for maintaining a well-functioning society and coping with disasters.

The framework is built in three steps. The first step is to break a disaster-related goal into basic components and present them in a Venn diagram. The second step creates a new Venn diagram based on the disaster-related goal components using the components of the SLF, which provides a model for a daily management system (SLF is for livelihoods, any type of daily management system model could have been used). Finally, the remaining blank circles are filled with the logical components in terms of the content of neighbouring circles. This work is based on Fig. 3 in Thorvaldsdóttir and Sigbjörnsson (2015).

2.4.1 Disaster-Related Goal

Based on the goal in Section 2.1, a disaster-related goal is comprised of three components:

1. The desire to have a well-functioning society
2. The problem of disruption and losses (due to non-specified causes)
3. The solution of coping by using a society’s own resources, where coping is to contend with difficulties and act to overcome them (www.thefreedictionary.com/cope, 2105).

The goal has a broad perspective. The research aim is limited to goals, objectives and methods for natural, disaster-related activities from civil and environmental engineering, and management perspectives. To narrow the goal in line with the research aim, the notion of a well-functioning society is reduced to a well-functioning physical and natural environment, which, when damaged, will affect human, financial and social assets. The above goal is narrowed to this perspective by:

1. Reducing the concept of society to man-made or naturally occurring objects.
2. Constraining disruption and losses to damages and injuries to objects and disruption of their functioning caused by natural processes.
3. Converting the concept of coping to the concept of managing activities, which tend to be difficulties and the acts to overcome them.

These adjustments lead to the following components for a natural disaster related goal from an engineering-management perspective:
1. The desire to have well-functioning objects
2. The natural processes, such as earthquake, floods and volcanic eruptions that cause damages, injuries and disruption.
3. The problem of damages and injuries to objects and disruption of their functioning
4. The solution seen as the ability to manage using a society’s own resources.

Figure 2.14 shows a Venn diagram of the components of a natural disaster related goal reduced to the perspective of engineering management. The upper two circles portray the desire to have fully functioning objects, the cause of a problem (natural processes) and the problem itself (damage and disruption). The lower circle portrays the solution in the form of management. The value of the Venn diagram is that it highlights the relationship between well-functioning objects and natural processes through damage, injury and disruption and highlights the need to link management with a well-functioning community, the cause of the problem and the problem itself. Thus the Venn diagram is a step in the development of the daily-disaster framework, which is completed in Section 2.4.2.

**Figure 2.14.** Venn diagram of the components of a disaster-related goal: desire, problem, cause, and solution.

### 2.4.2 Livelihood-Disaster Framework

The objectives of sustaining a livelihood can be seen as a subset of objectives needed to sustain daily life. The five components of the Sustainable Livelihood Framework (Fig. 1.5) define management components for maintaining a livelihood and are used to characterize daily life. They are: #1 livelihood assets, #2 vulnerability context, #3 transforming structures and processes, #4 livelihood strategies and #5 livelihood outcomes. Adjusting the components in Fig. 2.14 to the SLF leads to Fig. 2.15. The adjustment is based on the following:

1. The desire to have fully functioning objects, is adjusted to functioning assets (SLF component #1).
2. Problem and cause
a. Problems due to damage, injury and disruption to assets relate to issues of vulnerability (SLF component #2).
b. The cause also relates to the issue of vulnerability (SLF component #2).

3. Management issues relate to transformation structures and processes (SLF component #3).

The terms assets, damage, injury and disruption, shocks (natural processes), and transporting structures and processes replace the terms in Fig. 2.14, filling four of the seven outer circles in the Venn diagram in Fig. 2.15. The two remaining SLF components focus on the goal (the future) or the situation (the present):

4. Livelihood strategy (future situation)
5. Livelihood outcomes (present situation)

SLF components #4 and #5 are opposite ends of a single activity. One is either setting a strategy or observing the outcome of the strategy. These components are, therefore, placed in the same slot in Fig. 2.15, but represent different time frames. They are placed in the centre, because they represent the purpose of the system; to have a good strategy and to have a good outcome.

Figure 2.15. Venn diagram for the five components of a livelihood perspective on management.

The two remaining slots in Fig. 2.15 are filled based on the following logic:

1. The left, empty slot depicts the relationship between functioning assets and the transporting structures and processes. This relationship can be characterised by the daily objectives of the associated stakeholders.
2. The right, empty slot depicts the relationship between the shock and the transporting structures and processes. This relationship can be characterised by the set of objectives that deal with hazardous, natural
processes threatening to damage, injure or disrupt objects. Therefore, the disaster-related objectives fill this slot.

Fig. 2.16 presents the final livelihood disaster framework, which is one version of a daily-disaster framework. To summarise, this daily-disaster framework states that to ensure that both daily and disaster-related aspects are taken into account during disaster-related management, the following components have to be included:

1. Strategy (or outcome) of the intended daily system (e.g. a livelihood)
2. Objects of a well-functioning society (this can be expanded for other fields, such as the mental health of the population.)
3. Natural processes
4. Damages, injury and disruption associated with the objectives. For a future event, this is characterized as fragility and vulnerability or damage distribution. For a real or past event, it is characterized by actual occurrences.
5. Transporting structures and processes, such as actors and legal aspects
6. Daily objectives of the associated stakeholders
7. Disaster-related objectives

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Thorvaldsdóttir and Sigbjörnsson, 2015

*Figure 2.16. A daily-disaster framework depicting key components of both disaster-related and daily management, based on a livelihood perspective.*

Table 2.17 shows how the seven components of the daily-disaster framework correspond to the three basic components of the disaster-related goal.
Table 2.17  Components of a disaster-related goal and disaster-related framework.

<table>
<thead>
<tr>
<th>Disaster-related goal</th>
<th>Disaster-related framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Desire for a well-functioning society</td>
<td>1. Strategy</td>
</tr>
<tr>
<td>2. Problem</td>
<td>2. Built environment</td>
</tr>
<tr>
<td></td>
<td>3. Natural hazards</td>
</tr>
<tr>
<td></td>
<td>4. Vulnerability/damages</td>
</tr>
<tr>
<td>3. Solution</td>
<td>5. Transporting structures and processes</td>
</tr>
<tr>
<td></td>
<td>6. Daily objectives</td>
</tr>
<tr>
<td></td>
<td>7. Disaster-related objectives</td>
</tr>
</tbody>
</table>
3 Applications

Two types of applications are presented as examples of how the objectives, SFD variables, the S.M.A.R.T. criteria, and the daily-disaster framework may be used in practical situations. The first is a set of demonstrations of how scientific information and engineering methods relate to the SFD variables. The second is a method to compile and analyse data for developing recommendations for improvement of disaster-related management systems. Each example is based on information, data and methods provided in one scientific paper.

3.1 Create SFD Variables

Method 1 evaluates the content of published papers from a modelling perspective. The method involves identifying SFD variables within a paper’s content. Twelve research papers were analysed from authors who have published work on earthquakes, floods, volcanic eruptions, or on understanding elements exposed to the risk of such events. The twelve examples are set up as follows:

1. The source paper is cited
2. The content of the paper briefly described
3. A table listing SFD variables relevant to the content
4. A short description of the content of the paper in terms of the SFD variables.
3.1.1 Measuring Changes to Built Environment


Content: The paper presents a method to assess and quantify changes in performance states of systems, where a system is defined as a set of physical structures. The method is based on survey data to measure changes to the physical structures, either losses, for example, earthquake-induced damage, or gains, such as subsequent restoration during a recovery process.

| Table 3.1. Stock and flow diagram variables for Rupakhety and Sighjörnsson (2014). |
|--------------------------|---------------------------------|
| Variable | Description |
| OBJi,j | OBJ4 Impact operations project backlog increase. OBJ7 Recovery operations project backlog decrease. |
| DFAi,j | DF7.1 Convert contingency plans to recovery operations. DF7.2 Recovery operations restore life back to normalcy. DF7.3 Existing mitigation information restores normalcy better than before. |
| EXVd | Earthquake-induced damage is an excitation variable. |
| FLV(EXVh, EXVd) | Excitation variable activates this flow variable. |

The source paper presents SFD variables in the following way. The value of assessed changes from a normal performance state to an earthquake-induced damage state presents an excitation variable, EXV_d, which activates the flow variable FLV(EXVh, EXVd), which, in turn, increases the impact operations project backlog (OBJ4). Implementing impact operations projects converts contingency plans to recovery operations (DF7.1). Recovery operations restore life to normalcy (DF7.2) and use existing mitigation information to make the new normalcy better than before (DF7.3). The values of assessed changes from a damaged performance state to a restored state are a measure of the completion of the recovery. These values measure the reduced stock value in the recovery operations project backlog (OBJ7).
3.1.2 Quantifying Different Types of Losses


*Content:* The paper presents a study of earthquake-induced damage in Iceland, highlights a different type of earthquake-induced damage, and discusses how different regions experience different types of damage. Their study shows that structural damage to buildings in Iceland, despite strong ground shaking, is not a pressing issue, but that the safety of non-structural components and building contents need to be addressed.

*Table 3.2.* Stock and flow diagram variables for Rupakhety et al. (2015).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi, OBJ3</td>
<td>Operations preparedness project backlog for different types of damages.</td>
</tr>
<tr>
<td>FLVi,j FLV3.1-3.4.</td>
<td>Operation preparedness activities.</td>
</tr>
<tr>
<td>DFAi,j DF7.1</td>
<td>Converting recovery contingency plans to recovery operations plans.</td>
</tr>
<tr>
<td></td>
<td>DF7.4 Re-establish livelihoods.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. The method provides loss estimates that are grouped, based on different types of damages, and increase the operations preparedness project backlog (OBJ3) for different types of damages. This will lead to new values for the flow variables FLV3.1-3.4. Based on Rupakhety and Sigbjörnsson (2015), in Iceland, FLV3.4 will be more significant than FLV3.1. FLV3.4 will lead to DF7.1 (converting recovery contingency plans to recovery operations plans). DF7.1 leads to DF7.4 (reestablish livelihoods), thus emphasizing the need for recovery plans as opposed to rescue plans.
3.1.3 New Analysis of Past Events


Content: The paper presents new research on earthquakes that occurred over 100 years ago, which changes existing estimates of hazards values and subsequently loss values, by producing smaller magnitude estimates than those available from other sources.

Table 3.3. Stock and flow diagram variables for Sigbjörnsson and Rupakhety (2014).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi, OBJ1</td>
<td>Risk analysis project backlog increase.</td>
</tr>
<tr>
<td>OBJ2</td>
<td>Mitigation project backlog increase.</td>
</tr>
<tr>
<td>OBJ3</td>
<td>Operations preparedness project backlog increase.</td>
</tr>
<tr>
<td>DFAi,j</td>
<td>DF4.1 New hazard information is created for loss estimates.</td>
</tr>
<tr>
<td>EXVh</td>
<td>This information is a new excitation variable.</td>
</tr>
<tr>
<td>FLV(EXVh)</td>
<td>The new excitation variable will create a flow variable.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. This information is a new EXV\textsubscript{h} variable and will affect the risk analysis project backlog (OBJ1) through FLV(EXV\textsubscript{h}) and lead to new loss estimates through DF4.1. A new FD4.1 will lead to an increased project backlog for both mitigation (OBJ2) and operations preparedness (OBJ3).
3.1.4 New Hazard Information Based on New Modelling


Content: The paper presents a method to model abrupt shifts in temporal variability within hydroclimatic processes, such as precipitation, streamflow, and sea surface temperature, i.e., the shift from one stationary state into another in a hydroclimatic time series. The method is intended for simulation and generation of long sample records (more than a few decades) rather than forecasting. Short historical records and lack of mathematical frameworks for analysing and modelling the dynamics of nonstationary processes are stated as the reason for the lack of temporal analysis of hydroclimate data.

Table 3.4. Stock and flow diagram variables for Sveinsson et al. (2003).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi</td>
<td>OBJ1Risk analysis project backlog increase.</td>
</tr>
<tr>
<td>FLVi,j</td>
<td>FLV1.3 increased.</td>
</tr>
<tr>
<td>EXVh</td>
<td>New hazard values are created.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. This method creates new hazard values, EXh. The method also creates new data to be used in the future, FLV1.3, i.e., risk information ready for impact operations (OBJ4). This method shows how the generation of new data will increase a risk analysis project backlog (OBJ1) and can be kept for impact operations.
3.1.5 Modelling Extreme Events


*Content:* The paper presents a method that models extreme hydrological events in order to predict annual maximum floods and annual low flows. These can be caused by abrupt changes induced by large-scale, low frequency climatic mechanisms and hydrologic processes may be affected by storage, as can be the case, for example, in annual streamflow volumes. This method looks at the former.

*Table 3.5.* Stock and flow diagram variables for Sveinsson et al. (2005).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi,j</td>
<td>OBJ1 Risk analysis project backlog increase.</td>
</tr>
<tr>
<td>FLVi,j</td>
<td>FLV1.3 increased.</td>
</tr>
<tr>
<td>EXVh</td>
<td>This method creates new hazard values.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. This method creates new hazard values, EXh. The method might also produce data other than the extreme events that may shed light on a situation when an extreme event occurs, thus placing a value on FLV1.3, i.e., risk information ready for impact operations (OBJ4). This method could be described as a basic scientific method to activate the system. It focuses on abrupt changes induced by large-scale, low-frequency climatic mechanisms.
### 3.1.6 Continuous Modelling of Hazard Data


*Content:* The paper presents a method to provide constant monitoring and modelling of the EXH variables that can be fed continuously into an automated, disaster-related management system. Specialized software, *SAMS*, is presented for analysing, modelling, and generating synthetic samples of hydrologic and water resources time series, such as monthly and weekly streamflows.

*Table 3.6. Stock and Flock Diagram variables for Salas et al. (2006).*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi, OBJ2</td>
<td>Mitigation project backlog increase.</td>
</tr>
<tr>
<td>OBJ3</td>
<td>Operations preparedness increase.</td>
</tr>
<tr>
<td>FLV(EXh, EXd)</td>
<td>If the automated information is large enough, it will activate the excitation variable.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. The first automated batch of information will increase the project backlog for mitigation (OBJ2) and operations preparedness (OBJ3). If the automated system provides similar information, then there is no additional project backlog. However, if there is an increase in the hazard activity, it will call for an increase in the project backlog for mitigation (OBJ2) and operations preparedness (OBJ3) and if the increase is large enough, the system may activate FLV(EXh, EXd). This method provides a continuous flow of updated FLV(EXh, EXd) variables.
3.1.7 Forecasting Spring Streamflow


*Content:* The paper presents a set of methods and procedures for forecasting aggregated May–July streamflow. The models have different lead times and variable data, such as only past streamflow data, both past streamflow and precipitation, and atmospheric circulation data. The forecast skills of the different approaches are compared, using a variety of performance measures. A multimodel combination approach is found to be more effective than using a single forecast model.

*Table 3.7.* Stock and flow diagram variables for Sveinsson et al. (2008).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi, OBJ1</td>
<td>Risk analysis project backlog increase.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. These methods contribute to the risk analysis project backlog (OBJ1). However, the different variables may be of different interest to different stakeholders. For example, it may be impossible to mitigate floods or drought by affecting precipitation of atmospheric circulation, but streamflow might be possible to adjust. Therefore the question becomes, which variables are of interest from a stakeholder perspective.
3.1.8 Airborne Ash: Impact and Management


Content: The paper presents research based on interviews with key authorities in Icelandic aviation and highlights many aspects of disaster-related management through lessons identified by studying the impact of airborne ash and the response to the 2010 Eyjafjallajökull Volcano eruption. This research focused on stakeholders in the air traffic industry. Airborne ash can cause direct damage to engines, is a threat to safety, and can lead to economic losses for airlines. To avoid the risk, the response was to close airspace, which caused large economic losses.

Table 3.8. Stock and flow diagram variables for Ulfarsson and Unger (2011).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi</td>
<td>OBJ8 Systematic learning project backlog increase and decrease. OBJ3 Operations preparedness project backlog increased.</td>
</tr>
<tr>
<td>FLVi,j</td>
<td>FLV4.4 was activated.</td>
</tr>
<tr>
<td>DFAi,j</td>
<td>DF8.1-FD8.4 were activated to learn lessons.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. This research resulted from the activation of FLV4.4 during the response to the Eyjafjallajökull eruption, which increased the systematic learning project backlog (OBJ8). This research decreases the backlog by activating FLV8 through performing activities within DF8.1-FD8.4. This resulted in systematic learning being accomplished and stated that flight zone planning needed to be improved to limit the need for airspace closure. The learning has activated FLV8.3 and increased the operations preparedness project backlog (OBJ3) by identifying new projects with Operations Preparedness that aim to:

1. Update the notice-to-airmen messaging system
2. Enhance real-time ash monitoring and forecasting
3. Develop policies providing a structure for all stakeholders to harmonize their decisions and actions.
3.1.9 Prediction of Real Estate Development and Land Price


Content: The paper presents a method to study how real estate development and land prices interact with demand model components for residential and employment location. Parcel data are classified into composite development types and the year of construction is used to generate a chronology of development within each cell. Information used to characterize each parcel or neighbourhood includes: spatial measures describing the real estate and land use composition, recent development patterns, distance from existing developments, and site characteristics, such as proximity to highways and arterials. The real estate development model simulates the annual probability that a cell will remain in its current state or experience a development event involving the addition of housing or non-residential floor-space and a potential transition to one of 24 development types.

Table 3.9. Stock and flow diagram variables for Waddell and Ulfarsson (2004).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi, OBJ1</td>
<td>Risk analysis project backlog decrease.</td>
</tr>
<tr>
<td>OBJ2</td>
<td>Mitigation project backlog increases.</td>
</tr>
<tr>
<td>OBJ3</td>
<td>Operations project backlog increases.</td>
</tr>
<tr>
<td>FLVi</td>
<td>FLV1 Risk projects performed.</td>
</tr>
<tr>
<td>DFAi,j</td>
<td>DF1.2 Information about real estate development and land prices provide values for compiling exposure inventory.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. Producing exposure inventory information decreases the risk objective project backlog (OBJ1) and activates FLV1. Information about real estate development and land prices provide values for DF1.2, compiling exposure inventory. The paper provides estimates on how the exposure inventories will activate a new FLV1 for each time step. This leads to new loss estimates for each time step. Subsequently, mitigation (OBJ2) and operations preparedness project backlogs (OBJ3) increase at the same rate, allowing for planning of mitigation action to avoid development that increases disaster risk.
3.1.10 Why Urban sprawl and Fragmentation Occur


Content: The paper presents a method to analyse dynamic changes in exposure in terms of why they occur. The research states that political and spatial dimensions of US metropolitan areas are interconnected through a recurring cycle of fragmentation and sprawl. In a perfectly fragmented region, each individual would be his or her own mayor with the ability to tailor the community to his or her own particular preferences. Empirical research illustrates that fragmentation leads to greater homogeneity by way of division along socioeconomic, racial, and/or ethnic lines. The model is structured around five-year intervals to observe how the political landscape (urban development patterns) at time \( t - 5 \) affects spatial outcomes (municipal fragmentation) at time \( t \). The result is a recurring cycle of fragmentation and sprawl, as development is displaced to less regulated areas and new jurisdictions form around outlying growth centres. The results suggest that regulatory failure may bear as much blame for urban sprawl as the more commonly cited market failures and that it may, therefore, be worthwhile to shift the focus of the sprawl/antisprawl debate from its physical to its political dimensions.

Table 3.10. Stock and flow diagram variables for Ulfarsson and Carruthers (2006).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi</td>
<td>OBJ2 Mitigation project backlog increase.</td>
</tr>
<tr>
<td>DFAi,j</td>
<td>DF2.1 Mitigation options compared.</td>
</tr>
<tr>
<td></td>
<td>DF2.2 Future research to analyse each option.</td>
</tr>
<tr>
<td></td>
<td>DF2.3 A decision.</td>
</tr>
<tr>
<td></td>
<td>DF2.3 Implementation.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. The method increases the mitigation project backlog (OBJ2) by showing how loss estimates vary based on regulatory failures and market failures. DF2.1 is given values by stating that there are two mitigation options to compare: regulatory factors and market factors. This leads to the activation of DF2.2 (future research to analyse each option), DF2.3 (a decision), and DF2.3 (implementation), activating FLV2 and eventually accomplishing mitigation. Future research should focus on identifying the systematic nature of sprawl and, as an extension, the various policy levers that may be used to mitigate its negative consequences.
3.1.11 Complex Urban Interaction Affecting Operations


Content: The paper presents a method that develops a Disruption index (DI), which provides the likely impacts and consequences of an earthquake in an urban area, taking into account multiple interdependencies. For example, lack of education may produce population migrations, or malfunctions in the electricity distribution system can result in electrical power outages of varying duration with respect to time and space, which generates consequences in the water distribution system, transportation, communications, etc. The method estimates the dysfunction of some fundamental dimensions of urban systems on a broad level, starting with the physical damages directly suffered by the exposed assets, proceeding to the impacts that each node has on the functional performance of the nodes depending on them, until reaching the top node.

*Table 3.11 Stock and flow diagram variables for Ferreira et al. (2014).*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJi</td>
<td>OBJ5 Rescue Operations project backlog increase and decrease. OBJ6 Relief Operations project backlog increase and decrease. OBJ7 Recovery Operations project backlog increase and decrease.</td>
</tr>
<tr>
<td>CCVi,j</td>
<td>CCV5.1, how rescue operations affect relief operations. CCV5.2, how rescue operations affect recovery operations. CCV6.1, how relief operations affect recovery operations. CCV7.1, how recovery operations affect relief operations.</td>
</tr>
<tr>
<td>DFAi,j</td>
<td>DF5 are performed. DF6 are performed. DF7 are performed.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. A disaster creates rescue, relief, and recovery operations project backlogs (OBJ5, 6, and 7). The backlog is reduced through activities within DF5, DF6 and DF7.

1. CCV5.1, How rescue operations affect relief operations
2. CCV5.2, How rescue operations affect recovery operations
3. CCV6.1, How relief operations affect recovery operations
4. CCV7.1, How recovery operations affect relief operations
3.1.12 Road Functionality and Operations After an Earthquake


Content: The paper presents a method to handle post-earthquake functionality of road networks. The analysis includes interaction of the road network, residential buildings and emergency services on the network service level. Possible causes of road blockage are seismic countermeasures on buildings, as well as building partial and total collapses. Collapsed buildings can alter road capacity and even block roads so emergency services, such as fire and ambulance, cannot get through and relevant buildings, such as schools, cannot be accessed. If the evacuation is not controlled, mobility demand on the road network is difficult to define. During restoration, emergency countermeasures, such as propping, and incomplete debris removal still reduce road capacity while displaced people, due to unusable buildings, alter demand on the road network.


<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFAi,j</td>
<td>DF4.4 Halt or reduce on-going damages. DF5.3 Transport victims. DF5.4 Support operations for rescue. DF6.3 Temporary repair to structures. DF6.4 Temporary restoration of services. DF7.2 Restore life back to normalcy.</td>
</tr>
</tbody>
</table>

The source paper presents SFD variables in the following way. DF4.4 covers halting or reducing on-going damages, preventing additional collapse of buildings onto roads due to aftershocks or other reasons, propping up buildings collapsing into the roads, based on the need for open roads, and planning evacuation. Transporting victims from DF5.3 includes evaluating whether emergency vehicles can or cannot reach strategic and relevant buildings with the width of roads and level of building vulnerability taken into account. DF5.4 looks at support operations for rescue and includes directing emergency and other traffic. Temporary repair to structures, DF6.3, makes unusable structures usable as fast as possible through temporary repairs. Controlling traffic, allowing emergency services to go down one-way streets, and guiding them with special post-earthquake road signs are all part of DF6.4, temporary restoration of services. DF7.2 foecusses on restoring life to normalcy and is represented by debris removal to shorten the time of restoration and decrease road vulnerability. This method provides a good overview of the relationship between impact, rescue, relief and recovery operations.
3.1.13 Discussion of Application 1

All source papers were assigned SFD variables relating to one or more disaster-related objective. Viewing the assigned variables in context with the SFDs in chapter 2.2.7 will show how each source paper relates to the bigger picture of disaster-related activities. Thus, SFD variables tie the papers to a theme that is logical, both from the perspective of paper content and system manager. The system manager can use the SFD variables to see where engineering methods and scientific research link to activities of the disaster-related management system. Table 3.13 lists the sources papers, the hazards they address, and the perspective that is common to the source paper and disaster-related management system.

Table 3.13. Source papers in application 1.

<table>
<thead>
<tr>
<th>Sn</th>
<th>Description</th>
<th>Hazard</th>
<th>Common Perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Measuring changes in the state of the built environment</td>
<td>Earthquake</td>
<td>Measure changes in state of exposure</td>
</tr>
<tr>
<td>2</td>
<td>Quantifying different types of losses</td>
<td>Earthquake</td>
<td>Deaggregation of loss data</td>
</tr>
<tr>
<td>3</td>
<td>New analysis of past events</td>
<td>Earthquake</td>
<td>Update hazard information</td>
</tr>
<tr>
<td>4</td>
<td>New hazard information, based on new modelling</td>
<td>Flood</td>
<td>Develop new hazard models</td>
</tr>
<tr>
<td>5</td>
<td>Modelling extreme events</td>
<td>Flood</td>
<td>Model extreme events</td>
</tr>
<tr>
<td>6</td>
<td>Continuous modelling of hazard data</td>
<td>Flood</td>
<td>Model hazards in continuous time steps</td>
</tr>
<tr>
<td>7</td>
<td>Forecasting spring streamflow</td>
<td>Flood</td>
<td>Model hazards for periods of interest</td>
</tr>
<tr>
<td>8</td>
<td>Airborne ash, impact and management</td>
<td>Volcanic</td>
<td>Improved impact operations during eruptions</td>
</tr>
<tr>
<td>9</td>
<td>Prediction of real estate development and land price</td>
<td>None</td>
<td>Impact on loss estimates</td>
</tr>
<tr>
<td>10</td>
<td>Why urban sprawl and fragmentation occur</td>
<td>None</td>
<td>Impact on loss estimates</td>
</tr>
<tr>
<td>11</td>
<td>Complex urban interaction affecting operations</td>
<td>None</td>
<td>Level of disruption</td>
</tr>
<tr>
<td>12</td>
<td>Road functionality and operations after an earthquake</td>
<td>Earthquake</td>
<td>Improved rescue, relief and recovery operations.</td>
</tr>
</tbody>
</table>

Collectively, the papers collectively covered all eight objectives, but no one deals with all eight. Two papers have the same SFD variables (Sveinsson et al., 2003; 2005), but covered different aspects of the same hazard, showing a limitation of the method in being broad based and lacking ability to capture detail. Another limitation of the method is the subjective manner in which the variables are defined. The strength of the method lies in its ability to connect
the contribution of different types of stakeholders to the disaster-related objectives and paint a broad-based picture for different stakeholders to identify their contributions as part of an overarching perspective.

3.2 Develop Recommendations

This method uses the eight disaster-related objectives (research aim 1), the minimum projects list (research aim 2), the S.M.A.R.T criteria (research aim 3), and the seven components of the daily-disaster framework (research aim 4), to develop recommendations for improvement.

Step 1 Data Compilation

First, data from the source papers were used to compile information, based on the seven components of the daily-disaster framework:

1. A strategy determined by the purpose of the system
2. Built assets or objects
3. Natural processes
4. Damages, damage distribution, consequences, and vulnerability
5. Stakeholder identification, type (owners, customers/beneficiaries, or actors), and associated transformation processes and structures, categorized as depicted in Table 3.14
6. Stakeholder mandate and daily, related objectives
7. System disaster-related objectives specific to the situation (the first S.M.A.R.T. criterion)

Then the minimum projects list was used to identify relevant projects based on the information collected relevant to the specific disaster-related objectives.

Table 3.14. Actor type, level categories, and aspects for analysis, as defined for management for sustainable livelihood (DFID 1999).

<table>
<thead>
<tr>
<th>Type</th>
<th>Level</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public sector</td>
<td>Political (legislative) bodies at various</td>
<td>Legal/constitutional basis,</td>
</tr>
<tr>
<td></td>
<td>governmental levels from local to national</td>
<td>authority and jurisdiction (including degree</td>
</tr>
<tr>
<td></td>
<td>Executive agencies (ministries, agencies)</td>
<td>of centralization)</td>
</tr>
<tr>
<td></td>
<td>Judicial bodies (courts)</td>
<td>Membership/ownership structure</td>
</tr>
<tr>
<td></td>
<td>Parastatals/quasi-governmental agencies</td>
<td>Leadership/management structure</td>
</tr>
<tr>
<td>Private sector</td>
<td>Commercial enterprises and corporations</td>
<td>Objectives and activities</td>
</tr>
<tr>
<td></td>
<td>Civil society/membership organizations (of</td>
<td>Financial basis (sustainability)</td>
</tr>
<tr>
<td></td>
<td>varying degrees of formality)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NGOs (international, national, local)</td>
<td>Geographic location/extent</td>
</tr>
</tbody>
</table>

Step 2 Data Analysis

The data are analysed by viewing the information in connection with the disaster-related objectives relevant to the example. The application provides examples of recommendations. Other recommendations may also be identified from the data.
Step 3 Recommendations
A set of recommendations is made for each example on the steps to take in order to reach the disaster-related objectives.

3.2.1 Farming and Ash from the 2010 Eyjafjallajökull Volcanic Eruption


Step 1 Data Compilation
The strategy of this system is to address disaster-related objectives for sustainable farming in the proximity of a volcano.

*Table 3.15.* Objects, natural process and damages/vulnerable conditions in context with the Eyjafjallajökull volcanic eruption.

<table>
<thead>
<tr>
<th>Objects</th>
<th>Natural Processes</th>
<th>Damages/Vulnerability</th>
</tr>
</thead>
</table>

*Table 3.16.* Stakeholder name, type and daily objectives in context with the Eyjafjallajökull volcanic eruption.

<table>
<thead>
<tr>
<th>Name</th>
<th>Structure Type</th>
<th>Daily Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owners:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minister of Agriculture</td>
<td>Public, executive, national</td>
<td>Research on and supervision of agriculture, commercial forestry, import and export of animals and plants, food inspection and food research.</td>
</tr>
<tr>
<td>Minister of Interior</td>
<td>Public, executive, national</td>
<td>Civil Protection, including evacuation of public, search and rescue</td>
</tr>
<tr>
<td>Customers, Beneficiaries:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farmers</td>
<td>Private individuals</td>
<td>Profitable and sustainable farming</td>
</tr>
<tr>
<td>Actors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farmers’ Association</td>
<td>Executive and civil organization, national</td>
<td>Advocate for farmers. It works towards progress and prosperity within agriculture. It strives to improve conditions, provide professional guidance, publications and information and do projects for the government.</td>
</tr>
<tr>
<td>South-Agrí: Agricultural Association of South Iceland</td>
<td>Public and private, executive and civil organization, local</td>
<td>Organization of agricultural societies and clubs in South Iceland. South-Agrí operates for the benefit of individual farmers. Its aim is to increase agricultural efficiency in the area and the prosperity of the members and clients.</td>
</tr>
<tr>
<td>Food and Veterinary Authority</td>
<td>Public, executive, national, under Ministry of Agriculture</td>
<td>Authority for food safety, animal health and welfare, control of feed, seed and fertilizers, plant health and water for human consumption.</td>
</tr>
</tbody>
</table>
Local police  Government agency under Ministry of Interior  Head of local civil protection, including evacuation of public, search and rescue

National police  Government agency under Ministry of the Interior  Head of national civil protection, including evacuation of public, search and rescue

The Agricultural University of Iceland  Public, educational, national  Educational and research institution in the field of agriculture and environmental sciences. It focuses mainly on the conservation and sustainable use of land and animal resources, including traditional agriculture, horticulture and forestry, environmental planning, restoration sciences, rural development and sustainable development.

Land Conservation Authority  Public, executive, national  Responsible for combating desertification, sand encroachment and other soil erosion, promoting sustainable land use and the reclamation and restoration of degraded land. The speed of erosion is magnified by volcanic activity and harsh weather conditions. The Land Conservation Authority is dedicated to the prevention of erosion and the reclamation of eroded land.

Farmers Insurance Fund  Public, executive, civil organization, national  The State and the farmers own the Farmers’ Insurance Fund. It compensates individuals and farming societies for various damages caused by natural disasters and animal diseases, in addition to what is covered by Iceland Catastrophe Insurance.

Iceland Catastrophe Insurance  Public, executive, national  Insures real estate against natural disasters. If building content is insured against fire, then it is also insured by this fund.

Chief of Police  Public, executive, local  Besides law enforcement activities, the district police are in charge of civil protection operations in the district during a civil protection situation.

Local Municipality  Public, executive, local  Manages the community, such as schools, cultural buildings, sports halls, planning and construction, roads, sewage, cold water systems, harbours, playgrounds, tourist sites, campsites, and employment issues.

Table 3.17. Disaster-related objectives specific to the Eyjafjallajökull example.

<table>
<thead>
<tr>
<th>Sn.</th>
<th>DF</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Risk analysis</td>
<td>Estimated ash level in farmland area next to Eyjafjallajökull</td>
</tr>
<tr>
<td>2.</td>
<td>Mitigation</td>
<td>Option analysis and implementation</td>
</tr>
<tr>
<td>3.</td>
<td>Operations preparedness</td>
<td>For evacuation, rescue, relief and recovery due to ash</td>
</tr>
<tr>
<td>4.</td>
<td>Impact operations</td>
<td>Monitoring and evacuation</td>
</tr>
<tr>
<td>5.</td>
<td>Rescue operations</td>
<td>Not needed for people, but a solution needed for animals.</td>
</tr>
<tr>
<td>6.</td>
<td>Relief operations</td>
<td>Temporary arrangements for people and animals</td>
</tr>
<tr>
<td>7.</td>
<td>Recovery operations</td>
<td>Due to damages and losses</td>
</tr>
<tr>
<td>8.</td>
<td>Systematic learning</td>
<td>For farming actors</td>
</tr>
</tbody>
</table>
Table 3.18. Relevant projects in context with the Eyjafjallajökull volcanic eruption.

<table>
<thead>
<tr>
<th>DF#</th>
<th>Type I</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Not performed for ash/farming</td>
<td>Not performed for ash/farming.</td>
</tr>
<tr>
<td>2.</td>
<td>Not performed for ash/farming</td>
<td>Not performed for ash/farming.</td>
</tr>
<tr>
<td>3.</td>
<td>Not performed for ash/farming</td>
<td>Not performed for ash/farming.</td>
</tr>
<tr>
<td>4.</td>
<td>Monitoring of natural hazards was performed. Monitoring of damages and consequences was general and ad hoc the first 4 weeks, after which a highly organized and specialized recon mission took place. Some animals were evacuated. People were originally evacuated due to flood risk. Ash fall affected the willingness of people to be in the area. Health issues arose.</td>
<td>Information was shared with those working in relief and recovery.</td>
</tr>
<tr>
<td>5.</td>
<td>People did not need rescuing from the ash. Livestock was either housed or evacuated and did not need rescue.</td>
<td>Not needed.</td>
</tr>
<tr>
<td>6.</td>
<td>All stakeholders were involved in some sort of temporary relief activity.</td>
<td>Send real-time relief info to recovery operators.</td>
</tr>
<tr>
<td>7.</td>
<td>Many actors were involved in some sort of recovery activity.</td>
<td>The insurance companies provided information at the pace that their regulations state.</td>
</tr>
<tr>
<td>8.</td>
<td>Systematic learning has not been performed although some level of internal actor learning has taken place</td>
<td>Not performed, as no system-wide learning has taken place.</td>
</tr>
</tbody>
</table>

Step 2 Data Analysis

Objective #1 Risk Analysis:

A hazard analysis was performed that outlined a 20 cm isopach in the area most affected by the Eyjafjallajökull. The ashfall was measured less than 20 cm in that area. No analysis of the exposure objects, manmade or naturally occurring, was performed. Who bears responsibility of developing a risk analysis from the perspective of farms and farming actors?

Objective #2 Mitigation

Insurance, both from building and farming perspectives, was put in place prior to the eruption. What type of mitigation options would have come from a risk analysis and who is responsible for funding which options?

Objective #3 Preparedness

The preparedness only related to evacuation and life-saving operations for people due to flood and temporary relief in mass care centres. No preparedness activities for relief and recovery were performed from the perspective of farming. The national plan assumes the establishment of a temporary service centre. Why did the farming actors not plan and train for the activities that they eventually undertook in assisting farmers during the natural disaster? Is the lack of training due to gaps in their mandate? Does
the law on civil protection by the police reduce the likelihood that others will take initiative to prepare their own activities during a disaster?

Objective #4 Impact operations
The volcano was monitored and evacuation of people took place. An organized reconnaissance mission with farming experts took place four weeks after the main eruption. Delays in activities focused on farming can be attributed to a lack of training. The lack of plans for animal evacuation led to the need for planning after the situation became problematic, causing delays in the operations. These delays can be attributed to lack of disaster-preparedness training among farming actors.

Objective #5
Not needed due to evacuation or temporary measures or housing on-site.

Objective #6
The Red Cross provided temporary relief for evacuees in mass care centres. A temporary service centre was set up by the national police to provide general services to the centre.

Objective #7
Insurance paid out the funds that are built into the system. There was some disgruntlement over delays in informing farmers what exactly was insured,

Objective #8
The farming actors have not formulated any systematic lessons learned from their experiences. Why not? Does any actor have the legal responsibility to ensure that such learning takes place?

The analysis shows a total lack of attention to risk analysis, mitigation and preparedness regarding the ash problem between farmers and farming actors. The two insurance agencies did have a system in place. There is a lack of clarity on stakeholder responsibility. For example, there were complaints about the delays at the Agricultural University in measuring chemicals in the ash. However, it is unclear whether it was the university’s responsibility to perform or pay for the measurements. Before an analysis on how well the stakeholders performed can be carried out, clarification is needed on stakeholder responsibility.

Step 3 Recommendations
Due to farming actors’ total lack of attention of to the pre-event objectives (risk analysis, mitigation and operations preparedness), all recommendations focus on clarifying responsibilities.

1. Who is responsible for making a disaster-scenario from a farming perspective?
2. Who is responsible for minimising the risk of damages?
3. Who is responsible for the preparedness plans and training at the ministerial and professional levels?
4. Who decides the responsible parties? Do mandates exist? If so, why did these entities not perform the activities?
5. Who bears the responsibility for systematic learning among farming actors taking place?
6. What collaboration is required of the Ministries of Agriculture and the Interior during a disaster in a farming community?
7. The example showed that the permanent secretaries for the Ministries of Agriculture and the Interior were unsure what the answers were. According to Icelandic law, the prime minister is responsible for assigning duties to and coordinating the ministers so the Office of the Prime Minister is a logical place to start answering these questions.

The recommended next steps are
1. Systematic learning from EFJV
2. Risk analysis from a farming livelihood perspective
3. Mitigation from a farming livelihood perspective
4. Preparedness from a farming livelihood perspective

The responsible parties are the Government of Iceland and the farming actors.

3.2.2 Hydro-Electric Power Station and Possible Flooding in Jökla River


**Step 1 Data Compilation**

The system is to address a threat of dam failure at the Káráhnjúkar plant in Iceland and damages in a farming community downstream. Failure could be caused by internal erosion due to earthquakes or overtopping due to flooding upstream from the melting of ice during a volcanic eruption under a glacier in the river catchment.

The damaging sequence is a two-step process. First, the natural processes cause internal erosion or overtopping of the dam and loss of its capability to contain the reservoir. The second step is a flood from the reservoir downstream onto a farmland community.

Based on a ruling from the Minister of Environment on 20 December 2001, the National Power Company (NPC) was ordered to make a preparedness and response plan for an emergency situation due to a dam failure that includes:

1. Main plausible emergency circumstances
2. Area, population, and valuable assets at risk
3. Operations to react to such a situation
4. Operations to warn, protect, control, evacuate and other actions considered necessary to protect life and valuable assets
Table 3.19. Objects, natural process and damages/vulnerable conditions in context with the Kárahnjúka Hydropower Plant.

<table>
<thead>
<tr>
<th>Objects</th>
<th>Natural Processes</th>
<th>Damages/Vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kárahnjúkar Hydropower Plant in NE Iceland, Kárahnjúkar dam and Desjár dams, farming community downstream.</td>
<td>River and associated flooding caused by earthquakes or volcanic eruptions. Seismicity. Volcanic activity, especially under the Vatnajökull Glacier within the river catchment area.</td>
<td>Internal erosion or overtopping leading to dam failure, causing flooding of downstream farmlands. Seismicity at dam site due to Holuhraun eruption and possibilities of its migration under the glacier. Dam response to the Holuhraun eruption.</td>
</tr>
</tbody>
</table>

Table 3.20. Stakeholder name, type and daily objectives in context with the Kárahnjúka Hydropower Plant.

<table>
<thead>
<tr>
<th>Name</th>
<th>Structure Type</th>
<th>Daily Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Owners:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minister of the Environment</td>
<td>Government</td>
<td>Ordered the NPC to make a preparedness and response plan for an emergency situation due to a dam failure.</td>
</tr>
<tr>
<td>National Power Company of Iceland</td>
<td>Dam owner, owner of system related to the dam</td>
<td>Maximize profits. Provide electricity to aluminium plants. Ensure dam safety.</td>
</tr>
<tr>
<td>Minister of the Interior</td>
<td>Government</td>
<td>Civil protection, including evacuation of public, search and rescue</td>
</tr>
<tr>
<td><strong>Customers, Beneficiaries:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farming population downstream</td>
<td>Public Citizens</td>
<td>Sustainable farming</td>
</tr>
<tr>
<td><strong>Actors:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Power Company of Iceland</td>
<td>Quasi-national and local governmental company</td>
<td>Notify of threats, respond at dam site to damaging events.</td>
</tr>
<tr>
<td>Emergency services</td>
<td>National (police), local (fire department), volunteers (rescue teams, Red Cross)</td>
<td>Plan and conduct evacuation. Rescue and semi-relief due to dam failure.</td>
</tr>
<tr>
<td>Minister of Agriculture</td>
<td>Government</td>
<td>Research on and supervision of agriculture, commercial forestry, import and export of animals and plants, food inspection and food research.</td>
</tr>
<tr>
<td>Mayor</td>
<td>Local government</td>
<td>Local civil protection, including evacuation of public.</td>
</tr>
</tbody>
</table>
Table 3.21. Disaster-related objectives specific to Kárahnjúka Hydropower Plant.

<table>
<thead>
<tr>
<th>Sn.</th>
<th>DF</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Risk analysis</td>
<td>Estimated natural processes needed to damage dam and dam failure processes and flood parameters, magnitude and details of downstream damages and consequences.</td>
</tr>
<tr>
<td>2.</td>
<td>Mitigation</td>
<td>Mitigation for dam and downstream area.</td>
</tr>
<tr>
<td>3.</td>
<td>Operations preparedness</td>
<td>Preparedness for impact operations for dam failure and impact, rescue, relief and recovery for downstream damages and consequences.</td>
</tr>
<tr>
<td>4.</td>
<td>Impact operations</td>
<td>Impact operations due to ongoing eruption that started during the study.</td>
</tr>
<tr>
<td>5.</td>
<td>Rescue operations</td>
<td>Not relevant, as the disaster has not happened.</td>
</tr>
<tr>
<td>6.</td>
<td>Relief operations</td>
<td>Not relevant, as the disaster has not happened.</td>
</tr>
<tr>
<td>7.</td>
<td>Recovery operations</td>
<td>Not relevant, as the disaster has not happened.</td>
</tr>
<tr>
<td>8.</td>
<td>Systematic learning</td>
<td>Not relevant, as the disaster has not happened and current impact operations due to a new eruption are still ongoing.</td>
</tr>
</tbody>
</table>

Table 3.22. Relevant projects in context with the Kárahnjúka Hydropower Plant.

<table>
<thead>
<tr>
<th>DF#</th>
<th>Type I (DFA$_{ij}$)</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Disaster risk analysis for both dam and downstream areas (1.1-1.4)</td>
<td>1. Send scenario information to mitigators</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Send scenario information to preparedness planners</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Send scenario information for impact operators</td>
</tr>
<tr>
<td>2.</td>
<td>Mitigation for dam and downstream areas (2.1-2.4)</td>
<td>1. Send information on actual reduced risk to risk analysers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Send updates on reduced risk to preparedness planners</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Have information ready to send when recovery operations are activated</td>
</tr>
<tr>
<td>3.</td>
<td>Contingency plans, equipment, trained personnel, standard operating procedures,</td>
<td>1. Have plans, templates and info ready when impact operations are activated</td>
</tr>
<tr>
<td></td>
<td>facilities ready and available for impact operations related to dam and impact,</td>
<td>2. Have plans, templates and info ready when rescue operations are activated</td>
</tr>
<tr>
<td></td>
<td>rescue, relief and recovery downstream (3.1-3.4)</td>
<td>3. Have plans, templates and info ready when relief operations are activated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Have plans, templates and info ready when recovery operations are activated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Send feedback on the relevancy of the risk info to risk staff</td>
</tr>
<tr>
<td>4.</td>
<td>Monitoring natural hazards, damages (4.1)</td>
<td></td>
</tr>
</tbody>
</table>
Step 2 Data Analysis

Table 3.23. Type I expected projects (see Table 3.22, middle column) in context with the Kárahnjúka Hydropower Plant.

<table>
<thead>
<tr>
<th>DF#</th>
<th>DFA i,j Completed</th>
<th>DFA i,j Incomplete/Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1 Information has been produced to understand the natural processes that could lead to dam failure due to internal erosion during an earthquake or overtopping during a flood. 1.2 The dam characteristics are well understood 1.3 Information about movement of cracks under dams due to earthquakes that need to be restricted has been produced. 1.4 The flood size needed to cause dam overtopping and the size of the flood and estimated flooded area downstream has been calculated. Detailed information is provided about the flood path, peak and travel time (evacuation window) to every building down stream. Information about road, power lines and water-sources. A short reference is made to damages to fields and the possibility of farm abandonment.</td>
<td>1.1 No natural process parameters were identified as missing. 1.2 Analysis of the exposed element downstream relevant to farming operations and facilities. 1.3 Modelling of damaging processes of exposed elements and understanding of consequences of the flood within the farmlands, such as detailed damage to farm buildings, including homes, water and electricity supply, pumps, fuel storage, fields, crops, pastures, machinery, about the financial losses among farmers and others who own property in the area due to damages to objects, interruption of systems, the social impact among the families, livelihood impact and workers, and the evacuation needs of animals. 1.4 A scenario to plan recovery operations.</td>
</tr>
<tr>
<td>2</td>
<td>2.1 Options for mitigating the risk of dam failure due to crack movement. 2.2 Analysis of options 2.3 Comparison of options. 2.4 Measures have been taken to reduce the risk of damages from relative fault displacement under the dams, such as clearing the site of the dam down to bedrock and filling cracks with concrete paste or with reinforced concrete bolted to the bedrock. Expansion joints with elastic water-stops have also been placed in the concrete to avoid damaging movement. Boreholes were drilled diagonally and through the cracks and filled with concrete paste. Rubber coatings placed on expansion joints.</td>
<td>All activities for 2.1, 2.2, 2.3, and 2.4, in regard to damages to farmlands are missing. The community made no mitigation efforts (Ingimarsson, 2015).</td>
</tr>
<tr>
<td>3</td>
<td>3.1, 3.2, and 3.3. as relevant to impact operations: The NPC has produced impact operations and standard operating procedures in the event of a natural process that threatens or has led to dam failure:  - Plan activation and reconnaissance  - Duty officer monitors devices and activates action plan.  - Reconnaissance officer called out to assess situation.</td>
<td>3.1 No standard operating procedures exist for recovery operations for farmers (Thorvaldsdóttir and Sigbjörnsson, 2015a) 3.2 NPC is in the process of improving the mobile phone system to the farms, in order to secure evacuation, but this is not complete. 3.3 No contingency plans for recovery operations for the farmland area of Fljótsdalshérað Community exist.</td>
</tr>
<tr>
<td>DF#</td>
<td>DFA i,j Completed</td>
<td>DFA i,j Incomplete/Missing</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3</td>
<td>Assess situation, decide response level and take action accordingly.</td>
<td>3.4 An exercise should take place every 5 years. No exercise or training of personnel has taken place. The evacuation/rescue/mass care plan should be updated every three years. It has not been updated since completion on 2009. (Bjartmarz, 2015)</td>
</tr>
<tr>
<td></td>
<td>Notifications:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Notify and evacuate staff.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Notify civil protection for evacuation of population downstream.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information sharing:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Provide updates on actual flood and flood peak behaviour.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Provide prognosis.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The civil defence community (police, fire, medical, rescue, volunteers and others) have produced an evacuation plan (National Police Commissioner 2009), based on the disaster scenario from NPC, which includes resources to provide rescue operations and provide initial assistance to those who are displaced.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4.1 The NPC monitors the following geohazard monitoring systems for the dam area and the nearby volcanic systems daily (Askja, Kverkfjöll, Snæfell and Vatnajökull):</td>
<td>4.1 The activities required for monitoring were not assessed in this example, as they are specialized activities requiring specialized knowledge outside of the scope of this dissertation.</td>
</tr>
<tr>
<td></td>
<td>- GPS, microseismic and accelerometric networks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dam-related parameters are:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Subsidence and displacement in earthfill</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Pressure in the concrete coating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Displacements in concrete construction joints</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Displacements between concrete coating and dam footing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Changes in distance from bedrock to dam surface</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Groundwater level and groundwater pressure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Seepage through and under the dam</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Displacement of faults and cracks in the bedrock below the dams</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Dam response to earthquake loading</td>
<td></td>
</tr>
<tr>
<td></td>
<td>In case of a flood, NPC has plans to open the bottom outlet, place the plant into full operation and dispatch work crews. The Holuhraun eruption has increased monitoring and assessment efforts. NPC has tasked various engineering and academic institutions to calculate increased risk due to Holuhraun eruption.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Not relevant to this case</td>
<td>1. A general plan on how to organize systematic learning for risk analysis, mitigation and operations preparedness if a damaging flood occurs has not been completed.</td>
</tr>
</tbody>
</table>
**Table 3.24.** Actual type II projects for the dam (see Table 3.22, last column) in context with the Kárahnjúka Hydropower Plant.

<table>
<thead>
<tr>
<th>DF#</th>
<th>Type II Projects</th>
</tr>
</thead>
</table>
| 1   | 1. Yes, information about the risk was sent to mitigators (designers).  
     | 2. Yes, information about the risk scenario was sent to the preparedness planners (civil defence).  
     | 3. Yes, calculations from the original risk analysis are available to be used during an actual flood. |
| 2   | 1. Yes, mitigation has taken place and current risk is known.  
     | 2. Yes, planning took place after final mitigation, so updating of plans after mitigation is irrelevant.  
     | 3. Yes, mitigation measures that took place are available to be used during recovery, |
| 3   | 1. Yes, impact operations have been prepared and procedures are ready for activation.  
     | 2. Rescue operations for the dam are beyond the scope of this example.  
     | 3. Relief operations for the dam are beyond the scope of this example.  
     | 4. Recovery operations for the dam are beyond the scope of this example.  
     | 5. Yes, feedback was given on the relevancy of the scenario during the development of impact plans |

**Table 3.25.** Actual type II projects for the farmlands (see Table 3.22, last column) in context with the Kárahnjúka Power Plant.

<table>
<thead>
<tr>
<th>DF#</th>
<th>Type II Projects</th>
</tr>
</thead>
</table>
| 1   | 1. No scenario information has been sent to or requested from people who could analyse it for downstream mitigation, for example, the mayor or the local or national farming associations.  
     | 2. No scenario information has been sent to or requested from people who could write a recovery plan, such as the mayor, the local or national farming association, or the Ministry of Agriculture.  
     | 3. No direct information is available about scenarios to draw on during impact operations, only flood info. |
| 2   | 1. Since no mitigation has taken place, updating risk information after mitigation is irrelevant.  
     | 2. Since no mitigation has taken place, updating plans after mitigation is irrelevant.  
     | 3. Since no mitigation has taken place, no special information is available for recovery operations |
| 3   | 1. No impact operations are prepared for the intervention in damaging processes downstream. Unclear about animal evacuation.  
     | 2. Yes, rescue operations plans are ready, but not drilled or updated. Unclear about animal rescue.  
     | 3. Partial relief operation plans are ready, but not drilled or updated. Unclear about animal relief.  
     | 4. No plans for recovery operations have been prepared.  
     | 5. Feedback was given on the relevancy of the scenario during cooperation between civil defence and NPC, but not for operations beyond civil defence, e.g. recovery. |
Objective #1 Risk Analysis:

A dam failure would affect the NPC, its clients, the environment, the national economy, and the property owners, tourists and farming community downstream of the dam. This example application is limited to the farming community and addresses the main aspects of a disaster scenario. A detailed risk analysis was performed for the dam, but not for the farmland area. Who bears responsibility for developing a risk analysis from the perspective of farms and farming actors?

Objective #2 Mitigation

The only mitigation performed was related to the dam, not the downstream area. Insurance, both from building and farming perspectives, is available. What type of mitigation options would have come from a risk analysis and who is responsible for funding which options?

Objective #3 Preparedness

The preparedness for this event is only related to the dam, the evacuation and life-saving operations of people, and temporary relief in mass care centres. No preparedness activities for relief or recovery of farming exist, as no disaster-scenario existed to base it on. The national plan assumes the establishment of a temporary service centre, which may be set up. The Ministry of the Interior is mandated to manage civil defence, search and rescue and the emergency services, although some services belong to the local government and others are volunteer groups.

Objective #4 Impact operations

A volcanic eruption started in Holuhraun and is being closely monitored. The NPC and the prime minister have been active in making disaster-scenarios due to possible movement of the eruption under the glacier, causing flooding in other rivers than Jökla.

The analysis shows that risk analysis, mitigation and preparedness are performed by the NPC for the NPC, and by the NPC as ordered by decree. The previous example has shown the lack of attention to disaster-related objectives paid by the farming actors.

Step 3 Recommendations

The recommendations address issues relating to the farming population downstream.

1. The same questions related to the farming community as in the previous example apply to this example
2. In addition, the role of the Ministry for the Environment in ordering stakeholders to make a preparedness and response plans for emergency situations, where civil protection falls under the Minister of the Interior, is also an issue for clarification.
3. The example also suggests starting by addressing questions at the prime minister’s level.
The recommended next steps are

1. Analysis of legislation for disasters and farmers
2. Risk analysis from a farming livelihood perspective
3. Mitigation from a farming livelihood perspective
4. Preparedness from a farming livelihood perspective

The responsible parties are the government of Iceland and farming actors.

### 3.2.3 Urban Search and Rescue and the 2010 Haiti Earthquake


**Step 1 Data Compilation**

The aim of the system is to maximize opportunities of live rescue after an earthquake in Haiti.

*Table 3.26.* Objects, natural process and damages/vulnerable conditions in the context of the Haiti earthquake in 2010.

<table>
<thead>
<tr>
<th>Objects</th>
<th>Natural Processes</th>
<th>Damages/Vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete structures.</td>
<td>Main earthquakes and aftershocks.</td>
<td>Collapsed concrete structures with voids big enough for survival.</td>
</tr>
<tr>
<td>Building material, age, shape, and proximity to other buildings.</td>
<td>Magnitude, peak ground acceleration.</td>
<td>Trapped live people.</td>
</tr>
<tr>
<td>Building content.</td>
<td>Duration.</td>
<td>Aftershocks create on-going threats to the rescue team and those who are trapped.</td>
</tr>
<tr>
<td></td>
<td>Local soil conditions.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water level.</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.27. Stakeholder name, type and daily objectives in the context of the Haiti earthquake in 2010.

<table>
<thead>
<tr>
<th>Name</th>
<th>Structure Type</th>
<th>Daily Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Owners:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government of Haiti</td>
<td>Government level</td>
<td>Unclear due to challenges to the political, social and economic stability of Haiti</td>
</tr>
<tr>
<td>United Nations Security Council</td>
<td>Inter-governmental</td>
<td>Has primary responsibility for the maintenance of international peace and security</td>
</tr>
<tr>
<td><strong>Customers, Beneficiaries:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>People of Haiti, trapped people</td>
<td>None</td>
<td>To be free and healthy</td>
</tr>
<tr>
<td><strong>Actors:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICE-SAR Team</td>
<td>Volunteer International USAR team, INSARAG classified</td>
<td>Be well trained and prepared for missions. To perform thorough, rapid, on-site assessments and rescue people.</td>
</tr>
<tr>
<td>Ministry for Foreign Affairs</td>
<td>Government level</td>
<td>Facilitate the deployment of the ICE-SAR team. Have operating procedures for the deployment of the ICE-SAR team.</td>
</tr>
<tr>
<td>MINUSTAH</td>
<td>United Nations Stabilization Mission in Haiti</td>
<td>Maintain security in Haiti, placing night curfew, in conflict with rescue teams who wished to work through the night.</td>
</tr>
<tr>
<td>OCHA</td>
<td>Intergovernmental</td>
<td>Coordinate international disaster response.</td>
</tr>
<tr>
<td>USGS</td>
<td>American governmental agency</td>
<td>Monitor seismicity and alert.</td>
</tr>
</tbody>
</table>
Table 3.28. Disaster-related objectives specific to in the context of the Haiti earthquake in 2010.

<table>
<thead>
<tr>
<th>Sn.</th>
<th>DF</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Risk analysis</td>
<td>Did an estimate of collapsed buildings and the possible number of trapped people exist?</td>
</tr>
<tr>
<td>2.</td>
<td>Mitigation</td>
<td>Not relevant, as no mitigation was part of this example.</td>
</tr>
<tr>
<td>3.</td>
<td>Operations preparedness</td>
<td>Urban search and rescue training, INSARAG classification, home-base preparedness, written procedures to dispatch team, and sufficient planning and resources for security operations to support rescue operations.</td>
</tr>
<tr>
<td>5.</td>
<td>Rescue operations</td>
<td>Deploy and retrieve ICE-SAR team to Haiti, assess damaged buildings in search of possible live victims, search and rescue from buildings, hand over victims found to responsible parties, maintain security in Haiti in support of the rescue.</td>
</tr>
<tr>
<td>6.</td>
<td>Relief operations</td>
<td>Not relevant</td>
</tr>
<tr>
<td>7.</td>
<td>Recovery operations</td>
<td>Not relevant</td>
</tr>
<tr>
<td>8.</td>
<td>Systematic learning</td>
<td>Not relevant</td>
</tr>
</tbody>
</table>

Table 3.29. Relevant projects for specific objectives in the context of the Haiti earthquake in 2010.

<table>
<thead>
<tr>
<th>DF#</th>
<th>Type I</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Risk analysis</td>
<td>1. Disaster scenario, number of collapsed structures to #3.</td>
</tr>
<tr>
<td>3</td>
<td>Contingency plans, equipment, trained personnel, standard operating procedures, facilities ready and available for operations</td>
<td>1. Have plans, templates and info ready when impact operations are activated to #4. 2 to 5. Have plans, templates and info ready when rescue operations are activated to #5.</td>
</tr>
<tr>
<td>4</td>
<td>Monitoring natural hazards, damages and consequences and responding to these events or supplying information to the rescue operations</td>
<td>1. Send real-time impact info to rescue operators to #5.</td>
</tr>
<tr>
<td>5</td>
<td>Trapped persons located, accessed, extricated from immediate, life-threatening situations and brought to safety through the assistance of others</td>
<td>Intentionally left empty</td>
</tr>
</tbody>
</table>
## Step 2 Data Analysis

**Table 3.30.** Stakeholder relevancy to projects in the context of the Haiti earthquake in 2010.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type I</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Owners:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government of Haiti</td>
<td>All</td>
<td>All</td>
</tr>
<tr>
<td>United Nations Security Council</td>
<td>Authorizes MINUSTAH and provides it with a mandate</td>
<td>Authorizes MINUSTAH and provides it with a mandate</td>
</tr>
<tr>
<td><strong>Customers, Beneficiaries:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trapped people</td>
<td>Their opinion about team curfew</td>
<td>Their opinion about team curfew</td>
</tr>
<tr>
<td><strong>Actors:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICE-SAR Team</td>
<td>1. No projects, do not do risk analysis for other countries</td>
<td>1.1. Not relevant</td>
</tr>
<tr>
<td></td>
<td>3. Deployment and rescue plans</td>
<td>3.1 Yes, did have plans ready for monitoring</td>
</tr>
<tr>
<td></td>
<td>4. Monitored situation</td>
<td>3.2 Did have plans for rescue</td>
</tr>
<tr>
<td></td>
<td>5. Did provide rescue</td>
<td>4.1 Yes, the team collected and used real time information for rescue</td>
</tr>
<tr>
<td>MoFA</td>
<td>1. Not relevant</td>
<td>1.1. Not relevant, not their role.</td>
</tr>
<tr>
<td></td>
<td>3. Yes, did have plans to deploy rescue team</td>
<td>3.1 Yes</td>
</tr>
<tr>
<td></td>
<td>4. Yes, did seek information about the situation in country and access to it</td>
<td>3.2 Not relevant, not their role.</td>
</tr>
<tr>
<td></td>
<td>5. Yes, supported rescue operations through deployment</td>
<td>4.1 Not relevant, not their role.</td>
</tr>
<tr>
<td>MINUSTAH</td>
<td>1. Unclear</td>
<td>1.1 Unclear</td>
</tr>
<tr>
<td></td>
<td>3. Unclear</td>
<td>3.1 Unclear</td>
</tr>
<tr>
<td></td>
<td>4. Yes, provided information about the situation</td>
<td>3.2 Unclear</td>
</tr>
<tr>
<td></td>
<td>5. Yes, supported rescue by maintaining security. Placed curfew on nighttime operations.</td>
<td>4.1 Yes, did provide situational information to rescue teams</td>
</tr>
<tr>
<td>OCHA</td>
<td>1. Does not perform risk analysis</td>
<td>1.1. Not relevant, not their role.</td>
</tr>
<tr>
<td></td>
<td>3. Did prepare teams and have plans to activate a coordination mechanism.</td>
<td>3.1 Yes</td>
</tr>
<tr>
<td></td>
<td>4. Did provide information about the situation</td>
<td>3.2 Yes, for coordination of rescue</td>
</tr>
<tr>
<td></td>
<td>5. Did support the rescue operation through coordination</td>
<td>4.1 Yes, did provide situational information to rescue teams</td>
</tr>
</tbody>
</table>
Table 3.31. Resource availability per stakeholder type projects in the context of the Haiti earthquake in 2010.

<table>
<thead>
<tr>
<th>Name</th>
<th>Available</th>
<th>Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Owners:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government of Haiti</td>
<td>Very limited USAR resources or resources to coordinate USAR operations.</td>
<td>USAR resources</td>
</tr>
<tr>
<td>United Nations</td>
<td>Provides</td>
<td></td>
</tr>
<tr>
<td><strong>Customers, Beneficiaries:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trapped people</td>
<td>Insufficient to retrieve heavily entombed victims</td>
<td>Specially trained USAR teams</td>
</tr>
<tr>
<td><strong>Actors:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICE-SAR Team</td>
<td>USAR team</td>
<td>Funds for travel</td>
</tr>
<tr>
<td></td>
<td>Communication from Haiti to HQ in Iceland</td>
<td></td>
</tr>
<tr>
<td>ICE-SAR HQ</td>
<td>Operations room</td>
<td>No extra resources were needed</td>
</tr>
<tr>
<td>Ministry for Foreign Affairs</td>
<td>Funds for ICE-TEAM travel. Staff members to take initiative to find</td>
<td>No extra resources were needed</td>
</tr>
<tr>
<td>MINUSTAH</td>
<td>Personnel and transport to provide security</td>
<td>Personnel and transport to provide security</td>
</tr>
<tr>
<td>OCHA</td>
<td>Personnel to coordinate</td>
<td>Additional personnel to coordinate, taken from USAR teams, as planned.</td>
</tr>
</tbody>
</table>

Objectives #1 Risk analysis

A UN peacekeeping force, United Nations Stabilization Mission in Haiti, MINUSTAH, was installed in Haiti at the time of the earthquake. How did the presence of MINUSTAH affect the responsibility of performing a disaster risk analysis for Haiti? This is not clear from the data collected. What is the responsibility of the government of Haiti and of MINUSTAH?

Objectives #3 Preparedness

Which entity in Haiti is responsible for ensuring that life-safety operations are performed well? Who is responsible for maintaining the security of rescue teams and have they made adequate plans to do so?

Objective #4 Impact operations

USGA gave notice of the earthquake through their 24-hour notification system. Damage information came via UNOCHA and the media. The USAR team monitored the situation in order to decide whether to send a team.

Objective #5 Rescue Operations

The analysis shows a conflict between stakeholders:

1. Victims, one presumes, want to be rescued as soon as possible.
2. The rescue team wants to operate and rescue as many as they can.
3. MINUSTAH is concerned that it cannot ensure the life-safety of the team during the night and called for a team curfew.
The analysis shows that the main obstacle in the operation presented in this example is the curfew restriction on rescue teams to work at night.

**Step 3 Recommendations**

Understanding whether reducing a curfew during possible future rescue operations in Haiti is possible calls for further analysis of the stakeholders responsible for setting the curfew and performing the security operations. The United Nations Security Council (UNSC) Resolution (S/Res/1529 2004) authorized the deployment of a Multinational Interim Force to Haiti and, in April 2004, noting the existence of challenges to the political, social and economic stability of Haiti and after determining that the situation in Haiti continued to constitute a threat to international peace and security in the region, UNSC authorized the establishment of MINUSTAH (UN S/Re/1542, 2004). These resolutions require analysis and the matter must be discussed with the United Nations stakeholders. Did responsible parties estimate the need for rescue teams and plan for the necessary security operations required for 24-hour operations? Do they intend to provide 24-hour security in future operations? Is it needed? What is the opinion of the Haitian government and the possible future trapped people of Haiti? Do the teams and the people have unrealistic demands due to the political, social and economic stability in Haiti? Answering these questions is beyond the scope of this example. The recommended next steps are as follows:

1. Analyse the entities responsible for disaster-related objectives in Haiti.
2. Gain understanding of the need for USAR teams. Major earthquakes have happened in the region before.
3. Compare available resources for the size of the event.
4. Plan for receiving international USAR teams, including maintaining security for 24-hour operations the first week and update plans for maintaining security for 24-hour operations the first week.

The responsible parties are the Government of Haiti, MINUSTAH, and international donors working in the field of disaster operations.

**3.2.4 S.M.A.R.T. Flowchart**

The flowchart in Fig. 3.1 outlines a method for inserting S.M.A.R.T., disaster-related objectives into a disaster-related management system. It was developed by analysing the steps taken in the three papers analyzed above. The flowchart is designed to address the question of whether relevant objectives are being met and to incorporate each of the five S.M.A.R.T. criteria into that question.

A study of the examples shows that each one starts with identifying relevant disaster-related objectives for a given situation as defined by the system user or analyst. Next, data tables with situation details and the stakeholders involved, including their mandates, are developed. Then, tables depicting relevant projects are listed. Reducing the project list in Table 2.14 according to the relevant objectives creates the new tables. The work on Haiti goes on to evaluate the relevancy of each stakeholder to the project types and the resource
availability for each stakeholder to be able to perform the project. The Kárhnjúkar example provides detailed comparisons of the completed projects and the missing projects, based on the project list. This information was restructured into the format of the project list, taking into account the different perspectives of dam owners and people living downstream. Information about the relevant feedback loops is maintained in these tables in order to know which feedback loops need to be active. The analysis and recommendations show that problems may arise due to a lack of clarity about stakeholders’ roles and responsibilities. These factors collectively address the following:

1. Identifying relevant disaster-related objectives for a given situation
2. Situation details (natural processes, exposed objects and their vulnerability)
3. Relevant projects based on a project list
4. Comparison of completed and missing projects, based on the project list
5. Stakeholders, their mandates, and perspectives on the situation
6. Clarity of roles and responsibilities, both daily and towards the disaster-related objectives
7. Relevancy of each stakeholder to the project types
8. Resources availability for each stakeholder to be able to perform the project
9. Feedback loop activity

In addition to the above, the following factors were added to the flowchart from a system maintenance perspective:

1. Education and training of stakeholders in disaster-related objectives, expected projects, and information sharing
2. The actual assignment of projects to stakeholders
3. The design or improvement of a coordination system to ensure information flow and project completion
4. An evaluation of the activities, based on whether the relevant disaster-related objectives are met
Figure 3.1.A. Upper part of flowchart
Figure 3.1B. Lower part of flowchart

Figure 3.1. A and B, flowchart for incorporating S.M.A.R.T., disaster-related objectives into disaster-related management procedures.
3.2.5 Discussion of Application 2

The application uses the tools to portray information from a common perspective and systematically formulate recommendations from analysing the data. The application broke down the information in the source papers into meaningful pieces, showing performance gaps in the projects on the minimum projects list. The analysis demonstrated that projects were either missing or incomplete from a multistakeholder perspective (not all stakeholder perspectives are included). The question is, who is responsible for ensuring that all stakeholder perspectives are included. According to United Nations General Assembly Resolution on Natural Disasters and Vulnerability (UNGA, 2009), states have the primary responsibility for their own, sustainable development and for taking effective measures to reduce disaster risk, including protection of the people in their territories, infrastructure and other national assets from the impact of a disaster.

A limitation of the application is that it is based on sustainable livelihood and may not apply to all circumstances of interest. While its strength lies in capturing different types of information in a systematic way, the subjectivity of the user of this tool affects the results.
4 Discussion and Concluding Remarks

4.1 Discussion

Clearly stated objectives are the basis for disaster-related management, not phases. However, due to the widespread reference to the disaster life cycle phases (mitigation, preparedness, response and recovery), it is important to be able to discuss the objectives in relation to phases. By disregarding any dynamic interrelations, disaster-function activities can be grouped into those performed before a disaster (risk analysis, mitigation, and operations preparedness), when the functioning of a society is being disrupted (impact, rescue, relief, and recovery operations), and when a society has recovered from the disruption (systematic learning). Note that using UNISDR’s definition of a disaster, recovery operations are performed during a disaster, not after it, as is commonly stated. This is due to the fact that the disruption of a community persists until recovery is accomplished. As recovery operations gradually bring the community back to normalcy, the disaster (the disruption) gradually dissipates. Another grouping that is closer to the original phases would be: one first analyses risk, then mitigates it, then prepares for operations, then operates during a disaster, and then systematically learns from the operations. This shows the logical order of the five phases relevant to a simplified, but unrealistic, world.

The disaster-function activities are the next level of detail beyond objectives. They were developed from theorized statements constituting basic activities to reach an objective. The statements are not intended to be all encompassing and a user may wish to add disaster-function activities, thus adding lines to the CLD and the minimum project list. However, it is argued that at least all projects on the list are required for successful disaster-related management.

In today’s world, management, in particular project management, is an integral part of operating procedures within ministries, governmental institutions, businesses, non-governmental organizations, and other organizations that work within a society. Therefore, a theory for a disaster-related management system that is meant to have practical value, which is the cornerstone of engineering thinking, must have a link to management principles. Management by objectives, management functions, and S.M.A.R.T. criteria are simple, but highly effective, management principles. Applying them to disaster-related activities creates a bridge between disaster-related managers and project managers.

The almost countless number of stakeholder perspectives necessary to address serious societal disruptions calls for diverse details to be inserted into disaster-related management systems. Contextual frameworks, portraying a common perspective among the stakeholders, provide focus for data collection, compilation, and analysis. While it is the role of the system manager to find or build frameworks characterising the common perspective for the problem at
hand, the daily-disaster framework is an option when dealing with broad-based, societal, disaster-related problems.

4.2 Summary of Results

The results associated with each research aim are outlined below.

4.2.1 A Disaster-Related Goal and Core Objectives

A disaster-related goal is having a well-functioning community or society, that the risk of serious disruptions to the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts is low, and coping with such events using a society’s own resources, if they occur.

Core disaster-related objectives are as follows:

1. To understand disaster risk, components, and context
2. To measurably reduce known disaster risk
3. To prepare future operations for dealing with future disasters
4. To react to damaging processes prior to, during, and after impact
5. To save the lives of those caught in damaging or other injurious processes
6. To provide temporary relief of suffering to those affected
7. To implement final measures to bring a community to normalcy
8. To systematically learn from recent events and implement changes

4.2.2 Feedback Loops, Minimum Project List and SFDs

The dynamic relationship between the objectives is characterized with three tools (Fig. 5.1). The first tool is three feedback loops: normal (Fig. 2.4), disrupted (Fig. 2.5) and improvement (Fig 2.6), where the last one is a FBL containing the first two.

![Feedback loop diagram](image)

Figure 4.1. Feedback loops for disaster-related management systems.

The second tool is the minimum projects list (Table 2.14).
Discussion and Concluding Remarks

<table>
<thead>
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<th>Type I</th>
<th>Type II (Row # in Table 2.12 are in parenthesis)</th>
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</thead>
<tbody>
<tr>
<td>DF1.1</td>
<td>1. Send scenario information to mitigators (1)</td>
</tr>
<tr>
<td>DF1.4</td>
<td>2. Send scenario information to preparedness planners (4)</td>
</tr>
<tr>
<td></td>
<td>3. Send scenario information for impact operators (16)</td>
</tr>
<tr>
<td>DF2.1</td>
<td>1. Send information on actual reduced risk to risk analysers (2)</td>
</tr>
<tr>
<td>DF2.4</td>
<td>2. Send updates on reduced risk to preparedness planners (3)</td>
</tr>
<tr>
<td></td>
<td>3. Have information ready to send when recovery operations are activated (17)</td>
</tr>
<tr>
<td>DF3.1</td>
<td>1. Have plans, templates and information ready when impact operations are activated (6)</td>
</tr>
<tr>
<td>DF3.4</td>
<td>2. Have plans, templates and information ready when rescue operations are activated (6)</td>
</tr>
<tr>
<td></td>
<td>3. Have plans, templates and information ready when relief operations are activated (6)</td>
</tr>
<tr>
<td></td>
<td>4. Have plans, templates and information ready when recovery operations are activated (6)</td>
</tr>
<tr>
<td></td>
<td>5. Send feedback on the relevancy of the risk info to risk staff (5)</td>
</tr>
<tr>
<td>DF4.1</td>
<td>1. Send real-time impact information to rescue operators (7)</td>
</tr>
<tr>
<td>DF4.4</td>
<td>2. Send real-time impact information to relief operators (8)</td>
</tr>
<tr>
<td></td>
<td>3. Send real-time impact information to recovery operators (9)</td>
</tr>
<tr>
<td></td>
<td>4. Send information about impact operations to learning staff (14)</td>
</tr>
<tr>
<td>DF5.1</td>
<td>1. Send real-time rescue information to relief operators (10)</td>
</tr>
<tr>
<td>DF5.4</td>
<td>2. Send real-time rescue information to recovery operators (11)</td>
</tr>
<tr>
<td></td>
<td>3. Send information about rescue ops to learning staff (14)</td>
</tr>
<tr>
<td>DF6.1</td>
<td>1. Send real-time relief information to recovery operators (12)</td>
</tr>
<tr>
<td>DF6.5</td>
<td>2. Send information about relief operations to learning staff (14)</td>
</tr>
<tr>
<td>DF7.1</td>
<td>1. Send real-time recovery information to relief operators (13)</td>
</tr>
<tr>
<td>DF7.4</td>
<td>2. Send information about recovery operations to learning staff (14)</td>
</tr>
<tr>
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</tr>
<tr>
<td>DF8.4</td>
<td>2. Send identified lessons to mitigators (15)</td>
</tr>
<tr>
<td></td>
<td>3. Send identified lessons to preparedness planners (15)</td>
</tr>
</tbody>
</table>

**Figure 4.2. Compressed minimum projects list.**

The third tool is an SFD presented in five diagrams (Fig. 5.2, condensed versions of Fig. 2.9-2.13). The first diagram presents the normal loop. The next three present various stages of the disrupted loop, and the last presents the improvement loop.

**Figure 4.3. Compressed SFD for a disaster-related management system.**
4.2.3 A Flowchart for Incorporating S.M.A.R.T. Objectives

Disaster-related S.M.A.R.T. criteria are as follows:

1. Specific: decide which disaster-related objectives are relevant to a situation
2. Measureable: measure gap between the expected and actual projects completed
3. Assignable: assign projects to appropriate stakeholders
4. Realistic: procure sufficient resources to complete the projects
5. Time-related: ensure information movement based on feedback loops

The flowchart in Fig. 5.3 is a tool to incorporate S.M.A.R.T., disaster-related objectives into disaster-related management.

![Flowchart Image]

**Figure 4.4. Compressed version of flowchart.**

4.2.4 A Framework with Disaster-Related and Daily Objectives

The livelihood-disaster framework depicts the components of a well-functioning society and the components of a disaster-related goal. It is an example of a daily-disaster framework (Fig. 5.4).
4.3 Conclusions

The high frequency of disasters around the world calls for well-organized, disaster-related management systems. Good management is management by S.M.A.R.T. objectives. Research shows that, while many studies portray different aspects of disaster-related tasks, there is need for studies that theoretically derive fundamental objectives for the purpose of managing disaster-related activities. The objectives derived in this study aim to fill that gap. The objectives are developed from the most common characterization of disasters, the original disaster life cycle (mitigation, preparedness, response, and recovery). While phases may be a useful concept in some contexts, objectives are necessary for management purposes. The research also shows that the dynamic relationship between disaster-related activities must be taken into account during management, which would be lost if operating as if activities happen in an orderly fashion, such as phases.

The work herein presents a new application of systems dynamics for disaster-related management. The literature holds numerous studies that either discuss or use a SDA for analysing disasters and accidents. However, the novel application of a CLD and SFDs presented herein provides both new insight into the dynamic relationship of disaster-related activities and opens new doors for modelling disaster-related management systems by creating SFD variables from a joint engineering/scientific and disaster-related perspective. The SFDs are built on the objectives and basic activities, which create the load-bearing structure of the system on which control factors and feedback loops can be added. The SFDs demonstrate a high level of interaction amongst disaster-related activities. Ignoring the dynamic relationship would lead to fragmented and incomplete management.

The higher-level perspective requires an overarching frame of reference in order for staff to grasp the scope of their work and enable them to draw the big picture. Without an overarching perspective that seeks to encompass all fundamental aspects of disaster-related activities, system managers will not
know the boundaries of their work. The eight, disaster-related objectives constitute core disaster-related objectives that define the smallest logical boundary of the scope of disaster-related activities. This is a unique attempt to theoretically define an overarching perspective, i.e., to draw the big picture. The challenge is to know when the big picture has been fully – or sufficiently – drawn.

The most tangible result of this work is a unique set of management tools: objectives, project lists, information flow diagrams, flowcharts for incorporating S.M.A.R.T. objectives, and a daily-disaster framework. An organization that is mandated to work from a broad-based perspective during a disaster can adopt these procedures to help guide them to meet the objectives and reach the overall disaster goal. The overall disaster goal was defined herein as having a well-functioning community or society and coping with serious disruptions to the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, using a society’s own resources. The uniqueness lies in the array of tools that have a common basis in sound management, engineering and disaster-related principles and methodologies.

The four research aims are met and the journey has come to an end. What remains is an opportunity for organizations to adapt the eight, disaster-related objectives to their own daily objectives and develop internal, standard management procedures based on the array of tools. An organization that does so is likely to increase its disaster resistance and resiliency.

### 4.4 Future Work

The contribution towards a theoretical foundation for disaster-related management systems is based on theoretically derived, disaster-related objectives and a generalization of activities to reach those objectives. In this new approach, the terms response and recovery phases have been replaced with impact, rescue, relief and recovery operations, without order. In the earlier approach, response was a catchall phrase; everything that was not recovery is response. In the new approach, impact operations have become the catchall phrase; if is not rescue, relief or recovery, then is it an impact operation. Future work will involve delving deeper into operations activities and developing a clearer definition for impact operations. It is stressed that the number of objectives should be limited to a sensible span of control. Developing the activities for each objective (Tables 2.4 – 2.11) is also a future task.

The application of SDs herein shows a new way bringing computing technology into a disaster-related management system by focusing on SD conceptualization, which is the first step in developing SD software. The results shed light on the high-level interaction among disaster related activities and the implications of these interactions. As such, they are a useful product for disaster managers. However, further work on formulation, testing, and implementation of disaster-related management system software to test operational polices through computer simulations is a rather exciting and
challenging prospect. The objective of developing software includes finding ways to reduce the subjectivity with which the SFD variables are assigned to scientific information and engineering methods (as was done in the applications herein) by developing precise definitions of SDF variables, including units. It is likely that the work will reveal a cadre of new ideas for disaster-related management tools.

Another interesting suggestion for future work relates to the concept of modern systems engineering. Systems engineering is a combined engineering and management approach to evolutionary processes, where changes to system design may be needed as new components are integrated into the system. The process of incorporating disaster-related objectives into normal organizational procedures using the array of tools herein is an evolutionary process. Applying the tools to organizational procedures will require knowledge of the tools, the management/engineering aspects they are based on, and of the organization that is adopting the tools to their own daily objectives and procedures. A group of people with diverse backgrounds will be needed to brainstorm, develop, implement, test and adjust the system. Such a team will require a team leader who has the attributes of a systems engineer. Research and development based on modern systems engineering methodology and the work herein will lead to additional tools for a disaster-related systems engineer.


References


Paper I
Interactive On-Site and Remote Damage Assessment for Urban Search and Rescue

Solveig Thorvalsdóttir, a) M.EERI, Erlendur Birgisson, b) and Ragnar Sighbjörnsson c)

Extraction of victims entrapped in collapsed structures is the objective of urban search and rescue (USAR) operations. Assessing the potential for live victims and the stability of partially or totally collapsed structures are critical aspects of such operations. This paper outlines relevant activities of the first USAR team arriving in Haiti after the January 2010 earthquake and the supporting actions of their home-base team. The purpose of this paper is to illustrate the different aspects of damage assessment and discuss how those aspects relate to overall USAR field operations. Guidelines developed for USAR teams are used to shed additional light on the concept of USAR-related damage assessment. Three broad types of considerations are found to constitute damage assessment, requiring varying levels of detail in damage descriptions: area reconnaissance, exterior structural evaluation, and interior structural-member evaluation. Using available information and communication technology, a home-base team can become an active player in area reconnaissance by providing pre- and post-impact information about the affected area to the USAR team. [DOI: 10.1193/1.3638715]

INTRODUCTION

Experience has shown that bystanders can pull out people trapped in collapsed lightweight structures, but victims trapped in heavy debris require specialized tools and techniques to be safely extricated. Speed is essential, as the opportunity for saving lives diminishes quickly with time. Research has demonstrated that victims can survive much longer than 24 hours under heavy rubble (see, for instance, Macintyre et al. 2006), up to and beyond 16 days in a few documented cases that now include the Haiti earthquake (BBC News 2010). Therefore, search and rescue team efforts should not be limited to a mere day but should be considered for several days and even weeks after the collapse in extreme cases. To maximize their effectiveness, USAR teams need to be deployed rapidly, find those locations with the greatest need, and be well-trained to expedite their rescues. Essential to this activity are knowledge and techniques to assess damage, the risks to rescuers, and the potential for live victim extraction.

The purpose of this paper is to enable deeper understanding of USAR-related damage assessments, including how remote support can facilitate rapid on-site assessments. In pursuit of this goal, the paper describes the efforts of and challenges to members of the Icelandic Association for Search and Rescue’s (ICE-SAR) international USAR team, both on-site

a) Rainrace Consultancy and University of Iceland, member of ICE-SAR
b) Consulting engineer, member of ICE-SAR
c) University of Iceland
and at home-base, during their mission to Haiti in January 2010. The context in which decisions are made is important; therefore, a summary of the deployment from Iceland, arrival in Haiti and assignments is included. Procedures for evaluating collapsed structures and prioritizing potential work sites, in guidelines published by The International Search and Rescue Advisory Group (INSARAG), are introduced and used as a basis of discussion. The paper concludes by suggesting further research topics in on-site and remote damage assessment. Such research will aid in the development of standard operating procedures to expedite damage-assessment processes and improve judgments made by USAR engineers and other team members.

The initial notification that a severe earthquake had occurred in Haiti on 12 January 2010 came to ICE-SAR through the United States Geological Survey. From that moment, an ongoing assessment of the damages and the needs of USAR teams began. Information about the severity of the damage came from the media and information-sharing between INSARAG teams. Acting on behalf of the Icelandic Government, Iceland’s Minister for Foreign Affairs quickly decided to deploy a USAR team from ICE-SAR. With the cooperation of the Ministry for Foreign Affairs in Iceland and the Consulate of Haiti in Florida, ICE-SAR was the first USAR team to arrive in Haiti after the earthquake, landing in Port-au-Prince 23 hours after the earthquake struck. The next team arriving was the first from the United States along with officials from the U.S. Agency for International Development, arriving approximately a quarter of an hour later.

**AREA RECONNAISSANCE**

The Icelandic and U.S. teams coordinated their initial activities; the U.S. team undertook setting up a Reception and Departure Center for additional incoming teams—as outlined in the INSARAG Guidelines as a task for teams arriving first on site—while ICE-SAR looked for a Local Emergency Management Agency (LEMA) contact to initiate local coordination. The teams decided which areas each team would focus on for area reconnaissance, as little was known of the situation on the ground.

As the team did not travel with its own vehicles, reconnaissance efforts by ICE-SAR were hampered by the lack of available vehicles. The team initially obtained two trucks, which its search and rescue group used for their assignments (Figure 1a). This prevented ICE-SAR from dividing the search and rescue group into smaller units to serve as multiple reconnaissance teams. However, in densely populated areas, the trucks drove the main roads, and small units walked through the narrower streets (Figure 1b). When possible, the first location visited was a local emergency station, for example, a police station, to obtain any available information. This was followed by a drive-through of the area. The local drivers and local guides assigned to the team helped plan the drive-through. In general, the team focused their attention on larger collapsed structures. From experience, USAR responders know that locals search for their family and friends in the rubble and that groups gather near sites if they believe someone may be found alive. Checking on such groups was therefore part of the recon strategy.

During the mission, the headquarters of the Icelandic Association of Search and Rescue Teams in Reykjavik activated a 24-hour home-base team that maintained regular contact with the ICE-SAR team. The home-base team included members of the ICE-SAR national
and Search and Rescue (SAR) Commands, ICE-SAR office staff, and members of the USAR team that did not deploy. While the USAR team operated in difficult conditions in the disaster zone, the home-base team worked around the clock in fully equipped air conditioned offices, using computers, the Internet, and sufficient staff, none of which was available at the disaster site (Figure 2a). Skype messages and emails were the most common mode of communication, and voice communications occurred via Skype every three hours. On occasion, representatives of the Ministry for Foreign Affairs would join in the voice communications.

Standard operating procedures for the National SAR Command advise using Google Earth to get an overview of the area during an operation, and it was used to learn about the

Figure 1. (a) Trucks used by ICE-SAR during the Haiti mission and (b) during a reconnaissance mission

Figure 2. (a) ICE-SAR home-base team in Iceland collecting on-line information about the building stock in Haiti and using Skype to talk with the team members on-site and (b) Google Earth and its GPS navigation system used to locate and geo-code sites of interest.
layout in Port-au-Prince after the earthquake alert came in (Figure 2b). By analyzing the pre-event image on Google Earth, the home-base team gathered information to describe to the team what they could encounter; the city layout, street configuration, roads (width, tarmac or dirt, etc.) bridges, size and height of buildings (judged by their shadows). Despite the fact that the home-base team was not specially trained in analyzing satellite imagery, they gathered information that was useful to the USAR team. Once images taken after the earthquake became available, these too became an important resource for the home-base team. By comparing the before and after satellite images, the home-base team assessed the damage, a technique commonly used to assess overall damage (PDNA 2010). Attempts were made to identify critical buildings like schools, hospitals and governmental buildings. This was done with the help of Google. It seemed to be common for owners of large structures to put information, including pictures, on a Web site. These descriptions and photos were matched against the information taken from the images for verification. Churches were often easy to identify due to their unique architectural shape. The team used Google Earth to geo-code buildings that were deemed of interest and thus created a GIS dataset.

Initially, the information being collected remotely did not significantly aid on-site reconnaissance, as the information arrived too late for planning purposes. However, when ICE-SAR was given an assignment in advance (the evening before), the home-base team had the opportunity to work through the night and provide the USAR team with data prior to embarking on their reconnaissance assignment. For example, the home-base team had several hours to search the Internet for information about the city of Léogâne. Using pictures on Web sites (as mentioned above) of large buildings, such as schools, hospitals and large residential buildings, and information provided by Google Earth, the home-base team compiled a report with general information about Léogâne and specific information about the larger buildings, such as their name, use, size, GPS coordinates, and sometimes a photo. The report was emailed to the ICE-SAR team and they used it to plan the reconnaissance mission in Léogâne. Identifying buildings on Google Earth was not always easy, and GPS coordinates are not accurate in all cases; nevertheless, these resources significantly enhanced the home-base team’s role, compared with previous international missions; the team became a direct participant in the mission.

Another role of the home-base team was report work. Writing reports while trying to organize search and rescue operations is usually not a high priority or a popular task. The home-base team provided a simple, but important, service by finalizing drafts of situation reports. Also, information was analyzed and compiled from the situation reports into a final report and translated into English. The report listed the activities completed by the ICE-SAR USAR team. Attached to the list of activities were three timelines: the times in Haiti (local time) and Iceland (GMT) and the elapsed time since the earthquake. The ICE-SAR team leader in Haiti saw to final editing of the report, and the final report was handed over to the USAR Operations Cell when the USAR team departed from Haiti. Such work is relatively easy to perform in well-equipped nondisaster surroundings, whereas it is a burden for those working under difficult conditions in the field. A word of caution: the home-base team may overburden the USAR team with requests for information on issues going beyond the mission or ability of the team and are therefore not relevant to the mission, regardless of how interesting they may seem at the time.
STRUCTURAL EVALUATION FOR USAR

The Icelandic team located a make-shift coordination center set up by members of the United Nations Stabilization Mission in Haiti that directed them to a collapse site (the Caribbean Market), where locals had reported hearing voices from inside. The team worked at the Caribbean Market until they were reassigned by a USAR Operations Cell, which had taken over assigning tasks to the international USAR teams (for teams wishing to be part of the UN coordination system). The USAR Operations Cell was a sub-operations center of the UN’s On-Site Operations Coordination Centre (OSOCC), established under an internationally recognized process under the auspices of the United Nations.

When the ICE-SAR team arrived at the Caribbean Market, another international USAR team had detected a woman trapped in the rubble; however, the exact location was unclear. The other team lacked the equipment to break through concrete, so the ICE-SAR team took over the extrication. They could hear the victim call from inside the rubble, giving an indication where to focus the work.

Prior to entering the collapsed structure, the engineer evaluated the entire structure and then focused on the part of the structure the victim’s voice came from. He attempted to rebuild the structure in his mind; however, the damage was so severe he found it impossible to imagine how the building was configured before it collapsed (Figure 3a). Not being able to understand the original structure made it more difficult to understand the collapse pattern, and thus the stability and potential voids. As the situation called for immediate attention to a particular part of the structure, the exterior evaluation was then limited to assessing direct risk to the rescue workers and a detailed evaluation of local damages in the prioritized area. Climbing onto the rubble and walking over it gave the engineer an indication of the level of stability. Following these assessments, the engineer identified the safest means of entry and directed the team to an opening into the basement.

As the team penetrated into the rubble from below and broke into new voids, the engineer would evaluate the condition of each new area as it became exposed. Armed with a hammer, the engineer knocked on concrete and exposed rebar that were under stress and

![Image](a)
![Image](b)

Figure 3. (a) The Caribbean Market and (b) rescue efforts inside the Caribbean Market.
listened. It was, to some extent, possible to determine the amount of tension in the material by listening to the sound it made. The engineer advised the rescue-workers to avoid, as much as possible, cutting through rebar under tension. After a few hours of work, the victim was found in a small void created by two cashier desks on the ground floor. It took two more hours to reach the victim and complete the extrication, (Figure 3b). The victim was not seriously injured and had managed to reach nourishment (mainly ketchup) from the market shelves.

Once extrication was safely underway, the engineer shifted his focus back to his evaluation of the entire structure in order to seek additional viable voids for possible live victims. The question of the original building was once again addressed. By measuring and sketching the foundation and exterior walls, an image of the building footprint began to emerge. Seeking information on the interior layout, the engineer looked to locals who had been inside the structure prior to the collapse, such as employees and customers, and asked them to describe what they could remember. Initially, the information was inaccurate as the people interviewed gave different answers. As more and more people were interviewed, the layout, content and load-bearing structure of the building gradually became clearer. Then the original design engineer came to the site, which of course helped significantly. While these interviews took place, the rescue workers completed the extrication and then re-entered the building to provide input about the layout and continue the search for viable voids.

As information was added to the sketch, understanding of the layout and the collapse pattern of the first and second floor began to emerge, enabling the engineer to infer the location and size of viable voids. It became apparent that there were voids on the ground floor created by large and heavy objects such as cashier desks and massive shelves. Victim information was also added to the sketch as it became available. Employees were able to make a calculated guess of the number and locations of employees and customers trapped in the building. Rescue workers inside the building gave the location and descriptions of bodies found in the rubble.

Based on the sketch, the team mapped a strategy for further penetration into the building. From the basement the rescue workers marked on the ceiling, that is, under the ground-floor slab, where the boundaries of the aisles where believed to be. Small holes were then drilled through the slab, big enough to insert a small scope with a light to see inside the void above. Once, the scope was suddenly pulled upwards. A young woman trapped between the shelves in the aisle on the ground floor had grabbed the light. A larger hole was then made in the ceiling and the woman was taken out of the structure through the basement. This victim was also not seriously injured.

Throughout the operation, the engineer continuously monitored the stability of the entire structure and the conditions of voids in the areas considered stable enough for the team to penetrate. Marking pieces of rubble and periodically measuring the distance between them became the commonest method of monitoring.

The communication group accompanying the search and rescue group became an integral part of the damage assessments. Apart from maintaining internet connectivity and thus providing a link to the home-base team, the communication group was equipped to scan, print and laminate the sketch and distribute copies to the search and rescue group. This was repeated several times as the sketch became more detailed. When the team was called back
from the site (other teams later went to this site for additional live rescues), all drawings were handed over to the locals to be used for additional operations in the building.

THE INSARAG GUIDELINES

The INSARAG Guidelines (2010) aim to provide a methodology for urban search and rescue in a country where sudden disaster causes large-scale structural collapse, as well as for international USAR teams responding to the affected country. Structural damage is addressed in chapter F.12 Work Site Triage and Structural Evaluation. The key aspects are outlined below.

WORK SITE TRIAGE

The primary strategic goal of USAR is to save the most lives during the critical post-collapse window of survivability. Information about people trapped in collapsed buildings, missing persons and those accounted for, mold the initial and ongoing planning throughout the operation. However, this information is sporadic, so teams utilize other sources of information and methods to help direct the planning. Locating buildings where people were likely to congregate at the time of the earthquake is the basic first step. That means taking into consideration the hour of the earthquake, day of week (work day or holiday) and cultural activities (church/mosque activities, football games, etc.). This can direct rescue team activities until more accurate victim information becomes available. For example, one could expect that if an earthquake took place at night in Los Angeles, most people would be at home; if it took place in Pakistan on Friday afternoon, the mosques would probably be full of men.

In some cases, the order of assignments for USAR teams is clear from the information at hand about the situation. When information is lacking, the Guidelines suggest five main steps on how to collect relevant information for work site triage: 1) zoning, 2) identifying collapsed buildings, 3) information gathering, 4) categorization and 5) prioritization. Work site is a term for a collapse site, where a USAR team is operating, and the term triage means to prioritize.

First, a triage zone with a manageable number of buildings is identified. Second, all totally or partially collapsed buildings are identified (damaged but un-collapsed buildings do not require USAR). Third, information about the building and missing people possibly in the building should be collected. The fourth step involves an assessment of the damages and collapse pattern of the structure. The assessment focuses on two key aspects: voids and stability. Potential viable voids are identified through exterior evaluation based on collapse pattern and building content. Stability is evaluated considering the effects gravity, aftershocks and debris removal. The fifth and final step is to use the above mentioned information and evaluations to prioritize the work sites.

Prioritization is based on the following order of criteria: 1) collapsed structures with the highest number of victims trapped or missing; 2) those with the largest voids; and 3) those that are most stable. The engineer’s evaluation of stability, team leadership’s risk tolerance, the availability of shoring materials, and available tools or heavy machinery will affect the decisions made. Various factors may change the order of prioritization, for example, priorities set by LEMA and logistical issues.
STRUCTURAL EVALUATION

Teams assigned to work sites perform an external structural evaluation before entering. The INSARAG Guidelines (2010) present a checklist of ten key characteristics to be taken into consideration during structural evaluation (see Table 1). The steps outline an easy-to-remember workflow. The evaluation begins with an attempt to identify the foundation and envision the original structure. Next, the engineer will assess how the structure fell. These first two steps look at the structure as a whole. The next two steps assess the structure’s damaged sections, emphasizing the damage to members and how that damage affects the overall stability of the structure as well as the distribution and size of voids.

From here the steps link the structural evaluation to operational aspects, first identifying work priorities (e.g., identifying which parts of the structure will be given priority, and which will be avoided), then deciding search and rescue strategies, and whether shoring is needed. The last two steps are safety issues, monitoring the structure and making an

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**Table 1. Ten steps of Structural Evaluation (INSARAG 2010)**

<table>
<thead>
<tr>
<th>Step</th>
<th>Characteristics</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Original Building</td>
<td>Use and occupancy, Footprint and height, Architecture and interior layout, Building material, Construction type</td>
</tr>
<tr>
<td>2</td>
<td>Collapse Pattern</td>
<td>Why did it fall down?, How did it fall down?, What stopped the fall?, Distribution of rubble.</td>
</tr>
<tr>
<td>3</td>
<td>Local Damage</td>
<td>Damage to columns, load-bearing walls, beams, floors and connections</td>
</tr>
<tr>
<td>4</td>
<td>Voids</td>
<td>Location; created by structural elements and pattern of collapse, created by building content, Estimation of size of voids for chances of survival</td>
</tr>
<tr>
<td>5</td>
<td>Operation Priorities</td>
<td>Possible access route to priority voids, Mitigation of structural hazards, Entry and egress possibilities</td>
</tr>
<tr>
<td>6</td>
<td>Search</td>
<td>Where to enter and exit, Search routes</td>
</tr>
<tr>
<td>7</td>
<td>Rescue</td>
<td>Where to enter and exit, Rescue routes</td>
</tr>
<tr>
<td>8</td>
<td>Shoring</td>
<td>For safe penetration into the structure, To mitigate the risk of settlement and collapse</td>
</tr>
<tr>
<td>9</td>
<td>Monitoring</td>
<td>To monitor slow moving settlement of rubble, To gain an understanding of possible further collapse</td>
</tr>
<tr>
<td>10</td>
<td>Evacuation</td>
<td>Signaling procedures, Evacuation routes, Safe havens, Safe assembly locations</td>
</tr>
</tbody>
</table>
evacuation plan. These steps can be broken down into four parts: size up (steps 1, 2, 3, and 4), prioritize (steps 4, 5, and 6), plan (steps 6, 7 and 8) and map safety measures (steps 8, 9, and 10).

The level of detail in a structural evaluation will depend on the characteristics of the structure, the degree of collapse, the knowledge of the individual assessing the damage, and the ability of the team performing the search and rescue. The performance time will depend on the building, the collapse, the person performing the evaluation, and the amount of time available. If there is only one collapsed building, more time might be spent on structural evaluation than if there are many buildings to evaluate.

**DISCUSSION**

In large-scale disasters, the teams arriving first face a complex situation that must be broken down into manageable prioritized tasks. To the layperson, planning and implementing area reconnaissance may seem a rather simple task; however, in reality it is challenging and complicated by numerous factors. Throughout the Haiti mission, transportation and security impacted some teams’ efforts; the negative effect of transportation on damage assessment assignments cannot be overstated. In some cases, reconnaissance, structural triage, and structural evaluation were all part of one assignment—and the entire search and rescue group came along, as there was not enough transportation to split the group into smaller units and assign separate tasks. Addressing the issue of transportation for USAR teams is critical.

The ICE-SAR USAR team, which worked during the day due to security concerns, was supported by a home-base team that worked around the clock. The support was not planned, but evolved as the mission developed. Technical advancements, such as satellite imagery, GIS software, the Internet, voice communication—such as Skype and satellite communication—have opened opportunities for people sitting thousands of miles away from the disaster area to effectively support the operations. The key sources of information used by the home-base team were Google and Google Earth, pre-event and post-event images of Haiti. Post-earthquake images were not used as extensively as the pre-earthquake images, mainly due to their late arrival. Google Earth provides new opportunities for on-site and remote cooperation. The home-base team can generate much needed maps and GPS coordinates to send to the USAR team, locate roads and explore the conditions due to rubble and general accessibility in the area, and direct teams to important locations like hospitals and collapse sites. USAR teams can request information from the home-base team as the operations evolve, while the home-base team can track the USAR team’s location through GPS coordinates. Two people thousands of miles apart can be part of the same reconnaissance mission, be looking at the same area, one from the ground and the other from the air, and discuss options via voice communication. The question of how often these images are updated is an important issue. Daily updates would be useful in the beginning of the response.

Information for USAR can be grouped into two broad categories, post- and pre-impact information (Table 2). The first is information that can only be collected after impact, such as extent of damage, collapse-site locations and casualty information. The second category is information that could have been collected before the event, if response teams had known about the event beforehand, for example, construction material, architecture, demographics, infrastructure, and so on. The pre-impact related information is therefore collected after key
post-impact information is known, such as location (therefore the second column in Table 2). Both categories can be split according to whether information is collected on-site or remotely. Some information can only be collected on-site, for example, from interviews with locals and about the ongoing operations. On the other hand, the home-base team can collect useful information from various sources remotely, such as Web sites on the Internet and by being in contact with in-country sources.

The purpose of reconnaissance is to collect information for operational planning. Part of operational planning is to triage potential work sites in resource-deficient situations. The teams will first be sent to sites that are believed to have the highest numbers of confirmed live entrapped victims. When information on entrapped live victims is lacking, planning includes indicators that can lead to sensible conclusions, such as the number of people missing, void size and level of stability. The triage method in the INSARAG Guidelines starts with defining logical zones, as entire cities, or even neighborhoods will have too many structures to prioritize at one go. However, the guidelines say nothing on how to define the zones, which would be useful. The experience from the 2010 Haiti earthquake brings into question the ability to sensibly prioritize collapsed buildings in large-scale disasters and whether prioritizing zones should be included in the Guidelines. Remote support could greatly aid the zoning process, which could be started while the USAR teams are travelling.

Structural evaluation is an integral part of work-site operations. An after-action review by the ICE-SAR engineers led to the conclusion that the ten-step structural evaluation in the
INSARAG Guidelines is logical and useful. Each situation will dictate how they are applied. Recognizing the value of new information and hazards of changing conditions, the ICE-SAR engineer revisited steps and updated his assessment as work progressed. Interior structural evaluation can be categorized as an entity in itself; rather, it has been seen as part of the rescue operations. Indeed, it is part of the rescue operation, but the Haiti experience illuminated the need for a more detailed study of what actually goes on inside the structure during the collapse and residual strength of compromised structural elements. A USAR team has to breach, move or shore structural and non-structural elements of the collapsed structure. If this is not needed, there is no need for the team as bystanders could, and would, reach the victims and bring them to safety. The ICE-SAR engineer used various tactics to decide how to penetrate the buildings. Survivors and bystanders provide key information about the interior of structures that can be used to infer the size and location of voids and load-bearing structural components.

Other guidelines exist that are designed for engineers and are more technical, such as products issued by the U.S. Army Corps of Engineers (USACE). Engineers are an active part of the urban search and rescue community and have participated in the development of technical aspects of USAR since the response in Mexico City to the 1985 Michoacán Earthquake when organized USAR was first recognized (Thorvald 1995, Thorvaldsdóttir 2005). Trained USAR engineers are likely to be those best qualified to assess damage and efficiently mitigate hazards. The methodology in the INSARAG Guidelines is developed for rescue personnel and is in itself simple although the judgments are far from easy. The size of voids is often related to the stability of the remaining structure; the greater the collapse, the smaller the voids and the more stable the structure. Hence, rescue operations can be more dangerous where the voids are larger. Many damaged buildings have both small and big voids, which complicate the judgment; however, only viable voids need be taken into consideration.

CONCLUSIONS

By using available technology, such as satellite links, Google Earth, GIS software, GPS, and Skype, home-base teams can communicate interactively with deployed USAR teams and become integral parts of the response. Working in a hospitable environment, home-base teams can also collect, compile, analyze and distribute data, write reports, translate reports and provide support services that are virtually impossible to do in the field. If assignments are given to field teams in advance, home-base teams have time to prepare briefing packages. These packages could possibly include photos of the work sites taken prior to the collapse, providing engineers and rescue workers with valuable insight on viable voids. Home-base teams can have a formal role within the overall mission with their own guidelines. These teams could incorporate expert knowledge through crowd-sourcing. A remote team could support many on-site teams or strengthen the overall operational coordination. Technological advances offer many possibilities; rapidly evolving technology financial limitations are likely to be the main constraints to development in this area.

Damage assessment is an integral part of urban search and rescue operations. Assessments are made throughout the mission and can be divided into three broad decision-making levels: area reconnaissance, overall exterior structural evaluation and detailed
interior structural-member evaluation. Damage-related information from area reconnaissance is used to prioritize work sites. The five-step triage in the INSARAG Guidelines focuses on building triage but should also include area triage. Exterior structural evaluation assesses the structure as a whole; how it collapsed, locations of viable voids and the overall stability of the building. The ten-step structural evaluation in the INSARAG Guidelines is a logical and useful guide for evaluating partially or totally collapsed buildings during search and rescue operations. The interior evaluation looks at individual members of the structure in order to make decisions on which can be breached or should be shored.

Research into nondestructive test demos to measure stress in damaged elements could lead to more reliable methods for interior structural evaluation. Refinement of these three decision-making categories will lead to better standard operating procedures for USAR operations, thus improving the chances of live victim extrication. Further research includes better understanding of collapse patterns of current building stock in disaster-prone areas and the relationship between voids and the stability of collapsed buildings.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions from the Icelandic Association for Search and Rescue, members of the ICE-SAR USAR team, members of the ICE-SAR home-base team, the Ministry for Foreign Affairs in Iceland, Dewey Perks, Field Coordinator, US Agency for International Development/Office of US Foreign Disaster Assistance, and last, but not least, Dr. John Osteraas. Special thanks go to the reviewers of this paper for very useful comments on streamlining this paper. The photos in this paper are taken by members of the ICE-SAR team.

REFERENCES


(Received 15 September 2010; accepted 6 July 2011)
Paper II
Disaster-Function Management: Basic Principles

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Abstract: The introduction of the disaster life cycle in 1979 was a milestone in disaster management practice. Its four phases of a disaster, which were the basis for comprehensive emergency management (CEM), have been widely used by practitioners and researchers. However, the literature shows that the CEM model does not fulfill the requirements of an analytical framework, and field experience shows that it does not reflect all managerial aspects. Recognizing the need for an alternative approach—and focusing on managerial aspects—the authors introduce the concept of disaster-function management, placed within classical management theory, where the phases of CEM have been replaced by functions. Based on theoretical arguments as well as empirical considerations, the authors suggest eight functions, each characterized by an associated objective describing the common aim of the collective efforts to be managed within that function. The authors also contribute to the discussion of theory for the management of disaster-related activities. DOI: 10.1061/(ASCE)NH.1527-6996.0000118. © 2014 American Society of Civil Engineers.

Author keywords: Disaster-function management; Disaster life cycle; Phases; Disaster objectives.

Introduction

This paper presents a scientific discussion of a new approach to grouping and managing disaster-related activities with the intent of living with disaster risk and coping with disaster events. The approach has been in development since the late 1990s by practitioners and researchers in disaster management with the purpose of designing a management tool suitable for practical applications. One version of this tool has been applied to provide context (Thorvaldsdóttir et al. 2008; Björnsson et al. 2008). In this paper, the approach is placed in a theoretical framework. The novelty of the present approach is in substituting the four disaster phases of the original disaster life cycle (National Governors’ Association 1979) with eight disaster functions characterized by clear managerial objectives. Phases describe groups of functions performed in sequential order, whereas functions, in the management context, is a term for groups of activities required to meet a common objective, regardless of when they are performed. There is an important difference.

Managing a disaster is basically the management of activities required to meet disaster-related objectives (Hayes and Hammons 2002). Many objectives can be associated with disasters; however, the main research question in this paper is: What are the core disaster objectives? In other words, how does one group similar disaster-related activities in their simplest form? Eight core objectives are presented in this paper, obtained by theorizing the fundamental steps in dealing with disasters. These eight core objectives and the activities related to them are analyzed based on a comparison with the CEM model. The concept of disaster-function management (DFM), based on classical management theory, is introduced. A theory of DFM is addressed through epistemological concerns raised by McEntire (2004). McEntire et al. (2002) set criteria for a disaster paradigm to incorporate “triggering agents, functional areas, actors, variables and disciplines pertaining to calamitous events.” The DFM model fulfills these criteria.

Background

Coetzee and Van Niekerk (2012) trace the idea of disaster phases back to the 1920s as linear, descriptive conceptions of contemporary social behavior, which did not originally address how disasters should be handled. Eventually, the need for normative models that could assist in the effective management of disasters and their consequences was identified, possibly brought about by the frequency of instances as well as the damages caused by disasters in the 1970s and onwards (Coetzee and Van Niekerk 2012). Following a series of studies on contemporary disasters, the U.S. National Governors’ Association (1979) identified four phases of comprehensive emergency management (CEM): (1) mitigation, (2) preparedness, (3) response, and (4) recovery (National Governors’ Association 1979; Neal 1997; Rubin 2009) and portrayed them on a circle, termed the disaster life cycle. At the time, preparedness and response were already recognized activities within emergency management, but mitigation and recovery were added to create CEM—an all-hazards, all-phases, and all-actors approach to disaster management (National Governors’ Association 1979).

The CEM model was considered “a cornerstone in disaster management practice in the United States” (Neal 1997). The U.S. FEMA uses CEM as a basis for its mission statement (FEMA 2001), and the CEM phases have also been widely used in research (Quarantelli 1998; Burton 2008; Moore et al. 2009). The CEM model was the first concept to unify and give direction to the field; however, it has been recognized that CEM is somewhat limited from a practical as well as a theoretical point of view (McEntire 2004). For example, Neal (1997) sees disaster phases as an important means to develop research, organize timelines, and generate research findings but states that CEM has limitations as an analytical model to look for change or explain change.
The view that the CEM model is no longer sufficient is also manifested in the proliferation of variations of the CEM model in the scientific literature. For example, McEntire et al. (2002) present the concept of comprehensive vulnerability management (CVM), built “on the strength of CEM” by using the same four phases but expands what each phase involves. The United Nations (UN) (2002) chose to add two phases, prevention and development, to the disaster life cycle. Even FEMA has adapted the four phases to “prepare for emergencies and disasters, respond to them,” “recover from them, mitigate their effects, reduce the risk of loss,” and “prevent disasters […] from occurring” (FEMA 2011) and refers now to a risk-based CEM system (FEMA 2008). Various adaptations can be found in scientific papers. In addition to the scientific literature, when searching for disaster cycle, the Google internet search engine gives various versions.

Limitations of the original CEM model have also surfaced when the model has failed to support management activities. For example, during the 1996 Gjalp volcanic eruption in Iceland, it was evident that a phase after the volcanic activity had started, but before the damaging impact occurred, was not in the model. The response to the 2000 earthquakes in South Iceland called for clarity of focus in the response phase, leading to a separation of rescue and relief operations. During the response to the 2001 Bhuji earthquake in India, both rescue and relief teams were invited to the first coordination meeting, which turned out to be a mistake, and separate coordination structures were established. Shelter set up as a temporary response measure was still being used for years after the 2005 Pakistani earthquake, gradually turning an activity unintentionally from a response act to a recovery act, because the temporary housing became the norm. The development of loss-estimation methodology and its use in real-time loss estimation during the 1994 Northridge earthquake (Eguchi et al. 1997) demonstrated new possibilities for risk analysis to be formally linked to disaster management. Managers’ frustration with the lack of learning from so-called learning activities also contributed to the call for a new management model.

As outlined previously, scientific and practical knowledge now surpasses the four-phase framework and calls for a new model in line with current knowledge and experience, and many new versions exist. So why call for a scientific discussion on a new approach if so many versions exist? The reason lies in the powerful contribution that the original version made to the disaster management profession and disaster science, which was applicable to both practitioners and researchers, moved the many professions and multiple research disciplines further along, and provided them with a basis for communication. The proliferation of versions that are used for a single study, not justified through scientific discussions or design criteria, seems to result in divergence rather than move the field toward further development. A new paradigm is needed.

From Phases to Functions

Neal (1997) and McEntire et al. (2002) provide useful analyses on whether the CEM model depicts a sequence as was originally intended. Neal (1997) explains the activities of the four disaster phases and their logical order: first, mitigation to lessen or eliminate disaster effects; then, preparedness to fill in where mitigation cannot reduce the effects; next, emergency response after a disaster; and, finally, recovery, bringing the affected area back to its normal (or a better) state. However, Neal goes on to provide examples from disasters where the sequence of activities does not match this order and concludes that it is important to distinguish between whether the cycle depicts temporal or functional aspects of disaster. Neal investigates the temporal aspects (i.e., when activities take place) and offers new approaches to re-examine disaster phases to give scientific explanations without offering a new set of disaster phases. McEntire et al. (2002) also state that there is “considerable overlap and complexity, [and therefore] it may be more appropriate to label mitigation, preparedness, response and recovery as functional areas rather than phases.” Quarantelli (1996) also raises the point that generic functions need to be managed in disaster response.

Substituting disaster phases with functional areas, or functions, is a useful step from not only a sequential but also a managerial perspective. Different disciplines have found common ground within clear objectives. For example, planning and executing joint army, navy, and air force operations are commonly based on nine joint functions. These are (J1) manpower, (J2) intelligence, (J3) operations, (J4) logistics, (J5) plans, (J6) command, control, communications, and computer systems, (J7) engineering or operational plans, (J8) force structure resource and assessment, and (J9) civil-military operations (Air War College 2012). The incident command system, “a standardized, on-scene, all-hazards incident management approach” (FEMA 2012), is structured to facilitate activities of all emergency services and other services within five major functional areas: (1) command, (2) operations, (3) planning, (4) logistics, and (5) finance/administration. Similarly, having at their disposal a set of specific disaster functions can help managers to coordinate contributions from different disciplines and stakeholders. They help to build “bridges between all disciplines” and professions and create the much-needed “partnership[s] of academics and practitioners” (Poulin 2010). The literature holds many calls for partnerships among disciplines (Quarantelli 1998; McEntire 2007; Amendola et al. 2008; Kapucu 2008; Janssen et al. 2010; Thévenaz and Resodihardjo 2010; Wenzel et al. 2007). Wenzel et al. (2007) even claim that problems facing megacities can only be addressed with an interdisciplinary agenda and pose in this respect a significant challenge for science ranging from social sciences and engineering to natural sciences, such as geosciences and meteorology. One way to meet this interdisciplinary challenge is through a functional approach.

According to Rubin (2012), the major disaster events of the past 10 years have cast doubt on the adequacy of the current emergency management system and given greater urgency and prominence to the ongoing debate about fundamental emergency management principles and practices, including “the responsibilities of each level of government for appropriate functions of emergency management.” Whereas Rubin investigates the role of government, the authors investigate what constitutes appropriate functions.

Methodology

The scientific discussion in this paper on the question of what the core objectives are has two parts. The first one states a theoretical argument of how core management objectives can be obtained from logical consideration set in the context of the definition of a disaster. Quarantelli (1996) stated that it is possible to visualize common functions or response patterns that have to be carried out in each case during a disaster response. The approach of this paper is similar; the authors visualized and then theorized about patterns of activities, but instead of limiting the functions to response disaster activities, they expanded the visualization to disaster-related activities as a whole. Also, Quarantelli makes no attempt to group the functions, whereas the authors group functions and activities to seek core functions. The second part places the theoretical argument into context with the original CEM model and an empirical setting. The discussion is framed within an external feedback model developed by Coetzee and Van Niekerk [adapted from Skyttner (2005)] based on general systems theory. Their model was used to address how linear disaster
phases (the original system) were affected by factors of change (the external environment) leading to a normative disaster management cycle (the output). Their external environment was instances of disturbances, an increase in the devastating impacts of disasters, and the need for a normative disaster management tool. Applying an adapted version of their approach, the authors use their output, in the form of the CEM model, as the original system and the proposed DFM model as the output system. The external environment is the need for a normative tool, field experiences, and scientific references, using mainly the engineering and social sciences literature.

The original system, the output system, and the external environmental effects are discussed in the “Original System: Comprehensive Emergency Management Phases,” “Output System: Core Disaster Functions,” and “External Environmental Effects: Discussion” sections.

Original System: Comprehensive Emergency Management Phases

The original CEM phases are cited as follows (National Governors’ Association 1979) to facilitate the subsequent discussion:

- “Mitigation: Mitigation includes any activities that actually eliminate or reduce the probability of occurrence of a disaster (for example, arms build-up to deter enemy attack or legislation that takes the unstable double-bottom tanker off the highways). It includes long-term activities designed to reduce the effects of unavoidable disaster (for example, land-use management, establishing comprehensive emergency management programs, or legislating building safety codes).”
- “Preparedness: Preparedness activities are necessary to the extent that mitigation measures have not, or cannot, prevent disasters. In the preparedness phase, governments, organizations, and individuals develop plans to save lives and minimize disaster damage (for example, compiling state resource inventories, mounting training exercises, or installing warning systems). Preparedness measures also seek to enhance disaster response operations (for example, stockpiling vital food and medical supplies, through training exercises, and by mobilizing emergency personnel on a standby basis).”
- “Response: Response activities follow an emergency or disaster. Generally, they are designed to provide emergency assistance for casualties (for example, search and rescue, emergency shelter, medical care, mass feeding). They also seek to reduce the probability of secondary damage (for example, shutting off contaminated water supply sources, cordoning off and patrolling looting-prone areas) and to speed recovery operations (for example, damage assessment).”
- “Recovery: Recovery activities continue until all systems return to normal or better. They include two sets of activities: Short-term recovery activities return vital life-support systems to minimum operating standards (for example, cleanup, temporary housing). Long-term recovery activities may continue for a number of years after a disaster. Their purpose is to return life to normal or improve levels (for example, redevelopment loans, legal assistance, and community planning).”

Output System: Core Disaster Functions

The core disaster functions, objectives, and examples of actors are presented in Table 1. The theoretical argument for the eight core functions and associated objectives starts with the definition of a disaster: “A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources” [United Nations International Secretariat for Disaster Reduction (UNISDR) 2009].

The objective of disaster risk analysis is to understand the possible and probable impact, losses, and disruptions that could occur in future disasters and to what level they exceed the ability of a society to cope. From a theoretical point of view, this is the starting point, where the potential threat is analyzed and the problems are outlined and defined. The objective of mitigation is to measurably reduce disaster risk. Theoretically, this is a logical step following the analysis function, assuming the analysis reveals what can potentially be mitigated. However, not all eventual threat scenarios can be mitigated to the extent of being prevented, and therefore, it is logical to proceed toward the operational preparedness objective. The operational preparedness function consists of activities completed prior to an event to prepare a secondary set of activities performed later in reaction to a damaging process and its effects. In contrast, mitigation efforts are completed prior to an event in order to not have to react to a damaging process or react to a lesser degree. Then, with the analysis, mitigation, and operational preparedness objectives all defined and the associated functions activated, the logical extension from a theoretical perspective is to assume that eventually increased fluctuations in natural processes will lead to a damaging event. The time dimension of a fluctuation of natural processes and damaging sequences, termed in this paper as the damaging process, allows for activation of the impact operations function. It is logical to assume that, because of the time dimension, there is time allotted to diagnose the real-time process and sequences, to provide a prognosis regarding the turn of events, to intervene prior to impact to reduce real-time risk, to prepare for imminent impact, and to react to the actual damaging sequences and secondary events.

In theory, the damaging processes will injure and trap people, requiring an activation of the rescue-operations function for direct rescue operations and any support operations needed, for example, action planning, resource mobilization, and crowd control. Therefore, in theory, the impact operations address damages to the physical environment, and the rescue operations address injuries to people. In a perfect situation, it might be assumed that, directly following impact and rescue, it would be sufficient to activate the recovery operations function, i.e., to implement final sustainable solutions leading to a sense of normalcy, such as burials, resumed services, and new housing. However, it is more realistic to assume that, because of the time dimension of the recovery process, a temporary life-sustaining function also needs to be activated to bridge the gap, i.e., the relief-operations functions, such as sheltering, feeding, food security, water, clothing, hygiene facilities, cash, and possibly support activities, for instance, crowd control.

The logical framework of core disaster functions defined previously covers the direct activities in anticipation of a harmful event and coping with an event with more detailed reasoning than the original disaster life cycle. The term life cycle refers to the lifespan of an event that is born and dies: something that begins, goes through phases, and ends. Thus, the original disaster life cycle envisioned a single event. In theory, an event is an opportunity for accumulation of knowledge and experience that can lead to lessons learned and systematic changes to better deal with future events. In actuality, this may not be the case, making it important to place the systematic learning function as a core disaster function, making sure it gets the same attention as other functions.

External Environmental Effects: Discussion

Analyzing the DFM model from the perspective of the original CEM model placed in an external environment led to the following seven suggested changes to the original system (Fig. 1):
Table 1. Disaster Core Functions, Objectives, and Examples of Actors

<table>
<thead>
<tr>
<th>Functions</th>
<th>Objectives</th>
<th>Actors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disaster-risk analysis</td>
<td>To understand disaster risk, its components, and context</td>
<td>Engineers, scientists, hydrologists, academics</td>
</tr>
<tr>
<td>Disaster-risk mitigation</td>
<td>To measurably reduce known disaster risk</td>
<td>Urban planners, engineers, public, government</td>
</tr>
<tr>
<td>Operational preparedness</td>
<td>To prepare future operations for dealing with future disasters</td>
<td>All those responsible for any reactive type of activities</td>
</tr>
<tr>
<td>Impact operations</td>
<td>To react to damaging processes prior to, during, and after impact</td>
<td>Road administration, police, contractors, air traffic control</td>
</tr>
<tr>
<td>Rescue operations</td>
<td>To save lives of those caught in damaging processes</td>
<td>Police, fire fighters, rescue teams, medical staff</td>
</tr>
<tr>
<td>Relief operations</td>
<td>To provide temporary relief of suffering to those affected</td>
<td>Nongovernmental organizations, veterinarians, government agencies</td>
</tr>
<tr>
<td>Recovery operations</td>
<td>To implement final measures to bring a community to normalcy</td>
<td>Contractors, public works, schools, industry, governments</td>
</tr>
<tr>
<td>Systematic learning</td>
<td>To systematically learn from recent events and implement changes</td>
<td>All</td>
</tr>
</tbody>
</table>

Fig. 1. Disaster functions versus CEM phases

1. Add disaster risk analysis;
2. Clarify terminology regarding mitigation and preparedness;
3. Separate rescue and relief operations within response;
4. Expand impact operations within response;
5. Plan recovery operations prior to the event;
6. Expand the definition of preparedness to include preparing for impact, rescue, relief, and recovery operations, and rename it operational preparedness; and
7. Add systematic learning from recent events.

A discussion of each change is presented in the next seven sections.

Risk Analysis for Disaster Management

The CEM phases start with mitigating risk, assuming that the risk associated with a disaster is already known. This assumption does not necessarily hold from the theoretical point of view; it is therefore logical to determine the disaster risk before starting attempts to manage it. Any attempt to manage risk must address the question, “What is risk?” (Slovic 2001). Even when narrowing down the perspective to natural disaster risk, there are many answers. A more technical definition involves “the probability of an event and its negative consequences” such as losses “in lives, health status, livelihoods, assets and services” (UNISDR 2009, definition of disaster risk). The purpose of a technical risk analyses for disaster management is not only to produce data on probability and consequences but also to gain insight into factors that can lead to a disaster, such as the characteristics of hazards, vulnerability factors, and the exposed population—factors that can be used for mitigation or preparedness strategies. Analyzing the circumstances and processes causing a disaster (Wisner et al. 2004; Tierney 1999) and understanding what forms a future disaster may take and the consequences that may follow are important outputs of a risk analysis. The ability to produce detailed risk studies has improved significantly since the 1970s, as demonstrated by the Great Southern Californian ShakeOut (Porter et al. 2011). Risk analyses can be performed on specific aspects of risk, such as hazards [e.g., earthquakes as in Sigbjörnsson et al. (2009)], vulnerability factors [see, for example, the list in McIntire (2004)], damages (Jones et al. 1995), or understanding competing risk factors “when interests do not align or are in conflict in some way” [International Risk Governance Council (IRGC) 2011]. Specific studies need to be incorporated into the larger context to meet the overall disaster objective.

Sociological scientific perspectives on risk-related phenomena have also developed in the past decades. For example, social science has highlighted the importance of understanding how risk is perceived (Slovic et al. 1982). Research has shown that the public conception of risk incorporates many considerations, such as uncertainty, dread, catastrophic potential, controllability, equity, and risk to future generations, requiring public participation mechanisms to capture perceived risk (Kontouehler and Slovic 1996). The concept of social amplification of risk helps to explain how psychological, social, institutional, and cultural processes can heighten or attenuate perceptions of risk and thus generate secondary consequences that need to be dealt with (Kasperson et al. 1988; Rennt et al. 1992). In other words, risk means different things to different people (Slovic et al. 1982). Perceived risk is quantifiable and predictable, enabling scientists to identify similarities and differences between groups.
with regard to risk perceptions and attitudes (Slovic et al. 1982) and enabling disaster managers to take risk perception into consideration in mitigation and preparedness strategies. Social inequality, the dynamic aspects of risks associated with both physical and social systems, and processes in which risk are imposed on people are some of the factors further complicating the concept of risk (Tierney 1999).

Risk analysis projects involve judgment, even those based on a strong scientific basis. Defining the problem, choosing an approach to the analysis, and even framing the results to the users are subjective steps (Kunreuther and Slovic 1996). Deciding which risk perspectives to take into consideration, not only the technical or social, but also medical, economic, psychological, and the many others, is also a judgment call. The many perspectives require many actors to analyze and develop a common understanding of disaster risk.

**Mitigation versus Preparedness**

To convey information and knowledge in any meaningful way, issues and phenomena must be accurately and adequately defined (McEntire 2004). In their comprehensive review of the disaster preparedness literature, Sutton and Tierney (2006) point out that mitigation and preparedness are sometimes conflated with one another and that definitions contained in key resource documents reviewed for their project showed conceptual blurring. Sutton and Tierney need 3.5 pages to describe how the references state what they claim to define. De termining that the concept of phases causes confusion. It is argued in this paper that, when seen as functions with clear objectives, the concepts of mitigation and preparedness can be easily kept separate, because they involve distinct sets of activities performed mainly by separate groups of stakeholders, regardless of when they are performed.

Sutton and Tierney also reveal that some discussions use the term mitigation to refer to actions taken after an event occurs, for example, to contain an oil spill. Their review also found definitions of mitigative measures like warning systems and evacuation plans, justified because they must be implemented long before a hazardous event. In this paper, it is argued that mitigation and preparedness take an equally long time to implement—from now until the onset of the disaster. Again, the concept of phases is causing confusion. Sutton and Tierney (2006) further cite references that define mitigation as being passive protective measures and preparedness as active measures. Mitigation activities could be considered passive in the sense that they are performed in order for the actor not have to act later (strengthening your house to reduce the risk of it collapsing, buying insurance to reduce the risk of losing money), whereas preparedness comprises activities performed (at the same time) in anticipation of having to act on them later because of an event.

**Rescue versus Relief**

Response is defined by CEM as emergency assistance, such as search and rescue, emergency shelter, medical care, and mass feeding. These types of activities have two distinct objectives: to save lives and to sustain lives. The mission of search and rescue operations is straightforward: to search for those who are lost and/or in danger and provide life-saving medical services. The mission is over when they are found and saved or their bodies retrieved and their lives are no longer threatened. The window of opportunity is usually small; if the operations are not executed immediately, lives may be lost. The mission of a life-sustaining operation is less clear; especially when disasters occur in areas where poverty and suffering is part of daily life. Life-sustaining operations are commonly called relief operations or humanitarian operations. Their common theme is that they are temporary solutions, bridging a gap until permanent measures are in place.

In smaller operations, a single team may be involved in both types of missions. However, in larger operations rescue and relief operations are usually performed by specialized teams and coordination centers kept separate, as was demonstrated in the response to the 2001 India and 2010 Haiti earthquakes (Celik and Corbacioglu 2009). After having completed rescue operations, a rescue team may support relief operations; however, as stated, the objective of the activities remains the same, regardless of who performs them. Another indicator that these are two separate groups is their literature. International search and rescue teams have developed the guidelines (International Search and Rescue Advisory Group [INSARAG] 2012), whereas the relief community has the Sphere Handbook (2013). The authors argue that having separate rescue and relief functions is equally as important as having a separate recovery function. Indeed, relief operations have more in common with recovery operations than rescue operations, because good relief operations can expedite recovery (Christoplos 2011).

**Impact-Related Operations**

Impact is defined in this paper as the damaging interaction between the natural process and the physical environment, and impact-related operations are defined as any operations required before, during, or in response to the damaging interaction. The impact is often symbolized on a disaster cycle as a star, as being simply the event that causes the damages. Damages play a central role in disasters at multiple levels of society, from the household level (livestock, crops, homes, and tools are destroyed) to the national level (roads, bridges, hospitals, schools, and other facilities are damaged) (Wisner et al. 2004). However, because of the time dimension of initial and secondary natural processes and the time dimension of direct and secondary damage sequences, the impact process itself allows for interventions and warrants more attention. The stages of damaging processes are outlined in Table 2 and are subsequently discussed.

Natural processes fluctuate on a daily basis, usually causing no harm or alarm. The impact process, as defined in this paper, starts with increased natural activity, such as increased rain or increased CO₂ in rivers because of volcanic unrest, called natural unrest. The increased fluctuations may stabilize, stop, and cause no further alarm. The fluctuations may also magnify and cause secondary processes, such as landslides and tsunamis. The longer the period of natural unrest, the more time there is available for interventions. For example, it took 5 weeks for the volcanic eruption in Iceland in 1996 to melt ice, cause a flood, and damage the roads, giving ample opportunity to discuss what could happen, what happened in the past, and what could be done. Standard procedures for this period are needed to take appropriate action when time allows. The procedures require real-time data acquisition and associated databases “coupled with an effective modeling system [to] provide warnings of impending disasters and advice to various levels of authority, the emergency services and the public” (Price and Vojinovic 2008). The natural unrest prior to impact can also be virtually nonexistent, like a large earthquake without foreshocks.
Table 2. Examples of Impact-Related Operations

<table>
<thead>
<tr>
<th>Natural processes</th>
<th>Damages</th>
<th>Impact operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily fluctuations: do not cause alarm or further development</td>
<td>No damage</td>
<td>Monitoring daily fluctuations</td>
</tr>
<tr>
<td>Precursors alert to possible further developments</td>
<td>No damage or minor damage</td>
<td>Measurements/prognosis, diagnosis/warning/intervention</td>
</tr>
<tr>
<td>Precursors magnify, indicating a serious hazard</td>
<td>No damage or minor damage</td>
<td>Measurements/prognosis, diagnosis/warning/intervention</td>
</tr>
<tr>
<td>Main event initiating the damage sequences</td>
<td>Damage</td>
<td>Measurements/prognosis, diagnosis/warning/intervention</td>
</tr>
<tr>
<td>Secondary events: smaller events causing further damages</td>
<td>Additional damage to damaged elements and new damage</td>
<td>Measurements/prognosis, diagnosis/warning/intervention</td>
</tr>
<tr>
<td>Tail end: natural processes die down and come to an end</td>
<td>Additional damage decreases and eventually ceases</td>
<td>Monitoring the geomorphologic end and long-term damages</td>
</tr>
</tbody>
</table>

In Iceland, this period has been divided into two operational stages. The first is an alert stage where monitoring agencies alert disaster managers of any increased natural activities and call for intensified monitoring with more effort put into surveying and analyzing the natural process and the elements in harm’s way. This is an information-sharing phase between scientists, engineers, disaster managers, authorities, and others, leading to a diagnosis of the situation (understanding the current state of a natural process), followed by a prognosis (assessing how the process will evolve and possibly cause impact and cascading damages). The second operational stage, the hazard stage, starts when it is decided by the appropriate bodies that magnified precursors warrant action by public services, such as closing roads and pre-positioning rescue equipment, by the public, such as closing windows and self-evacuation, or by others.

Alert procedures are similar to those in the risk analysis function, and hazard procedures are similar to those in the mitigation and preparedness functions. However, instead of dealing with a future event that may or may not happen, impact operations deal with real-time natural processes; the question is not about when the process will start but when it will stop. In real time, the modus operandi changes. An indicator of this is the change in the perceived risk. As discussed, risk can be perceived and acted upon with analysis (logic, reason, and scientific deliberation brought to bear on risk management), but it can also be perceived and acted upon with feelings (individuals’ fast, instinctive, and intuitive reaction to danger) (Slovic et al. 2005; Slovic and Peters 2006). As the threat increases, time becomes important, and risk in terms of feelings plays a greater role in the decisions making (authors’ personal experience).

Eventually, an event initiates the main damage sequences. The impact may only cause damage to the more vulnerable structures, but increasing magnitude will cause, in general, damages to less and less vulnerable structures. Techniques are available to produce real-time loss estimates by systems that are activated by the natural processes (Eguchi et al. 1997). The damage sequence itself can be short or long, relatively speaking, for instance, the shaking and collapse of a large building on soft soil far away from the epicenter is likely to be longer than for a small building on bedrock next to the epicenter, flood damage may take days, and volcanic eruptions may spew ash over a community for months. Opportunities to intervene vary. During an earthquake, for example, it is basically everyone for themselves during the duck-cover-hold sequence, whereas during a river overflow, there may be time for organized sandbagging, and ash may be shoveled as it falls.

Secondary events require continued diagnosis and prognosis. Eventually, the magnitude of the natural processes attenuates to a normal level. However, damages can continue to grow for a considerable time, such as renewed propagation of cracks in unrepaired buildings. Operations during this stage include maintaining situational awareness and monitoring the ending of a geophysical process.

Examples of impact operations include the cooling of flowing lava in the Westman Islands eruption in Iceland in 1973 (Bryant 1993) and special air traffic control over Europe during the eruption of Eyjafjallajökull in Iceland in April/May 2010 when “air traffic was repeatedly interrupted because of volcanic ash in the atmosphere” (Langmann et al. 2012; Ellason et al. 2011; Weber et al. 2012). In 2005, hurricane Katrina caused severe damage in the United States. Early impact operations focused on the uncertainty of whether levees had been overtopped so that water in New Orleans could be readily pumped away or whether they had been breached so that water continued to pour in and could not be pumped out until after major reconstruction (Abbott 2007; Cooper and Block 2006). Another example of an impact sequence is the earthquake in Japan on March 11, 2011, generating a tsunami that stopped the power supply for cooling in the Fukushima Dai-ichi Nuclear Power Station, causing hydrogen explosions that released artificial radionuclides into the environment (Hosoda et al. 2011).

Modelers have had difficulties in placing these activities in a phase of the CEM. Early warning (EW) has gained much attention and has been particularly problematic in the context of CEM, and its location in the disaster cycle has varied. Mora and Koipi (2006, p. 159, Table 2) chose to place EW as a preparedness activity, which it is not as the event has started. In their depiction of a crisis life cycle, Janssen et al. (2010) place early signals between prevention and response and therefore not in any phase. Impact operations are defined in this paper as any activity in relation to natural unrest and direct and secondary damage sequences.

Recovery Operations

From a recovery viewpoint, disasters are perturbations to urban systems that reflect longstanding environmental, economic, and social issues, which are exacerbated in the years following the event (Blanco et al. 2009, pp. 200–209). The objective of recovery as the “restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities” (UNISDR 2009) has several dimensions. Other terms used in relation to recovery, such as redevelopment, reconstruction, and rehabilitation, should be defined as subfunctions of the recovery process (Neal 1997). Recovery research has addressed several recognized dimensions of sustainable recovery (Smith and Wenger 2007). Recent work by Johnson and Olshansky (2011) states that, in many ways, “the work of recovering from a disaster involves normal life, business, and government tasks: residents seeking accommodations and building homes, businesses surviving lean times and upgrading commercial space, and utilities and public agencies improving infrastructure and facilities.” The difference lies in “pressures to restore a sense of normalcy and conflicts

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between speed and quality as measures of recovery success. Their term time compression explains many of the principles and key observations made about recovery processes. They further define warping as the differential rates of recovery happening at any given time across the community, which cause problems in the recovery process in community systems, such as structures, infrastructure, public services, social networks, the economy, and institutions. “As a result, during recovery, certain things get ‘out of sync’ compared to normal times, things get rebuilt in the wrong order, and some apparently lower priority actions may be completed before higher priorities.”

Disaster recovery planning therefore requires a specific organization and programs (Berke et al. 1993) to deal with the inter-disciplinary nature of disaster recovery. Local officials involved in complex intergovernmental processes in key public policy choices, public participation in these processes, institutional cooperation, and local businesses all need to be part of the organization (Berke et al. 1993; Rubin and Barbee 1985).

**Operational Preparedness for Impact, Rescue, Relief, and Recovery**

Originally, CEM preparedness referred only to emergency response, i.e., rescue, relief, and reducing secondary damages. As the authors have explained, responding to a situation involves more than these three activities. All impact operations require prior planning. Recovery should not be an afterthought taken into account when the emergency is over but done in parallel with other preparedness planning (Wein et al. 2011; Sutton and Tierney 2006; Fallara 2003).

Various parts of the literature provide an overview and guidance on preparedness from a social science perspective (Tierney 1999; Covington and Simpson 2006; Sutton and Tierney 2006). Sutton and Tierney list a variety of preparedness measures: developing planning processes to ensure readiness; formulating disaster plans; stockpiling resources necessary for effective response; and developing skills and competencies to ensure effective performance by different units of analysis (households, agencies, and businesses).

**Systematic Learning from Recent Events**

An event tests the system. It enables practitioners to gain experience and gives them grounds to judge the system. It also provides researchers with an opportunity to collect data and study processes of change (Birkmann et al. 2010) and opens policy windows (Kingdon 1995). One might imagine that learning is then implicit, that it is not maintained. Therefore, critical lessons can be derived from smaller events and disasters.

However, despite these changes, the hurricane season of 2005 and terrorist attack on September 11, 2001 in the United States “glaringly displayed the weaknesses and failures of certain emergency management systems, processes, and leadership” (Rubin 2012).

Bilham’s (2009) account of 3,000 years of history reveals that as inhabitants of a seismically active planet people have shown remarkable indifference to the potential loss of life from earthquakes. Rubin (2012) discusses the difference between addressing past events and recent events, that to gain a broad perspective of a disaster and its far-reaching consequences, a decade or two is required. This highlights the need to develop a mechanism for learning and change that utilizes the momentum of a recent event while incorporating the broad perspective given by time.

Establishing a systematic learning function as part of a disaster management system gives learning and change equal importance to other functions. Poliowski (2007) illustrates how good practice can be lost if “comprehensive learning steps and learning processes do not culminate in a learning evolution” that is maintained. Therefore, specific learning procedures need to be established before an event to increase the likelihood of improving disaster systems after an event. Furthermore, disasters of all sizes should be considered, because “while smaller disasters do not often lead to significant changes in societies and organizational structures” (Birkmann et al. 2010), it is argued that critical lessons can be derived from smaller events and accidents.

**Utilizing Classical Management Concepts**

Classical management theory states that management by objectives (MBO) as a concept is an integrated management system to manage an organization by aligning the entire managerial effort with specific performance goals (Ghram 2010). Using objectives changes the question from “In which phase does an activity belong?” to “Which objective(s) does the activity meet?” or more importantly “Which activities are needed to meet specific objectives?” For example, the question “In which phase is public education preformed?” is not relevant. “What is the objective of a public education project?” is. A public education project could address many objectives in a single package: to understand risk (e.g., teaching people about hazards and consequences), to mitigate risk (e.g., teaching people to fasten bookshelves to walls), or to prepare people for disasters (e.g., teaching people to make a home emergency kit to use when disasters strike). Another example is damage assessment. Damages are assessed differently, depending on the objective: is it to understand the overall impact, to save lives from collapsed buildings, to estimate shelter needs as a result of inhabitable buildings, to plan recovery, or to understand how to rebuild better? Hence, damage assessment too falls under many objectives. A comprehensive set of objectives provides a checklist: have all the core disaster objectives been met? If not, the question becomes “What functional activities need to be addressed to meet them?”

Using objectives leads to new ideas for theoretically integrating relationships between core functions (see Table 3 on the inter-relationships of core functions). For example, Slovic (2001) stated that it is important to define risk. The authors argue that it is important to not only define risk but also define risk in context with other functions. For example, to ensure that risk information provides output that is valid as a mitigation-strategy input, risk must be characterized in context with mitigation from the beginning of the risk analysis project. The relationship will reach a balance: when risk is mitigated to the extent possible, the risk-mitigation relationship defines the possible circumstances that initiate damages. Valid risk information can also be determined in context with operational decision-making that can be derived from smaller events and accidents.
Each plan will of course entail numerous subfunctions. Quarantelli
stakeholders, with the purpose of achieving the associated objective.
a single plan developed by a manager in cooperation with relevant
having the same objectives (Mitigation-preparedness)
prolonged recovery will increase the need for relief. Finally, the
concept of systematic learning leads to three verifications:
impact; the usefulness of mitigation efforts is compared with the
ships: the validity of risk information is compared with actual
mitigation and preparedness is such that increased mitigation is
an event that the resources can deal with. The relationship between
there are costs. Preparedness activities cannot be based on proba-
mitigation or de
vulnerability, i.e., the impact magnitude exceeding the level of coping.
prepare and deal with events with the capacity to deal with
or decrease preparedness.
functions, subfunctions, and inter-
and coping more effectively with disasters, and the objectives would
be management objectives to reach this improved situation.
mitigation-preparedness Increased mitigation leads to decreased
Operations
The four types of operations (impact, rescue, relief, and recovery) are planned and executed
in context with each other.
Impact-risk Was the risk appropriately defined based on the
actual impact?
Impact-mitigation Were mitigation strategies appropriate?
Operations-preparedness Was preparedness appropriate given that the
impact conformed to expectations? What can be inferred about preparedness if the impact
was unexpected?

<table>
<thead>
<tr>
<th>Functional pairs</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk-mitigation</td>
<td>Risk information informs mitigation strategies, leading to reduced risk or a defined level of vulnerability, i.e., the impact magnitude initiating damages.</td>
</tr>
<tr>
<td>Risk-preparedness</td>
<td>Risk scenarios inform preparedness strategies or define the level of capacity, i.e., impact magnitude exceeding the level of coping.</td>
</tr>
<tr>
<td>Mitigation-preparedness</td>
<td>Increased mitigation leads to decreased preparedness.</td>
</tr>
<tr>
<td>Operations</td>
<td>The four types of operations (impact, rescue, relief, and recovery) are planned and executed in context with each other.</td>
</tr>
<tr>
<td>Impact-risk</td>
<td>Was the risk appropriately defined based on the actual impact?</td>
</tr>
<tr>
<td>Impact-mitigation</td>
<td>Were mitigation strategies appropriate?</td>
</tr>
<tr>
<td>Operations-preparedness</td>
<td>Was preparedness appropriate given that the impact conformed to expectations? What can be inferred about preparedness if the impact was unexpected?</td>
</tr>
</tbody>
</table>

preparation. Preparedness activities cannot be based on probability; an exact amount of resources can deal with a certain size of event; therefore, a second type of valid risk information is required to create scenarios for preparedness strategies. The relationship also works in reverse: the scenario may be determined by the resources; there are x fire trucks to manage y-sized fires, so determine the size of an event that the resources can deal with. The relationship between mitigation and preparedness is such that increased mitigation is expected to decrease preparedness needs. If not, the value of the mitigation effort is brought into question. Regarding operations, all four should be planned and executed in context with each other. Impact and rescue are specifically linked through a situation where time is of the essence. Relief and recovery are specifically linked, as prolonged recovery will increase the need for relief. Finally, the concept of systematic learning leads to three verification relationships: the validity of risk information is compared with actual impact; the usefulness of mitigation efforts is compared with the impact; and the operational preparedness is compared with the operations conducted, given that the impact conformed to expectations and given that it did not.

Fayol offered 14 principles of management aimed to help managers ascertain what to do to manage more effectively, including unity of direction as one head and one plan for a group of activities having the same objectives (Rodrigues 2001). Under the concept of unity of direction, management of each core function is based on a single plan developed by a manager in cooperation with relevant stakeholders, with the purpose of achieving the associated objective. Each plan will of course entail numerous subfunctions. Quarantelli (1996) and McEntire (2004) list many functions and disaster-related activities. Those that coincide with the theoretical framework presented in this paper fall directly under a core function. Others seem general in nature and are often crosscutting activities. For example, managing donations or volunteers may be in support of one core function or many and may support the overall activities, but are not fundamental activities that the system is designed to manage.

Classical management theory therefore can be used to characterize the role of disaster-function managers: to manage activities intended to meet the objectives of core functions, subfunctions, and interfunctional relationships, along with basic management activities, such as planning and budgeting. Many organizations in industries have interpreted Fayol’s principles quite differently from the way they were interpreted in Fayol’s time (Rodrigues 2001); now, it is time for disaster managers to interpret the principles from a disaster management perspective.

Discussion of Theory
McEntire (2004) calls for discussion of theory for emergency management and discusses different meanings of theory. His first example is that theory refers to “the ideal or preferred conditions that academics are trying to promote in the world around us,” that “we desire a better situation,” and that, “therefore, our desired objectives are to reduce the probability or impact of disaster and improve post disaster functions should” an event take place. In this paper, the improved situation would be living with a lower level of disaster risk and coping more effectively with disasters, and the objectives would be management objectives to reach this improved situation.

McEntire (2004) presents 10 interrelated epistemological problems hindering the development of knowledge in this field (McEntire and Marshall 2003). These questions are answered subsequently from the point of view of DFM, based on the theoretical model presented in this paper.

1. What is a disaster? “A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources” (UNISDR 2009) fits a management perspective. It is not suggested that this definition fits all those who research disasters; it is suggested that this definition suits those who research disasters to advance the profession of disaster managers, using the term broadly. McEntire’s (2004) definition, “disasters are the disruptive and/or deadly and destructive outcome or result of physical or human-induced triggering agents when they interact with, and are exacerbated by vulnerabilities from diverse but overlapping environments,” also fits a management perspective but does not address the issue of coping, which is a critical aspect of management.
2. What is DFM? The management of disaster-related activities grouped into core functions, their interrelationships, and their subfunctions.
3. What hazards should managers focus on? The focus in this paper is limited to natural processes, but it need not be.
4. Should managers continue to give preference to the concept of hazards? No, preference should be given to the concept of risk, which includes hazard, exposure, vulnerability, damages/injuries, consequences, probability, uncertainty, perception, and any other risk factor.
5. What variables should be explored in academic research? Academic research for DFM should explore all variables contributing to meeting the objectives of the core disaster functions.
6. What actors should be incorporated into academic studies? Academic studies of DFM should include all actors and all epistemological inquiries contributing to meeting the objectives of the core disaster functions.
7. What phases should be given priority? There are fundamentally two phases: event and nonevent activities. The three phases—pre-event, event, and postevent activities—require a division of how postevent activities are gradually replaced by pre-event activities, which is outside the scope of this paper. All phases regardless of format should be treated equally.
8. What disciplines should contribute to DFM? Any discipline that can contribute to achieving disaster objectives should be included.

Table 3. Interrelationships between Core Functions

<table>
<thead>
<tr>
<th>Functional pairs</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk-mitigation</td>
<td>Risk information informs mitigation strategies, leading to reduced risk or a defined level of vulnerability, i.e., the impact magnitude initiating damages.</td>
</tr>
<tr>
<td>Risk-preparedness</td>
<td>Risk scenarios inform preparedness strategies or define the level of capacity, i.e., impact magnitude exceeding the level of coping.</td>
</tr>
<tr>
<td>Mitigation-preparedness</td>
<td>Increased mitigation leads to decreased preparedness.</td>
</tr>
<tr>
<td>Operations</td>
<td>The four types of operations (impact, rescue, relief, and recovery) are planned and executed in context with each other.</td>
</tr>
<tr>
<td>Impact-risk</td>
<td>Was the risk appropriately defined based on the actual impact?</td>
</tr>
<tr>
<td>Impact-mitigation</td>
<td>Were mitigation strategies appropriate?</td>
</tr>
<tr>
<td>Operations-preparedness</td>
<td>Was preparedness appropriate given that the impact conformed to expectations? What can be inferred about preparedness if the impact was unexpected?</td>
</tr>
</tbody>
</table>
9. What paradigms should guide our field? The objectives of the core disaster functions should guide the field.

10. What is the proper balance for knowledge generation? McEntire and Marshall (2003) discuss the process of how academia derives knowledge for emergency managers. They ask, “should theory always be grounded in reality, and should practitioners accept new ways to advance the profession?” The answer is yes, and the balance is 50-50.

Conclusions

In this paper, DFM is introduced as a term for a management system based on core disaster functions. Classical management theory provides a framework to characterize the role of a disaster function manager, who manages by objectives and utilizes unity of direction. The authors addressed the critical question of what the core disaster objectives are. They conclude that eight distinct core objectives define core disaster functions needed for good management of disaster-related activities. These functions are disaster-risk analysis, disaster-risk mitigation, operational preparedness, impact operations, rescue operations, relief operations, recovery operations, and systematic learning. The authors conclude that using management theory can lead to new opportunities to theorize relationships between functions.

The DFM approach incorporates all disciplines into the management perspective but does not attempt to incorporate all disaster-related perspectives or the interests of all disciplines. Finally, the authors conclude that DFM, as defined in this paper, can satisfactorily address key epistemological concerns regarding theory for the management of disaster-related activities.

Further research is needed to validate the eight functions presented in this paper as the core disaster functions and their interrelationships. The authors hope to inspire further discussion of an alternative model for the disaster life cycle and what constitutes core functions of disaster-related activities.

Acknowledgments

The authors gratefully acknowledge the research grant from the University of Iceland Eimskip Fund. Professor Dr. Kurt Petersen is thanked for his fruitful criticism in streamlining the content. Dr. Ana Maria Cruz Naranjo is also thanked for her insightful comments. Three anonymous reviewers and the editor of Natural Hazards Review are thanked for their constructive contributions to the development of this paper. The authors also appreciate the financial support from the European Union (EU), Civil Protection Financial Instrument, in the framework of the European project Urban Disaster Prevention Strategies Using Macroseismic Fields and Fault Sources (UPStrat-MAFA), Grant Agreement No. 23031/2011/613486/SUB/A5.

References


Paper III
Framing the 2010 Eyjafjallajökull volcanic eruption from a farming-disaster perspective

Sólveig Thorvalsdóttir · Ragnar Sighjörnsson

Received: 11 December 2013 / Accepted: 17 February 2015 / Published online: 28 February 2015
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Abstract The aim of this paper was to shed light on the 2010 Eyjafjallajökull volcanic eruption in Iceland from a farming perspective to identify lessons for livelihood professions regarding disasters. Scientists had detected activity under the volcano for over a decade prior to the eruption and had notified the Civil Protection. Preparedness activities included disaster planning and training in evacuation procedures in the event of flooding caused by an eruption under the Eyjafjallajökull icecap. However, the main concern for farmers turned out to be ashfall. Previous research has shown that specialized information to farmers on ashfall was inadequate. Here, information is presented from a livelihood-disaster perspective and used as a basis for an analysis of pre-eruption, real-time and post-eruption activities by farming actors. The livelihood-disaster perspective is built on the Sustainable Livelihoods Framework and a set of eight disaster-related objectives. The study shows that farming actors were not informed about the scientific monitoring, not included in pre-eruption coordination by the Civil Protection but were indeed the main actors responding to the needs of farmers having ash problems in the weeks and months following the eruption. A literature survey shows that sufficient hazard, exposure and vulnerability information had been available prior to the eruption to produce useful risk-related information to inform risk reduction and contingency planning amongst farming actors. Livelihood professionals are highly specialized and should take the initiative in performing their own pre-disaster activities to effectively and efficiently assist their communities during a disaster.

Keywords Farming · Eyjafjallajökull volcano eruption · Livelihood-disaster perspective · Sustainable Livelihood Framework · Disaster-related objectives

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1 Introduction

By law, disaster coordination in Iceland is under the umbrella concept of Civil Protection. It is the responsibility of the police (Act on Civil Protection, *Lög um almannavarnir* 2008), at both the local (local chiefs of police) and national levels (National Commissioner of the Icelandic Police). In 2002, prompted by information from the scientific community, the local chief of police requested funding from the Ministry of Justice for a risk analysis and organized preparedness activities for a possible eruption of the Eyjafjallajökull volcano and flooding due to melting of the icecap (Thorkelsson 2013). In 2010, the police chief coordinated various response activities (Thorkelsson 2013). Previous research on the response to the 2010 Eyjafjallajökull volcano (EFJV) eruption shows that whilst emergency management agencies in Iceland responded immediately to ensure people’s safety and disseminated geophysical information during the crisis, specific information with respect to ongoing problems associated with the ash was lacking, including specialized information for farmers (Bird and Gisladottir 2012).

Delivering the right information to the right people, in the right format, in the right place and at the right time is a key disaster-related activity (Iannella and Henricksen 2007), requiring good organization, concerted efforts and allocation of resources, along with knowledge of hazard phenomena (Alexander 2006). This study looks for explanations on why information to the farmers was inadequate, and what could have been done differently, in order to learn lessons for livelihood professions in general. The conceptual framework used here is a livelihood-disaster perspective. As implied, the perspective is a combination of a livelihood perspective and a disaster perspective. The Sustainable Livelihoods Framework (SLF) (DFID 1999) is used to define the farming perspective and guided the data collection. The eight disaster-related objectives of Disaster-Function Management (Thorvaldsdóttir and Sigbjörnsson 2014) define the disaster perspective and guide the analysis. The combined perspective is presented in a Venn diagram. Information and data are collected for each component in the Venn diagram from data sources on farming and the EFJV. The data sources include scientific literature and secondary information available prior to the eruption, field reports and interviews. Information from a

![Fig. 1 The method (numbers relate to sections)](image-url)
reconnaissance mission performed by farming actors four weeks after the onset of the EFJV eruption provides insight into the problems and response within the farming community. Eleven actors identified in the report are interviewed for information about their pre-eruption, real-time and post-eruption activities. After the interviews, seven actors were defined as direct farming actors and included in further analysis, based on each disaster-related objective.

The results show that farming actors were not included in any pre-eruption coordination by the police, did not perform any pre-event disaster-related activities specific to the pending EFJV eruption due to limited knowledge of the risk of an eruption, but did respond to the eruption. An analysis of the information shows that risk analysis, mitigation and preparedness activities performed by farming actors before the eruption could have improved the response of the farming actors and thus better addressed the needs of farmers.

2 Method

The method involves four steps (Fig. 1). First, a livelihood-disaster perspective is developed (Sect. 2.1). The perspective is a combination of a livelihood and disaster perspective. The former is based on the SLF and the latter on the DFM objectives. The second step is identifying data sources for each component of the livelihood-disaster perspective in relation to farming, Eyjafjallajökull, and the 2010 EFJV eruption (Sect. 2.2). The third step is to extract relevant information from the data sources, thus presenting the farming-EFJV eruption perspective (Sect. 3). The final step is analysing the information in Sect. 3 for each DFM objective (Sect. 4).

![Sustainable Livelihood Framework](image)

Fig. 2 The Sustainable Livelihood Framework (Based on Fig. 1 DFID 1999)
2.1 Livelihood-disaster perspective development

2.1.1 Livelihood perspective

The Sustainable Livelihoods Framework (SLF) (DFID 1999) is used to outline a livelihood perspective. The SLF “presents the main factors that affect people’s livelihoods and typical relationships between these”. The “aim is to help stakeholders with different perspectives to engage in structured and coherent debate about the many factors that affect livelihoods, their relative importance and the way in which they interact”. The framework captures how people’s decisions on their livelihood are influenced by regulatory opportunities and restrictions that are produced by transforming actors, and the vulnerability context within which they live.

The SLF consists of five main components (see Fig. 2): (1) outcomes of livelihoods, (2) strategies to reach these goals, (3) livelihood assets (human, natural, physical, financial and societal), (4) transformation structures (hereafter termed actors as the study is limited to actors and their activities) and policies affecting the assets and, finally, (5) issues of vulnerability, such as shocks (including natural disasters), monetary trends and changing seasons.

The SLF allows for the perspectives of numerous actors that all relate to livelihood and thus create a general livelihood perspective. The SLF defines actors by types of organizations “that set and implement policy and legislation, deliver services, purchase, and trade and perform all manner of other functions that affect livelihoods”. Table 1 (extracted from DFID 1999) depicts actor types and levels, and various types of units for actor analysis. All of these help define actor perspectives.

Various disaster studies have used a sustainable livelihoods approach, such as Cannon et al. (2005) (reducing social vulnerability from a development agency perspective), Twigg (2004) (project cycle approach from a primarily humanitarian and development agency perspective) and studies specifically on volcanic risk (see overview presented in Kelman and Mather 2008). Odero studied the SLF (2006) and suggests that relevant, accurate and timely information be added as the sixth asset. This is a key aspect of this study.

2.1.2 Disaster perspective

The disaster perspective is presented through a set of disaster-related objectives associated with Disaster-Function Management (DFM) (see Table 2). DFM is derived from

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Actor categories and aspects of analysis (DFID 1999)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td><strong>Level</strong></td>
</tr>
<tr>
<td>Public sector</td>
<td>Political (legislative) bodies at various governmental levels from local to national Executive agencies (ministries, agencies) Judicial bodies (courts) Parastatals/quasi-governmental agencies</td>
</tr>
<tr>
<td>Private sector</td>
<td>Commercial enterprises and corporations Civil society/membership organizations (of varying degrees of formality) NGOs (international, national, local)</td>
</tr>
</tbody>
</table>

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Comprehensive Emergency Management, which was defined in 1979 (NGA 1979) as the management of disaster-related activities in four phases: mitigation, preparedness, response and recovery. However, since then the concept of phases as the appropriate approach to disaster management has been challenged (Neal 1997; McEntire et al. 2002) and the idea of functions or functional areas suggested (McEntire et al. 2002; Quarentelli 1996). Thorvaldsdottir and Sigbjörnsson (2014) outline how current scientific and practical knowledge has surpassed the four-phase framework and describe why and how phases are replaced by objectives for management purposes. DFM is set within classical management theory, governed by “management by objectives”, and has been introduced as a contribution towards a new paradigm for addressing disaster-related management. Classical management theory states that “management by objectives”, as a concept, is an integrated management system to manage an organization by aligning the entire managerial effort with specific performance goals (Ghuman 2010). Applying “management by objectives” to coordination creates a coordination process that meets chosen objectives, thus giving the process a clear focus.

Table 2 Disaster functions and objectives (Thorvaldsdottir and Sigbjörnsson 2014)

<table>
<thead>
<tr>
<th>No.</th>
<th>Functions</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Disaster risk analysis</td>
<td>To understand disaster risk, its components and context</td>
</tr>
<tr>
<td>2</td>
<td>Disaster risk mitigation</td>
<td>To measurably reduce known disaster risk</td>
</tr>
<tr>
<td>3</td>
<td>Operational preparedness</td>
<td>To prepare operations for dealing with future disasters</td>
</tr>
<tr>
<td>4</td>
<td>Impact operations</td>
<td>To react to damaging processes prior to, during and after impact</td>
</tr>
<tr>
<td>5</td>
<td>Rescue operations</td>
<td>To save the lives of those caught in damaging processes</td>
</tr>
<tr>
<td>6</td>
<td>Relief operations</td>
<td>To provide temporary relief of suffering to those affected</td>
</tr>
<tr>
<td>7</td>
<td>Recovery operations</td>
<td>To implement final measures to bring a community back to normalcy</td>
</tr>
<tr>
<td>8</td>
<td>Systematic learning</td>
<td>To systematically learn from recent events and implement changes</td>
</tr>
</tbody>
</table>

Fig. 3 Venn diagram for livelihood-disaster perspective
2.1.3 Livelihood-disaster perspective

The livelihood-disaster perspective is presented by a Venn diagram consisting of three overlapping rings (Fig. 3). First, the five basic components of the SLF are placed in the diagram. The Livelihood Strategies and Livelihood Outcomes are placed at the centre, representing the desired and actual outcomes when adopting the SLF. The three remaining components, Assets, Shock, and Transporting Structures and Processes (actors), are placed in each of the outer rings. The overlaps are filled with aspects that link the two basic SLF components on either side. The linking components are as follows:

- **Actor daily activities**, linking Transporting Structures and Processes (actors) and Assets, addressing how actors manage assets.
- **Disaster-related activities**, linking Transporting Structures and Processes (actors) and Shock, addressing how actors manage shock-related issues.
- **Damages, injury and disruptions**, linking Assets and Shock. When addressing future disasters, the link is **vulnerability to damages, injury or disruptions**. When addressing actual disasters, the link is **actual damages, injury or disruptions**

2.2 Data sources

The following data sources were identified as relevant to the respective components in Fig. 3 for the farming-EFJV context:

1. **Farming livelihood strategies**
   b. Discussions with a teacher at the Agricultural University of Iceland
   c. Discussions with a farmer in the affected area

2. **Shock (volcanic ash)**
   a. Farming next to a volcano, literature-based discussion
   b. Literature survey for an overview of volcanic activity in Iceland
   c. Literature survey for an overview of the EFJV hazard and eruption 1991–2010

3. **Damages, injuries and disruption**
   a. Literature survey on the vulnerability of physical and natural farming assets due to ash
   b. Actual damages, injuries and disruption described in Farmers’ Reconnaissance Report (2010)

4. **Actor identification and classification**
   b. SLF actor classification (Table 1)

5. **Actor daily activities**
   a. Daily objectives stated on actor websites

6. **Actor disaster-related activities**
   a. Interviews with actors
b. Literature on the EFJV before and after the eruption
c. EFJV activity reports acquired from websites
d. Act on Civil Protection

7. Farming livelihood outcome (situation in 2010)

8. Farming assets
   a. Farming assets are apparent in the text, e.g., animals, buildings, land, but they are not presented here in a separate discussion.

2.2.1 Farmers’ Reconnaissance Report 2010

The key source of information about the status of farmers and their farms and for determining relevant actors is a report from a reconnaissance (abbreviated recon) performed 11–12 May 2010, approximately 4 weeks after the explosive episode of the eruption began (Farmers’ Recon Report 2010). The Farmers’ Association, The Agricultural Association of South Iceland and other regional farmers’ associations, and the Ministry of Agriculture organized the recon. Its purpose was to bring relevant actors together to share information and ideas, collect information, maximize the use of resources and plan assistance to the affected farmers (Farmers’ Recon Report 2010). The first day was spent on site visits and the second on planning and developing recommendations. Approximately 35 people were divided into 2–3 people teams and visited approximately 120 farms (see Fig. 4). The organizers decided on the following questions to ask during the site visits:

1. How many animals are on the farm (cows, sheep, horses)?
2. What is the housing need for animals (cows, sheep with lambs, horses)?
3. Is there sufficient feed and (uncontaminated) running water for all the animals?
4. For how many days will the current quantity of hay last?
5. Has the farmer secured extra hay, if needed?
6. If the eruption ends within 15 days, how many animals need to be transported, and how much hay is needed?
7. If the eruption continues into the summer, how many animals need to be transported, and how much hay is needed?
8. What type of solutions does the farmer recommend?
9. What damage has occurred that will be insured by the Farmers’ Insurance Fund?
10. Is extra manual labour required?

When asked what prompted the recon, the organizers stated they had gradually realized their own lack of understanding of the magnitude of the problems amongst farmers. Four explanations are stated here. First of all, questions arose about housing and feeding sheep. It was now spring so sheep were inside in pens, and lambing season was approaching. Sheep are usually kept inside during the winter months and put outside 3–4 days after their lambs are born. Then, after all lambs are born, the ewes, lambs and rams are driven to the highlands for the summer, and in the autumn the sheep are collected and the lambs slaughtered. The ash could hinder farmers putting the sheep outside and render the highlands unusable. This meant that the farmers had to somehow cope with an expanding sheep population inside the pens, causing overcrowding. Second, field staff members assisting the affected farmers, for example, from South-Agrí, were beginning to show
fatigue and needed support. A multi-organization recon would provide an overview of the situation and generate ideas on how to support them. Third, there was concern over the possible impact if the wind changed direction. The winds had been northerly; if they
changed to easterly winds, new farming areas would be affected. The organizers wondered what problems this would create, and how they should respond to assist farmers. A recon would allow organizers to understand the problems and concerns of the farmers (i.e., obtain the farmer’s perspective) and seek their opinion on possible solutions. Finally, the organizers wanted to support the affected farming population by showing their concern. The eruption was still going on, and the end of the eruption could not be predicted.

2.2.2 Interviews

Interviews (Aug–Nov 2013) provided information about the activities of the actors in respect of the eight objectives of DFM as related to EFJV 1991–2013. A representative of each actor was asked eight questions; one question on each of the eight DFM objectives: what activities did you perform towards this objective in relation to the EFJV hazard/eruption? Discussions with a teacher at the Agricultural University of Iceland and with a farmer in the affected area were also used to generate information.

3 Farming-EFJV perspective

This section presents extracts from the data sources listed in Sect. 2.2 relevant for farming in the vicinity of the EFJV. The tables and figures created herein relate to the Venn diagram in Fig. 3, as depicted in Fig. 5.
3.1 Farming livelihood strategies

“Livelihood strategies” is the term used to designate the range and combination of activities and choices that people make/undertake in order to achieve livelihood goals (DFID 1999). Livelihood goals are broader than a pure business goal. For example, investments, such as in technology, may be for the purpose of increased production to increase income or to ease physical labour and shorten working hours, leading to healthier and longer lives, giving opportunities to spend time on other things, whether farming-related or leisure (Jóhannesson and Agnarsson 2005). Livelihood goals are therefore affected by an individual’s motive for choosing a particular livelihood. Farming is the business of growing crops and/or raising livestock (Jóhannesson and Agnarsson 2005). There are many motives for choosing farming, such as family tradition, wanting to be your own boss, desire to work with animals or desire to work with machinery (Gislason 2013). Attachment to the land can also influence choosing farming as a livelihood (Eyvindsson 2013). A farming strategy is based on decisions on a variety of livelihood variables that characterize farming, including (Jóhannesson and Agnarsson 2005):

- Type of production
- Type of livestock
- Proximity to market
- Level of technology
- Level of debt

The farming market is unique in that its products are seen as essential for human survival. This is reflected in product demand being relatively insensitive to market price (Jóhannesson and Agnarsson 2005). Government strategy in Iceland regulates to some degree both the supply and price of these products through various regulatory tools, such as production quotas and subsidies, and includes ensuring food security on the island and avoiding total migration to the capital (Jóhannesson and Agnarsson 2005). Government agencies monitor animal welfare and production and control the risk of disease by establishing control areas. Live animals, hay and other farm products may not move between these areas. The 2014 annual meeting of the Farmers’ Association concluded that the association should work with the government on a long-term farming strategy in association with the specialized farming organizations (for cattle, eggs, pig farming, etc.) (Bændabladid Newspaper 2014), showing farmers’ interest in influencing government farming strategy.

3.2 Shock (volcanic ash)

3.2.1 Volcanic activity in Iceland

Iceland is one of the most active and productive volcanic regions in the world. Its eruption frequency is up to 20 events per century (Thordarson and Höskuldsson 2008). Eruptions are broadly grouped into effusive eruptions, where over 95% of the erupted magma is lava, explosive eruptions if more than 95% of the erupted magma is tephra and mixed eruptions if they include tephra but less than 95% (Thordarson and Larsen 2006). Explosive events in Iceland are dictated by sub-glacial events and are more common than effusive activity or mixed eruptions (Thordarson and Larsen 2006). A summary of verified eruptive events is presented in Table 3. A total of 2400 eruptions have been identified from post-glacial times (last 11,000 years). In historical times (last 1100 years), a total of 192
single eruptive events have been verified, based on volcanic products, and 33 were mentioned in oral accounts. In addition, 13 fires (multiple events) lasting for months or years have been verified in historical accounts.

Four volcanoes or volcanic systems have been most active in historical times: Katla Volcano under the Myrdalsjökull icecap (21 eruptions), Grímsvötn/Laki (~70), Hekla (23 eruptions) and Bardarbunga/Heidivötn (23 eruptions) (Gudmundsson et al. 2008). Both Hekla and Katla Volcanoes have produced ash layers over 20 cm thick over the area surrounding Eyjafjallajökull (Fig. 3 in Gudmundsson et al. 2008, reprinted as Fig. 6). Figure 6 shows “areas that may receive over 20 cm of tephra fall in major explosive eruptions indicated with circles around volcanoes or fissure swarms, where explosive activity is common or the dominant mode of activity. The radius of each circle is defined as the distance to the 20-cm isopach along the axis of thickness for the largest historical and prehistoric explosive eruptions of each volcano. Also shown are populated areas and the main route, Highway 1. The volcanic zones are shown with a shade of grey” (Gudmundsson et al. 2008).

3.2.2 Eyjafjallajökull volcano

Eyjafjallajökull (glacier) is in South Central Iceland in the Eastern Volcanic Zone. Prior to the 2010 eruption, the volcano is believed to have erupted four times. The most recent was in 1821–1823. Chronicles provide relatively detailed accounts of a small intermittent explosive eruption, producing ash levels harmful to livestock (Larsen 1999). The ash led to considerable fluoride poisoning and negatively impacted farming activities in general, including reduction in livestock (Larsen 1999). Historical accounts indicate that there may have been an eruption in 1612 or 1613 (Vetter 1983) although the physical evidence of ash is inconclusive (Larsen 2013), and it may have been its more active neighbour Katla Volcano that the accounts refer to Sturkell et al. (2003). Dugmore et al. (2013) have recently identified and dated floods that verify flank eruptions in ca. 920 AD and in the sixth to seventh century. Dugmore et al.’s work is referenced as “unpublished results” in Gudmundsson et al. (2005), so it was known prior to the 2010 eruption.

A chronological outline of key geological and scientific events from 1991 to 2010 and post-eruption activities, based on Sigmundsson et al. (2010), Gudmundsson et al. (2010, 2012) and other references, is presented in Table 4. The recognition of geophysical precursors to volcanic activity is a primary challenge in volcanic monitoring (Vogfjörd et al. 2005). Prior to the 1990s, only about a handful of earthquakes associated with the Eyjafjallajökull volcanic system had been detected (Pedersen and Sigmundsson 2006); after that the situation gradually changed. The 2010 eruption was the culmination of two decades of intermittent volcanic unrest, providing ample precursors, many of which were
captured by scientists. An effusive flank eruption began on 20 March, ended on 12 April and caused no damage (Gudmundsson et al. 2010). Increased seismic activity was noted by seismometers in EFJV at 2300 local time on 13 April. The summit eruption commenced at 0115. A plume was visible in the early hours of the 14th, and the first signs of glacial flooding were seen at 0650 at a gauging station (Gudmundsson et al. 2010). Concern arose about health risks from fallout, because ash can transport acids as well as toxic components, such as fluoride, aluminium and arsenic (Gislason et al. 2011). The summit eruption lasted 39 days, till 22 May. Persistent north-westerly winds transported the ash towards the southeast (Gudmundsson et al. 2012). The intensity of tephra fallout varied throughout the eruption. As explained by Gudmundsson et al. (2012, Fig. 4, reprinted as Fig. 7), Fig. 7 shows isopach maps (thickness in cm) of tephra deposition on land (a) during the first 3 days of the first explosive phase, erupting from a water-filled vent (14–16 April), (b) during the second part of the first explosive phase (17 April until early 18 April) and (c) total fallout on land in the eruption (14 April–22 May) and estimated fallout thickness (dotted lines) to the south and south-east of Iceland. Based on Fig. 7, the entire ash fallout in the recon area is estimated to be less than 5 cm thick over the main area. Less than 10 cm were measured at the foothills of the volcano (Gudmundsson 2014).

3.3 Damage, injury and disruption

Large explosive volcanic eruptions can potentially distribute heavy ashfall across large areas of agricultural land (Wilson et al. 2011a, b). Farming near an active volcano has both positive and negative aspects (Kelman and Mather 2008). Volcanic soils are often physically and chemically suited for growing crops, and long periods between eruptions
Table 4  Geophysical events of EFJV from 1991 to 2013

<table>
<thead>
<tr>
<th>Year/date</th>
<th>Geophysical events</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>The 1994 deformations were observed using interferometric synthetic aperture radar (InSAR).</td>
<td>Pedersen and Sigmundsson (2004)</td>
</tr>
<tr>
<td>1999</td>
<td>Earthquake swarm. Deformation detected. The results interpreted to mean intrusions into an opening of a narrow magma channel at depth, feeding into a sill at a depth of 4–6 km</td>
<td>Pedersen and Sigmundsson (2006)</td>
</tr>
<tr>
<td>2000</td>
<td>In 2000, research indicated that a magma chamber could be at a shallow depth</td>
<td>Gislason (2000)</td>
</tr>
<tr>
<td>2000–2009</td>
<td>During the period 2000–2009, earthquakes were measured intermittently at rates of 1–4 events per month, whilst deformation remained negligible</td>
<td>Vogfjörd et al. (2009)</td>
</tr>
<tr>
<td>2009</td>
<td>By 2009 scientists had identified, through seismic analysis, a pipe-like structure under the volcano, mapping the route of magmatic intrusions through the crust</td>
<td>Vogfjörd et al. (2009)</td>
</tr>
<tr>
<td>2010-Jan-Mar</td>
<td>In January 2010, deformation was again detected, and the level of seismicity increased to several earthquakes a day. These changes marked the onset of magma flow into the roots of the volcano, culminating late in the evening of 20 March 2010 in the opening of a short effusive fissure eruption on the volcano’s flank</td>
<td>Sigmundsson et al. (2010)</td>
</tr>
<tr>
<td>2010-Mar 20</td>
<td>A short effusive fissure eruption began on the flank of the volcano at Fimmvöðuháls Ridge around 2330 UTC on 20 March</td>
<td>Gudmundsson et al. (2010)</td>
</tr>
<tr>
<td>2010-Apr 12</td>
<td>Flank eruption on Fimmvöðuháls Ridge ended on 12 April, causing no damage</td>
<td>Gudmundsson et al. (2010)</td>
</tr>
<tr>
<td>2010-Apr 13</td>
<td>Increased seismic activity started at 2300 local time, lasting a few hours</td>
<td>Gudmundsson et al. (2010)</td>
</tr>
<tr>
<td>2010-Apr 14</td>
<td>Summit eruption commenced at 0115, a plume visible in the early hours and the first signs of glacial flooding seen at 0630 at a gauging station. The eruption plume (tephra, gases and chemicals) reached a height of almost 10 km the first day. Lightning was seen in the ash cloud</td>
<td>Gudmundsson et al. (2010)</td>
</tr>
<tr>
<td>2010-Apr 14–15</td>
<td>Intense fallout occurred on 14–15 April</td>
<td>Gudmundsson et al. (2012)</td>
</tr>
<tr>
<td>2010-Apr 14–May 22</td>
<td>Tephra fallout during the entire eruption of April 14 to May 22 estimated less than 5 cm thick in the recon area (see Fig. 4c in reference)</td>
<td>Gudmundsson et al. (2012)</td>
</tr>
<tr>
<td>2010-Apr 14–26</td>
<td>Lava flowed for 12 days, spilling north into Gigjökull Glacier Lake</td>
<td>Gudmundsson et al. (2010)</td>
</tr>
<tr>
<td>2010-Apr 15</td>
<td>Absolute darkness in the middle of the fallout zone at 12:45 PM</td>
<td>Gislason and Alfredsson (2010)</td>
</tr>
<tr>
<td>2010-Apr 17</td>
<td>Tephra fallout caused total darkness for 20 h</td>
<td>Gudmundsson et al. (2012)</td>
</tr>
</tbody>
</table>
make agriculture common in volcanic regions (Cronin et al. 1998, Wilson et al. 2011a, b). The negative aspects involve the susceptibility of assets, people and farming processes to damage, injury and disruption, respectively, due to eruptions. The problems the farmers faced in Iceland in 2010 were due to ashfall and remobilized ash. The nearest farms were roughly 20 km from the summit.

### 3.3.1 Pre-eruption knowledge on vulnerability

A literature survey of papers published before the 2010 EFJV eruption was done to gain understanding of the information available prior to the eruption on vulnerable conditions for farming assets due to ash (see Table 5). Two of the papers in Table 5 are published after the eruption: one relays information available before the eruption regarding lack of visibility during an eruption (Bird and Gisladottir 2012) and the other describes an eruption in 1991 (Wilson 2011a, b). The papers discuss the vulnerability of mainly natural and physical farming assets, such as livestock, farming processes, buildings, infrastructure, utilities and mechanical equipment. More recent papers illustrate the ever-expanding knowledge of volcanic vulnerability (see, for example, Wilson et al. 2012a, b and Magill et al. 2013).

Impacts from past eruptions provide insight into the vulnerability associated with farming close to volcanoes (e.g. Kelman and Mather 2008, Lebon 2009). All forms of agricultural production are vulnerable to the physical and chemical effects of volcanic
Fig. 7 Ash distribution from the 2010 Eyjafjallajökull eruption (Fig. 4 in Gudmundsson et al. 2012)
Table 5 Farming vulnerability due to volcanic ash

<table>
<thead>
<tr>
<th>References</th>
<th>Content</th>
<th>Asset category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kristinsson et al. (1997)</td>
<td>Fluoride poisoning of sheep (diarrhoea, loss of appetite and general prostration, dental fluorosis at different concentration levels)</td>
<td>Natural</td>
</tr>
<tr>
<td>Cronin et al. (1998)</td>
<td>Livestock starvation when pastures were covered by tephra. Chemical impact of tephra on soil and pastures, and their effect on grazing livestock</td>
<td>Natural</td>
</tr>
<tr>
<td>Spence et al. (1999)</td>
<td>Building damage (collapse, roof failure)</td>
<td>Physical</td>
</tr>
<tr>
<td>Arnalds et al. (2001)</td>
<td>Wind erosion and loss of soil and ecosystems due to volcanic ash and sands</td>
<td>Natural</td>
</tr>
<tr>
<td>Annen and Wagner (2003)</td>
<td>Damage to farmlands, buildings, roads, bridges, forest fires and interruption of agricultural activities</td>
<td>Physical, natural</td>
</tr>
<tr>
<td>Spence et al. (2004)</td>
<td>Resistance to lateral pressures of glazed openings; shuttered openings; masonry wall panels; and reinforced concrete frame buildings</td>
<td>Physical</td>
</tr>
<tr>
<td>Wilson and Cole (2007)</td>
<td>Dairy shed, milking machine, electrical supply and distribution, water supply and distribution, tractors and other farm vehicles, farm buildings (hay sheds, pump sheds, etc.), milk tanker access to farm and critical needs of dairy cows and farm to keep milking</td>
<td>Physical and natural</td>
</tr>
<tr>
<td>Wilson et al. (2010)</td>
<td>Blocked or damaged water delivery systems due to sedimentation of irrigation ditches and potable water ponds, turbidity-induced abrasion of sprinkler nozzles and water pumps, and damage to electric pumps (by ash on air intakes)</td>
<td>Natural</td>
</tr>
<tr>
<td>Bird et al. (2010)</td>
<td>Darkness during daytime</td>
<td>Natural</td>
</tr>
<tr>
<td>Bird and Gisladottir (2012)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wilson et al. (2011a, 2011b)</td>
<td>Livestock deaths due to pasture burial by ashfall and ongoing suppression of vegetation recovery. Livestock impacts: gastrointestinal impacts, tooth abrasion, dehydration, immobilization, and blindness. Vegetation and soil impacts: effect on soil fertility, effects on water retention. Ongoing damage to crops from wind-blown ash. Changes to soil properties increased irrigation and cultivation requirements. Long-term farm abandonment. Farms with natural advantages and greater investment in capital improvements led to greater damage potential initially (at least in cost terms), but ultimately provided a greater capacity for response and recovery. Better soils, access to technological improvements, such as cultivation tools, irrigation and wind-breaks, were advantageous. Government agencies’ dissemination of information for appropriate farm management responses, ash chemistry analysis, evacuations and welfare, and technical and credit assistance to facilitate recovery</td>
<td>Natural</td>
</tr>
</tbody>
</table>

Ashfall, including vegetation, soils, animal health, human health and infrastructure (Wilson et al. 2011a, b). The impact of eruptions in Iceland includes people being killed (by drowning, lightning and CO₂ suffocation), livestock deaths (by tephra fall leading to lack of access to feed and fluorine poisoning) and crop damage from ash coverage, leading to farm abandonment and famine. Heavy tephra fall in past Katla eruptions has been known to obstruct visibility (Bird et al. 2010), causing total darkness during the day (Bird and Gisladottir 2012).
Fluoride is a potentially toxic element for people and animals and can severely impact sheep through diarrhoea, loss of appetite and general prostration and dental fluorosis at different concentration levels (Kristinnsson et al. 1997). The degassing of magma chemicals produces fluorine, sulphur and chlorine in the atmosphere (Thordarson et al. 1996). Soluble fluorine can be chemically adsorbed on the surface of tephra particles (Oskarsson 1980) and thus transported with the ash. Fluorine can also be transported by water due to leaching from tephra and gas particle disposition. Fluorine concentration has even been measured to rise 5 days after an eruption ended due to the melting of polluted snow and leaching of pollutants from volcanic ash into a river discharge area during a rainstorm (Gudmundsson et al. 1992). Fluoride can contaminate open drinking water sources. Outbreaks of fluoride toxicosis (fluorosis) in farm animals have repeatedly been observed in Icelandic sheep when pastures and drinking water have become contaminated with fluoride from volcanic eruptions (Kristinnsson et al. 1997), for example, from Hekla and Laki eruptions (Gudmundsson et al. 2008), and EFJV (Larsen 1999). According to Wilson et al. (2011a), the impacts and consequences of remobilized ash were seldom examined prior to the EFJV eruption. However, the seriousness of remobilized ash was already identified following an eruption of Vulcan Hudson in Patagonia in 1991 (Scasso et al. 1994). Remobilization is related to wind erosion. Problems associated with sand and dust production from volcanic eruptions, wind erosion and loss of ecosystems in Iceland are well known (Arnalds et al. 2001). Iceland has about 22,000 km$^2$ of sandy deserts that are a major source of atmospheric dust. Icelandic dust is mostly basaltic volcanic glass, which is rather unique for global dust sources (Arnalds et al. 2001). The sandy areas have black surfaces due to their basaltic origin. The sand originates largely from glacial margins, glacio-fluvial deposits and volcanic eruptions, but also from sedimentary rocks (Arnalds 2010). Wind erosion has been extensively studied in agricultural fields, but knowledge of field conditions and wind erosion rates of fresh volcanic deposits under severe wind conditions is limited (Arnalds et al. 2013).

### 3.3.2 Actual damages, injuries and disruption

The main and most affected areas, according to the recon, are depicted in Fig. 4a, corresponding to the ash plume in Fig. 4b. There were less than 20 farms in the main affected areas, and less than 10 of these were in the most affected area (see Fig. 4a). The issues raised by farmers during site visits are divided into four categories (see Table 6): coping strategies, constraints to the coping strategies, complaints about the response and concerns over issues that they did not know how to deal with. The main factors amongst farmers, according to the recon, were questions related to the natural assets (air quality, the impact of chemicals on pastures and fodder, etc.), physical (housing of animals, etc.), farming processes (lambing, fencing, temporary pastures, etc.) and financial concerns. Financial worries included the overall impact of the damages and disruption on farmers’ ability to pay debts. For example, lambs are normally slaughtered in the autumn, but if the situation called for early slaughtering, lambs would be smaller than at the normal slaughtering time, and farmers were concerned about being compensated for such losses. Farmers’ Insurance Fund coverage was also a concern at the time of the recon. The Fund determines compensation on a case-by-case basis (i.e., per eruption, earthquake, snowstorm, etc.), depending on the typical types of damage each time. At the time of the recon, farmers were still uncertain about which types of damages would be compensated.
3.4 Actor identification

The Farmers’ Recon Report mentions 11 institutions. Each of these was by default an actor relevant to the study, since they were either directly involved in the recon or referred to as an actor of relevance in the report. Each actor is characterized in Table 7 by name, type (public or mixed public and private) and level (executive or civil organization, both national and local). The Farmers’ Association, The South-Agri and other regional farmers’ associations, and the Ministry of Agriculture organized the recon. Representatives from the Food and Veterinarians Authorities, the Agricultural University of Iceland, police authorities, and the Rangarthing Eystra Municipality participated in the data analysis and development of recommendations. The Land Conservation Authorities, the Farmers’ Insurance Fund, the Icelandic Catastrophe Insurance and the Directorate of Labour are mentioned in the report.
<table>
<thead>
<tr>
<th>No.</th>
<th>Actor</th>
<th>Type</th>
<th>Level</th>
<th>Description in relation to daily objectives</th>
<th>Relevance as actor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ministry of Agriculture</td>
<td>Public</td>
<td>Executive</td>
<td>National</td>
<td>The Ministry is responsible for research on and supervision of agriculture, commercial forestry, import and export of animals and plants, food inspection and food research</td>
</tr>
<tr>
<td>2</td>
<td>Farmers’ Association of Iceland</td>
<td>Public and private</td>
<td>Executive and Civil Organization</td>
<td>National</td>
<td>The Farmers’ Association is an advocate for farmers. It works towards progress and prosperity within agriculture. It strives to improve conditions, provide professional guidance, publications and information and do projects for the government</td>
</tr>
<tr>
<td>3</td>
<td>South-Agri: Agricultural Association of South Iceland</td>
<td>Public and private</td>
<td>Executive and Civil Organization</td>
<td>Local</td>
<td>The Agricultural Association of South Iceland is an organization of agricultural societies and clubs in South Iceland. South-Agri operates for the benefit of individual farmers. Its aim is to increase agricultural efficiency in the area and the prosperity of the members and clients</td>
</tr>
<tr>
<td>4</td>
<td>The Icelandic Food and Veterinary Authority</td>
<td>Public</td>
<td>Executive</td>
<td>National</td>
<td>The Icelandic Food and Veterinary Authority is the competent authority in Iceland for food safety, animal health and welfare, control of feed, seed and fertilizers, plant health and water for human consumption</td>
</tr>
<tr>
<td>5</td>
<td>The Agricultural University of Iceland</td>
<td>Public</td>
<td>Educational</td>
<td>National</td>
<td>The Agricultural University is an educational and research institution in the field of agriculture and environmental sciences. It focuses mainly on the conservation and sustainable use of land and animal resources, including traditional agriculture, horticulture and forestry, environmental planning, restoration sciences, rural development and sustainable development</td>
</tr>
<tr>
<td>6</td>
<td>Land Conservation Authority</td>
<td>Public</td>
<td>Executive</td>
<td>National</td>
<td>The Land Conservation Authority is responsible for combating desertification, sand encroachment and other soil erosion, promoting sustainable land use and the reclamation and restoration of degraded land. The speed of erosion is magnified by volcanic activity and harsh weather conditions. The Land Conservation Authority is dedicated to the prevention of erosion and the reclamation of eroded land</td>
</tr>
</tbody>
</table>
### 3.5 Actor daily activities and categorization

An actor’s daily activity is inferred from their general objectives described on the website (see Table 7). The relevance of the actors to the study is based on the relevance of their daily objectives to a farming livelihood perspective and falls into one of the two following categories:

1. **Direct farming actors**: those working directly for, or with, farmers for the sake of livestock or production matters, at any level.
2. **Associated actors**: those who deal with farmers for reasons other than farming, influence farmers’ lives and livelihoods, but are not involved in farming-related activities.

Seven of the 11 actors were direct farming actors (No. 1–7, Table 7). Five were on a public executive level, dealing with matters of government strategy, implementation and monitoring, government insurance companies and educational establishments. The other two were a national and a regional farmers’ civil organization (Farmers’ Association and

---

Table 7 continued

<table>
<thead>
<tr>
<th>No.</th>
<th>Actor</th>
<th>Type</th>
<th>Level</th>
<th>Description in relation to daily objectives</th>
<th>Relevance as actor</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Farmers Insurance Fund</td>
<td>Public Executive and Civil Organization</td>
<td>National</td>
<td>The State and the farmers own the Farmers’ Insurance Fund. It compensates individuals and farming societies for various damages caused by natural disasters and animal diseases, in addition to what is covered by Iceland Catastrophe Insurance</td>
<td>Direct farming actor</td>
</tr>
<tr>
<td>8</td>
<td>Iceland Catastrophe Insurance</td>
<td>Public Executive</td>
<td>National</td>
<td>Iceland Catastrophe Insurance insures real estate against natural disasters. If building content is insured against fire, then it is also insured by this fund</td>
<td>Associated actor</td>
</tr>
<tr>
<td>9</td>
<td>Directorate of Labour</td>
<td>Public Executive</td>
<td>National</td>
<td>The Directorate of Labour is responsible for the management of the National Employment Service as well as the daily operation of the Unemployment Benefit Fund, the Wage Guarantee Fund, the Childbirth Leave Fund and payments to parents of children with long-term illness</td>
<td>Associated actor</td>
</tr>
<tr>
<td>10</td>
<td>Chief of Police</td>
<td>Public Executive</td>
<td>Local</td>
<td>Besides law enforcement activities, the district police are in charge of civil protection operations in the district during a “civil protection situation”</td>
<td>Associated actor</td>
</tr>
<tr>
<td>11</td>
<td>Rangarthing Eystra Municipality</td>
<td>Public Executive</td>
<td>Local</td>
<td>Manages the community, such as schools, cultural buildings, sports halls, planning and construction, roads, sewage, cold water systems, harbours, playgrounds, tourist sites, campsites and employment issues</td>
<td>Associated actor</td>
</tr>
</tbody>
</table>
South-Agri), with executive roles, and were the main organisers of the recon. The Ministry of Agriculture is the highest ranking governmental farming actor. The ministry interacts with the national civil organization, which interacts with the local civil organization. Four of the 11 actors were associated actors (Nos. 8–11, Table 7). The Iceland Catastrophe Insurance provides insurance against natural disasters for buildings that have fire insurance; the Directorate of Labour deals with issues of unemployment and paid for temporary labourers to farmers and farming actors; the police deal with law enforcement and take charge in matters of Civil Protection; and the municipality manages community services and affairs.

3.6 Actor disaster-related activities

3.6.1 Interview summaries

A narrative summary of the answers to the interviews is presented in Table 8. Not all actors are necessarily associated with all disaster-related objectives, e.g., the insurance companies in this study do not address life safety, resulting in no action towards objective #5.

For overview purposes, Table 9 shows the results in Table 8 coded as: Y (action taken), 0 (no action taken) and L (limited action). Limited action usually referred to addressing DFM objectives similar to their daily objectives, but not specifically with respect to EFJV. One exception was the municipality, which addressed objectives with respect to EFJV, but from a police perspective, not their own.

3.6.2 Activities in the context of Civil Protection

For the purpose of placing farming actors’ activities in context with the overall response, the activities of the local chief of police are discussed here and the broader aspect of Civil Protection. Disaster-related activities in Iceland are by law coordinated by chiefs of police at the local level and by the National Commissioner of the Icelandic Police at the national level, managed by a Civil Protection and Emergency Management Department (Act on Civil Protection, Lög um almannavarnir 2008). The national level also responds locally, for example, by running a temporary service centre, and providing guidance to residents regarding ash and other volcanic hazards through pamphlets and the Internet (www.almannavarnir.is).

Shortly after the 1999 earthquake swarms in EFJV, scientists notified the National Civil Defence of Iceland (now Civil Protection Department of the National Commissioner of the Icelandic Police since 2003) of these events, which initiated a discussion of a possible eruption. At the time, a significant amount of research had been published on eruptions of Katla, the neighbouring volcano and subsequent flooding, as it was seen as a risk due to past activity (see Fig. 6), but less on the EFJV.

The interview with the local chief of police revealed the following (see Tables 8 and 9). The local police do not perform natural disaster risk analyses, but they sent a letter of request to the Minister of Justice (now Interior) in 2002 to fund a scientific risk analysis for the Katla and Eyjafjallajökull volcanoes. The analysis was published in 2005 (Gudmundsson et al. 2005). It was a flood hazard analysis only; ash hazard was not included. A digitized simulation of floods on topographical maps was produced for the area; however, exposure, vulnerability or risk studies were never completed. The local police did not perform or coordinate any direct mitigation activities, but did encourage others to do so.
Table 8  Actors’ activities to achieve objectives

<table>
<thead>
<tr>
<th>No.</th>
<th>Actor</th>
<th>Activities to achieve objectives</th>
<th>Activities to achieve objectives</th>
<th>Activities to achieve objective 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1–3</td>
<td>4–7</td>
<td>Systematic learning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-disaster</td>
<td>Disaster operations</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Ministry of Agriculture</td>
<td>Did not perform any pre-event activities</td>
<td>Financial issues and high-level coordination. Responsible for the recon mission</td>
<td>The process of monitoring the situation, discussing the situation at meetings and listening to presentations was a learning process, but no systematic learning has taken place within the ministry. The Secretary General of the Ministry of Agriculture had asked those legally responsible for disaster coordination (Minister of Interior and National Police Commissioner), at a meeting during the response, for clarification on the role of the Ministry of Agriculture, but did not receive any clarification and remains uncertain who is responsible for initiating a systematic learning process</td>
</tr>
<tr>
<td>2</td>
<td>Farmers’ Association of Iceland</td>
<td>Did not perform any pre-event activities</td>
<td>Responsible for the recon mission. Monitored information about ash and chemicals, and supported the Farmers’ Insurance Fund in collecting information about damages to fields, field roads, ditches, field fences, loss of harvest, evacuation of animals (transport and care-taking at a new location), livestock and livestock production</td>
<td>Dedicated a one-day session of their 2011 Annual Conference to presentations on EFJV and published the abstracts (Farmers’ Association 2011), thus providing a venue for others, but had not performed any internal learning at the time of the interview</td>
</tr>
<tr>
<td>3</td>
<td>South-Agri: Agricultural Association of South Iceland</td>
<td>Did not perform any pre-event activities</td>
<td>Responsible for the recon mission. Lower-level coordination role, for example, on animal evacuation. Monitored information about ash and chemicals, and supported the Farmers’ Insurance Fund in collecting information about damages to fields, field roads, ditches, field fences, loss of harvest, evacuation of animals (transport and care-taking at a new location), livestock and livestock production</td>
<td>Updated their website information and wrote an evaluation paper presented at the Annual Meeting (Sigurmundsson 2011) and have the view that the government officials should develop response plans covering livestock evacuation and support to farmers. Have not formally institutionalized lessons from the event</td>
</tr>
<tr>
<td>No.</td>
<td>Actor</td>
<td>Activities to achieve objectives 1–3 Pre-disaster</td>
<td>Activities to achieve objectives 4–7 Disaster operations</td>
<td>Activities to achieve objective 8 Systematic learning</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>4</td>
<td>The Icelandic Food and Veterinary Authority</td>
<td>Worked on risk and mitigation from their daily perspective of food and animal health. Requested to be included in an emergency evacuation and communication exercise in 2006, but the request was denied due to relevance</td>
<td>Participated in developing an ad hoc coordination mechanism and focused on situation monitoring, assigned experienced vets (but untrained for surveying) to survey the area, monitored the conditions of the animals, discussed issues of emergency slaughtering of animals with slaughterhouse managers, issues of collecting milk and spoilt milk with the dairy</td>
<td>Are in the process of deciding how to address the issue of improving their procedures</td>
</tr>
<tr>
<td>5</td>
<td>The Agricultural University of Iceland</td>
<td>Teaches students about the risk to animals from fluoride</td>
<td>Participated in measuring chemicals on the farmlands</td>
<td>Do not plan to systematically learn from this event</td>
</tr>
<tr>
<td>6</td>
<td>Land Conservation Authority</td>
<td>Battles land erosion due to wind and floods, e.g., builds flood barriers and cultivates land, and worked towards stabilizing ash with a focus on Hekla and Katla Volcanoes</td>
<td>Did not have a direct role, but offered resources, such as, land for temporary grazing, fencing, machinery and housing for families. Witnessed during the eruption how cultivating land next to roads improved road safety increases driver’s road visibility</td>
<td>Developed ideas for changed working procedures and incorporated some of them</td>
</tr>
<tr>
<td>7</td>
<td>Farmers’ Insurance Fund</td>
<td>Procedures were available prior to the 2010 eruption for the staff to follow in case of a natural disaster, but the procedures were not specific to EFJV</td>
<td>Developed payment rules for the EFJV event (Farmers’ Insurance Fund Rules 2010) after the extent of damage was known. Played a relief role by paying out insurance prior to final investigation of damages, when the damage was obvious</td>
<td>Believe their procedures work well and require no revision</td>
</tr>
<tr>
<td>8</td>
<td>Iceland Catastrophe Insurance</td>
<td>Procedures were available prior to the 2010 eruption for the staff to follow in case of a natural disaster, but the procedures were not specific to EFJV</td>
<td>Financial role. Was prepared to pay for measures to stop ongoing damage, if needed</td>
<td>Implemented improved procedures</td>
</tr>
</tbody>
</table>
The 2005 hazard analysis was used to update existing evacuation plans for Katla to include EFJV. The police/Civil Protection coordinated a full-scale evacuation and communication exercise in 2006 for emergency services and citizens (Department of Civil Protection and Emergency Management 2006). In the weeks prior to the eruption, the local chief of police held approximately 10 town hall meetings, including one with presentations from scientists, rescue teams and the National Commissioner of the Icelandic Police. The main focus of learning from the police perspective after the event has been on improving technical communications.

In the early morning of 14 April, some 800 residents were evacuated due to the summit eruption. Most of them were allowed to go back the same day and the rest the day after (Gudmundsson et al. 2010) for safety reasons, depending on how close they lived to the rivers that were in danger of flooding. After the evacuation, the farmers wanted to go back to their farms to tend to their animals. The police allowed temporary visits during the evacuation period after a mobile phone-monitoring system had been set up to call farmers out of the area if need be.

A temporary service centre was set up in the lowland farming area at the south-western corner of EFJV (Heimaland), where those affected could talk to representatives of various
The manager was a policeman and represented the National Commissioner of the Icelandic Police. His role was to provide advice and information to the affected population (citizens and municipal staff), coordinate projects with the municipalities in recovery and liaise with ministries and agencies, for projects related to the eruption (Department of Civil Protection and Emergency Management 2010). The manager also had considerable knowledge of agriculture, which motivated The Farmer’s Association to work with him (Bjarnason 2014). A staff member of the National Police Commissioner also visited farms during the eruption to give general advice to farmers.

3.7 Farmers’ livelihood outcome in 2010

The farming livelihood outcome for 2010 is described, based on the evaluation of farmers’ situation by the recon team (see Table 10). The organizers identified various unanswered questions, issues of concern and priority actions relating to chemical analysis and monitoring, animal sheds, hay and fodder, labour support, rest periods for farmers, animal transport, pastures, soil, crops and the use of fertilizer for farmland rehabilitation. Damage to buildings was not an issue because the Iceland Catastrophe Insurance insured building damage, and fire departments, rescue teams and volunteers, organized by non-farming actors, provided services to wash buildings.

4 Analysis

The farming-EFJV perspective (presented in Sect. 3) was used as a basis to answer a question relevant to each disaster-related objective (in italics below). The answers are
presented in bullet form for each objective and summarized in Table 11 as missing or unplanned activities.

For the sake of brevity, only the activities of the direct farming actors (first seven in Table 7) are included, and the activities for all four operational objectives (4, 5, 6 and 7) are viewed together.

4.1 Risk analysis activities (Table 2, Obj. 1)

Would it have been possible to perform a useful risk analysis from a farming perspective prior to the eruption? A risk analysis is based on exposure, hazard and vulnerability analyses. The area exposed to an eruption in EFJV is a small farming community. Information about farming livelihood strategies was available, and numerous actors were involved in the farming processes (Sect. 3.1). Therefore, detailed information about exposure in terms of assets and processes could have easily been collected. Hazard research prior to the eruption indicated that Iceland is an active volcanic island, that an explosive

<table>
<thead>
<tr>
<th>Category</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questions needing answers</td>
<td>Where is it safe for the sheep to be in regards to ash? Are the highlands safe?</td>
</tr>
<tr>
<td></td>
<td>Where should the sheep that normally graze in the summer, roaming free in the highlands, be sent?</td>
</tr>
<tr>
<td></td>
<td>Should transport be the responsibility of each farmer, or should it be a collective effort?</td>
</tr>
<tr>
<td></td>
<td>Where are farmers allowed to move their sheep in regards to disease control zones?</td>
</tr>
<tr>
<td></td>
<td>Who will pay for fencing for temporary pasture areas and fertilizing?</td>
</tr>
<tr>
<td>Issues of concern</td>
<td>The fluoride sampling, analysis and reporting are taking too long as analysts are not working on weekends</td>
</tr>
<tr>
<td></td>
<td>Need to discuss in earnest how to help farmers wanting to stop farming and permanently relocate, which requires financial support</td>
</tr>
<tr>
<td></td>
<td>The working procedures adopted by the Farmers’ Insurance Fund for the eruption were not yet clear</td>
</tr>
<tr>
<td></td>
<td>Information to farmers needs to be more appropriate; both the content and method of the Internet are not enough, nor is general information</td>
</tr>
<tr>
<td>Priority action areas/ responsible actor(s)</td>
<td>The actors involved in decision-making processes need to be more decisive</td>
</tr>
<tr>
<td>Temporary pasture/South-Agri</td>
<td></td>
</tr>
<tr>
<td>Sheds/South-Agri</td>
<td></td>
</tr>
<tr>
<td>Hay and fodder/Municipality, Farmers’ Association and South-Agri</td>
<td></td>
</tr>
<tr>
<td>Labour support/Farmers’ Association and South-Agri</td>
<td></td>
</tr>
<tr>
<td>Rest periods for farmers/Ministry of Agriculture</td>
<td></td>
</tr>
<tr>
<td>Animal transport/Farmers’ Association and South-Agri</td>
<td></td>
</tr>
<tr>
<td>Soil, crops and use of fertilizer for rehabilitation of farm land/Recon teams were not sure which actors were responsible for this issue</td>
<td></td>
</tr>
<tr>
<td>Chemical analyses and monitoring/Agricultural University, Farmers’ Association and South-Agri</td>
<td></td>
</tr>
</tbody>
</table>
Iceland, and that Eyjafjallajökull was an active volcano (Table 4). Ash levels from EFJV had not been estimated in the hazard analysis of EFV in 2005, but a 20-cm ash cover (Fig. 6) was expected in the exposed area, given eruptions in other nearby volcanoes. Degassing of magma and subsequent chemical transfer into the atmosphere, onto the ground and into rivers, were known threats. When EFJV erupted in 2010, it did indeed involve effusive and explosive eruptions, flank and summit eruptions, magma discharge of lava flow, water-transported ash and airborne ash, plume, ice melt, glacial river flooding and lightning, and the ash level in the farming areas was measured well below the 20 cm mark (Fig. 7). Therefore, the EFJV 2010 was well within the range and type of an expected volcanic eruption in the region. In regard to vulnerability, research had presented numerous possible effects on natural and physical assets (Table 5). A comparison of Tables 5 and 6 shows that various issues for farmers, such as ash covering pastures, fodder, water, visibility, animal fluoride tolerance, soil conditions and general interruption of agricultural activities (Table 6), had been discussed in previous research (Table 5). Farming in Iceland has changed significantly through the centuries, for example, through technical advances in harvesting and milking, increased societal knowledge and increased education amongst farmers (Jóhannesson and Agnarsson 2005). Changes in production lead to changes in vulnerability; for example, increased technology may decrease (e.g., produce fodder faster) or increase disaster vulnerability (e.g., damage to machinery), calling for periodically updated disaster risk analysis from a farming perspective.

<table>
<thead>
<tr>
<th>No.</th>
<th>Function</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Risk Analysis</td>
<td>Information was available on the volcanic hazard in Iceland, particularly on Eyjafjallajökull, on the exposed area, on the vulnerability of farming due to ash and on general livelihood strategy variables. A useful risk analysis to inform mitigation and preparedness from a farming perspective could have been developed</td>
</tr>
<tr>
<td>2</td>
<td>Mitigation</td>
<td>Efforts to control ash, sand and dust from volcanoes in Iceland systematically applied in various regions in Iceland could have been systematically applied to the EFJV area to reduce the risk of negative affects of ash distribution</td>
</tr>
<tr>
<td>3</td>
<td>Preparedness</td>
<td>Some discussions during the response, such as which actor would monitor chemical levels, which actor would pay for it, whether to perform a recon, etc., could have been a preparedness activity and resulted in coordination plans. Training in disaster assessment and coordination could have inspired farming actors to perform recon missions soon after the onset and periodically, to develop specialized farming information management procedures and might have increased operational decisiveness</td>
</tr>
<tr>
<td>4–7</td>
<td>Operations (impact, rescue, relief and recovery)</td>
<td>Due to necessity and regardless of any preparation, farming actors will organize their own coordination mechanism, based on their daily modes of communication, to deal with activities for damaging processes, rescue, relief and recovery from their perspective, and link it to other operational coordination mechanisms</td>
</tr>
<tr>
<td>8</td>
<td>Systematic learning</td>
<td>In 2013, no systematic learning had taken place amongst the farming actors since the eruption in 2010. It is unclear who should take the initiative for starting a learning process</td>
</tr>
</tbody>
</table>
Yes. The actual impact from Eyjafjallajökull was within the range of a hazard analysis from a volcanic eruption in the region, so a risk analysis would have been useful.

4.2 Disaster Risk Mitigation activities (Table 2, Obj. 2)

Could a mitigation analysis prior to the eruption have led to ideas on how to reduce disaster risk? A sound risk analysis would have informed a detailed mitigation analysis and led to realistic ideas for mitigating measures taken by farmers, their families and farming actors in regard to damage, injury and disruption. One example is given here on increased visibility and traffic safety during ash storms. The Land Conservation Authorities systematically cultivates vegetation along roads to limit ash, sand and dust remobilization (e.g., in the Hekla region and the sands along the south coast) to increase visibility whilst driving in sandstorms and reduce the risk of scratching car paint (see daily objectives in Table 7). A stretch along the main road in the EFJV area had been cultivated by Land Conservation prior to the eruption for these reasons, which were reasons unrelated to the risk of an eruption in EFJV. During ash storms from the eruption, Land Conservation staff members saw that ash density blowing over the roads along the cultivated land was less than in other places, facilitating traffic and increasing road safety because it was easier to see the road. If the agency had been aware of the risk, they could have put efforts into cultivating more land next to the main road in the EFJV region to reduce ash mobilization over main roads.

Yes. A systematic mitigation analysis could have led to increased visibility and road safety during ash storms and knowledge of vulnerability processes would have been the basis for further analysis.

4.3 Operational Preparedness activities (Table 2, Obj. 3)

Could a useful contingency plan have been written by and for the farming community to guide impact, rescue, relief and/or recovery operations? When prompted by a realistic risk scenario, farming actors, with their knowledge of farming processes, such as lambing, sheltering of animals, the need for feed, etc., would likely have been able to identify content for a contingency plan to guide the response of the farming actors. Examples include: identifying responsible parties for paying for fencing and fertilizing, for temporary pastures, for the transport of animals and for people organizing chemical analysis and reporting; developing standard operating procedures to ensure that information to farmers is appropriate in content, format, timing and delivery; and that farmers are provided with rest periods. The actors may have identified the need for further research on animals’ fluoride tolerance, health effects, the effect of ash on soil and vegetation of fields and pastures, on factors to consider in deciding whether to build additional shelter for animals or to evacuate them, and, if they are evacuated, who will tend to them in the new location—for example, milking cows. Preparing a contingency plan could have led farming actors towards training in establishing coordination mechanisms and needs assessment.

Yes, useful contingency plans could have been written by and for the farming community prior to the eruption, if based on a sound risk scenario and accompanied by training in disaster operations.
4.4 Operational activities (Table 2, Obj. 4, 5, 6 and 7)

Could coordination and assessment efforts amongst farming actors have been performed better? Impact, rescue, relief and recovery operations require effective coordination and timely needs assessments. Establishing such processes at the onset of a disaster is a standard operating procedure (UNOCHA 2006). Coordination was initiated by the national government when it formed a committee of the secretaries general of the ministries the day after the eruption. Subsequently, the Secretary General of the Ministry of Agriculture formed a coordination group of farming actors that included the Farmers’ Association. The Farmers’ Association coordinated with South-Agri. The South-Agri offices, situated in the town of Selfoss between the capital, Reykjavík, and the affected area (See Fig. 4), became the centre of coordination for field activities. South-Agri field staff in the affected area also reacted to the situation by helping farmers move animals into shelters. Thus, the farming community created its own disaster coordination mechanism under the Ministry of Agriculture, based on their normal collaborative network. This mechanism was linked to the coordination mechanism of the police/Civil Protection, for example, through cooperation between the Ministry of Agriculture and South-Agri with the manager of the Temporary Service Centre. The Food and Veterinary Authorities also participated in developing an ad hoc coordination mechanism with various other actors. The initial reaction to the eruption was more or less immediate (according to interviews) and mainly in accordance with their daily objectives (see Table 7). However, in regard to assessments, despite a general understanding of the situation, a joint needs assessment was not performed until four weeks into the operation when the situation in the field had become problematic and farming actors were beginning to show fatigue. The eventual needs assessment systematically and collectively gathered and analysed information to allocate resources and assist the affected farming and animal populations and agricultural facilities in a concerted effort.

- Yes. Whilst initial efforts were immediate, the coordination for farming actors was ad hoc, and a systematic needs assessment was performed four weeks into the event, prompted by awareness of the problematic situation. This is reactive management. Proactive management could have led to a better performance, e.g., an earlier recon mission.

4.5 Systematic learning activities (Table 2, Obj. 8)

Would systematic learning from farming actor activities associated with the 2010 eruption be useful? Lack of farming-disaster risk analysis (4.1), systematic mitigation analysis (4.2) and disaster training and planning (4.3) led to ad hoc, reactive and delayed measures (4.4). These facts provide reasons for farming actors to separately and jointly review their pre-eruption and real-time EFJV-related activities to learn lessons in case of future and possibly larger eruptions. Lack of pre-disaster planning leads to more time spent on operational planning after the onset of the disaster, causing delays in assistance reaching the affected population. Indeed, the lack of plans resulted in discussions amongst farming actors on what to do, on clarifying actors’ responsibilities, such as determining responsibility for organizing field sampling and reporting schemes for chemical monitoring, determining logistical support for animal evacuation, estimating operational cost and deciding who shall pay for what, determining coordination mechanisms and resolving other issues normally addressed in contingency plans to ensure effective and efficient response operations, taking place after the eruption started. Learning processes should also
address gaining clarity on the roles and responsibilities of ministries before, during and after disasters. The Ministry of Agriculture sought clarification on their role from those legally responsible for disaster coordination, i.e., the Minister of the Interior and National Commissioner of the Icelandic Police, but no clarification was received. At the time of the interview, it was still unclear who bore the responsibility for initiating a systematic learning process.

- Yes. A systematic learning process could reveal the current knowledge of farming actors in regards to risk analysis, mitigation and preparedness, could increase pre-planning to shorten operational planning and hasten field response and could clarify roles and responsibilities in the farming community.

5 Results

The reason for inadequate information getting to farmers during the 2010 includes lack of pre-eruption activities by farming actors regarding an eruption in EFJV. Four of the seven farming actors performed no risk analysis at all, whilst three performed general activities related to ash risks. Five farming actors took no mitigation measures, and two participated in mitigation-related activities for general volcanic threats. No farming actor initiated any activity towards designing a coordination mechanism or writing a contingency plan for farming actors as a group. Risk analysis, mitigation analysis and contingency planning could have prepared the actors to collect, compile and timely share relevant information.

Inadequate information for farmers can also be linked to the delay in joint needs assessment. The reason for the delay can be attributed to lack of training in disaster management, leaving farming actors to gradually realize problems amongst farmers as the problems grew bigger and therefore manage reactively.

The lack of pre-event activities is not due to insufficient pre-eruption information. On the contrary, substantial information was available to perform a realistic risk analysis for EFJV from a farming perspective. The hazard was well known, the exposure area was small with well-understood assets and processes, and relevant vulnerability studies existed that could have been used as a basis of further vulnerability analysis. The resulting risk scenario would have resulted in a higher intensity scenario than actually occurred; therefore, any planning for the risk scenario would have been within the scope of the actual event.

The study shows a lack of post-event learning. Four farming actors had not initiated a process to learn from their experiences (one actor believed its institute did not need to do so). Two have initiated, but not completed, a learning process. One has changed response procedures, based on the experience, but none has initiated a learning process for the farming community in general. The experience did give some actors insight into what could have been improved. For example, during an interview one actor stated that, in retrospect, the recon should have been performed sooner and more often, but this has not been enough to initiate a learning process within the learning community.

6 Discussion on perspective

The impact of the EFJV eruption was not a disaster by the UN’s definition of disaster (UNISDR 2009), as it did not cause disruption at the community level to the extent that it
exceeded society’s ability to function. The serious disruption was on the farm level. There were less than 20 farms in the main affected areas, and fewer than 10 of these were in the most affected area (see Fig. 4a). There was general agreement amongst the interviewees that the coping level of actors and farmers was due to fortunate circumstances: a small, homogeneous, sparsely populated affected area, where the farmers and institutional farming staff knew each other very well, and unfavourable winds were of short duration. Nevertheless, numerous groups were involved, demonstrating the diversity of perspective in the disaster-related activities. For example, scientists, police and farming actors have different roles and responsibilities and demonstrated different perspectives on what constitutes disaster-related activities.

Scientists had monitored the EFJV volcano since 1991, reported the activity to the Civil Protection after it increased in 1999, presented a detailed analysis of flood-related hazards due to EFJV and Katla Volcano in 2005, where ash was not considered, published a hazard assessment in 2008 of a 20 cm ashfall around EFJV and increased their monitoring of EFJV as the activity increased in the months prior to the eruption. A scientific field assessment includes a detailed assessment of ashfall, e.g., analysing the thickness of ash versus the intensity or degree of impact, the frequency, duration and magnitude of the ashfall event, along with the characteristics of ash, such as grain size, mineralogy and content of soluble acidic salts associated with the ash (Wilson et al. 2011a, b). The results of such activities include information like that presented in Fig. 7. No risk analysis was performed, other than mapping of a flood zone and locating constructed elements in the flood zone.

The police, after being informed of the hazard by the scientific community, initiated funding for further hazard analysis relevant to life safety from flooding due to eruption under icecaps, and organized evacuation exercises in the event of flooding. Icelandic law makes pre- and real-time disaster coordination the responsibility of the police. They were actively engaged in coordinating various actors, mainly emergency management agencies, for eight years prior to the eruption. They focused on life-saving activities. In March 2013, three years after the eruption, the local and national police and the local Civil Protection Committee published the first formal response plan specifically for an eruption in the EFJV (Police Chief Hvolsvelli et al. 2013). Its content focuses on population control, evacuation, mass care, traffic control, rescue and flood control. The only farming actor is the National Veterinarian, who works within the Food and Veterinarian authorities. His role during an eruption, according to the plan, is to “work according to his own plan”. The new plan clearly shows that the police perspective does not include the perspective of farming actors.

Despite a history of volcanic impact on farms in Iceland, the farming actors were not informed of the increasing risk. They did not initiate any type of pre-disaster activities and have not (at the time of the interviews) engaged in systematic learning as a community. The farming actors are not considered part of the Civil Protection umbrella since they were not invited to participate in preparedness activities with emergency agencies and are not part of the latest police response plan. However, farming actors were highly active during the response and are important response actors for farmers. The Ministry of Agriculture, the Farmers’ Association and South-Agri participated to some degree in activities regarding all four operational objectives, where the life-saving objective (Objective 5 in Table 2) relates here to the lives of the livestock. Failure to identify relevant stakeholders (actors and those affected) has been documented as one of the possible reasons for systems failure (Lyytinen 1988, Pouloudi and Whitely 1996). The question becomes who is responsible for identifying and activating stakeholders to avoid systems failure.
The point argued here is that the level of specialization amongst livelihood professionals in general requires them to do their own risk and mitigation analyses and to prepare their own disaster-related activities and coordination mechanisms. The consequences of ashfall on farming are not well understood by non-specialists. Brunsdon and Park (2009) reach a similar conclusion from the perspective of designing and managing infrastructure when they suggest that consequences to a community due to infrastructure failure are not well appreciated by other utility providers, civil defence agencies, businesses and communities.

7 Conclusions

The reason for inadequate information to farmers can be attributed to lack of pre-eruption activities amongst farming actors, stemming from lack of clarity on who bears the responsibility for identifying actors to assist farmers from a livelihood perspective and initiating their pre-disaster activities.

Livelihood actors provide specialized knowledge on their specific fields and in times of disaster can offer specialized solutions for their industry that are beyond the perspective of emergency services. However, being highly specialized in their field is not enough when it comes to responding effectively and efficiently to disasters. First, specialists need to be updated on any developments regarding natural hazards. Second, they need to be trained in disaster-related activities and standard operating procedures, such as developing disaster risk scenarios from a livelihood perspective, building coordination mechanisms, initiating timely needs assessment and sharing specialized information. The failure to identify farming actors prior to 2010 resulted in lost opportunities to analyse farming-disaster risk and mitigation options, organize coordination mechanisms for farmers and write contingency plans. Livelihood actors should take the initiative in analysing disaster-related legal frameworks from their own perspective to identify and address gaps, such as the provision of information important in their field.

This study provides numerous ideas for further research. For example, additional questions can be asked on the information in Sect. 3. For instance, how to develop a risk-planning scenario from a farming perspective, and what recon questions provide the most useful information. However, the main topic of future research is seeking clarity on the roles within legal frameworks for disaster-related activities, in order to determine necessary changes to such frameworks, to ensure effective and efficient pre-event, real-time and post-event activities amongst livelihood actors.

Acknowledgments Sincere gratitude is expressed for the time and invaluable contributions of the staff members at the 11 institutions interviewed for this study. Runolfs Sigurdsen at South-Agri is especially thanked for his role in providing information for this study. Einir Blöndal, managing director of the Farmers’ Association, is thanked for his eloquent summarization of the key lesson drawn from the EFIV for the farming industry in Iceland. Sigurgeir Thorgerisson, former Secretary General of the Ministry of Agriculture, is thanked for his review comments. Puja Acharya is thanked for her assistance in generating the maps and her patience. Dr. Magnus Tumi Gudmundsson is thanked for permission to use Fig. 6. We also thank the anonymous reviewers for constructive comments and their guidance in restructuring the paper. The authors gratefully acknowledge the research grants from the University of Iceland’s Eimskip Fund and the South Iceland Science Fund. Furthermore, the co-support provided by the EU Civil Protection Financial Instrument, in the framework of the European project Urban disaster Prevention Strategies using MACroe-seismic Fields and Fault Sources (Acronym: UPStrat-MAF, Grant Agreement No. 23031/2011/613466/ SUB/A5), is gratefully acknowledged.
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Conceptualizing societal safety systems using a system dynamics approach

Sóveig Thorvaldsdóttir¹ and Ragnar Sighjörnsson²

Abstract

This paper presents a theoretical discussion of societal safety systems. Safety is seen as a control problem. The discussion leads to management techniques for identifying projects and guiding actors to collectively meet specific disaster-related objectives. The inherent dynamic relationship between the disaster-related objectives makes the System Dynamics Approach (SDA) a suitable theoretical foundation for the proposed societal safety system, which provides tools, such as causal loop diagrams, feedback loops, and stock and flow variables. A practical application is given, showing how to evaluate an existing societal safety system and develop recommendations for improvement. The example involves the risk of dam failure of a hydroelectric power plant that could cause flooding in farmland areas downstream. The conceptualized societal safety system provides an interface between the organizations involved, such as, the owners of the dam, the design engineers, the threatened population and government; the technological aspects, both of the dam itself and early warning systems, and the safety controllers managing the safety of the dam and society.

Key words: disaster-related objectives – system dynamics approach – dam failure – floods - safety systems

1. Introduction

Safety systems aim at controlling adverse impact on people (e.g., injuries), structures (damage and loss of investment) and the natural environment (e.g., pollution) (Rasmussen 1997). A societal safety system is defined here as one looking at impact on society as a whole, as opposed to, for example, only an industrial installation where an accident may occur. A safety system from an industrial perspective combines different aspects of an organization’s safety management system, including safety officials, safety committees, permit to work, safety policies, and safety equipment (Flin et al.). The concept of societal safety management system broadens the range of actors from all levels and sectors of society. The intent of this work is to provide a theoretical basis for transparent, straightforward safety management techniques for major accidents and natural disasters.

The proposed concept of societal safety system is built on the principle of Management by Objectives, using a set of eight objectives derived for disaster-related activities (Thorvaldsdóttir and Sighjörnsson 2013, Table 1). Consequently, a disaster function is defined as a management function to organize activities aimed at accomplishing a specific disaster-related objective. The application of the disaster functions is termed Disaster-Function Management.

The following statement specifies the disaster-related objectives and explains their relationship: disaster-related activities aim to understand disaster risk, to measurably mitigate disaster

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risk, prepare for future events associated with any residual unmitigated risk, intervene in damaging
processes and react to life-threatening situations, recover from the impact, provide temporary relief
until recovery is accomplished and, finally, learn from the operations in order to improve the system
used to meet the objectives. The objectives were derived from an expansion of the four phases of the
original Disaster Life Cycle (NGA 1979), which express basic disaster-related activities: mitigation,
preparedness, response and recovery (Thorvaldsdóttir and Sighjörnsson 2013). While many adaptations
of the phases exist, these eight objectives are the first attempt to theoretically derive objectives from the
original phases. Phases depict disaster-related activities in a linear process, whereas objectives allow
them to be addressed as a non-linear, dynamic process.

The above statement indicates interdependency of the objectives, displaying the dynamic
nature required of a management system designed to meet them. A System Dynamics Approach (SDA)
is an obvious candidate for the theoretical foundation of a dynamic management system. SDA utilizes
tools, such as stock variables, describing the state of the system at any given moment; flow variables,
describing the rate of change; and connecting variables, carrying information from one element to
another (constants, algebraic or graphical relationships), (see, for example, Ahmad and Simonovic,
2000). Stock and Flow Diagrams are created during the first step of a modeling process. Stocks are
defined in a variety of ways, for example, water level in reservoirs (Ahmed and Simonovic 2000), or
amount of waste at waste disposal sites (Chaerul et al. 2008). System dynamics is a methodology to
understand the behavior and dynamics of complex systems of time (Goh and Love 2012). They are used
for a variety of purposes, for example, management and policy analysis in flood management
(see, for example, Ahmed and Simonovic (2000 and 2004), Simonovic and Ahmed (2005), Deegan
(2007), Simonovic (2011), and Lehman (2011)), accident control (Leveson 2011 and 2015, Goh et al.
2010), finding solutions for complex disaster management problems (Simonovic 2011, Gillespie 2004,
and Patwardhan and Sharma 2005), modeling patterns of breakdown in human and organizational
processes in accidents (Kontogiannis 2012), and formalizing causal interdependencies between
technical, organizational and human safety factors (Bouloiz et al.).

Here, SDA is not used to analyze a system, but to build a system for controlling a situation.
Stock is here associated with the number of projects to be completed to meet a disaster-related
objective, and each disaster function is characterized as a single feedback-loop system. The non-linear
relationship between the eight single feedback-loop systems creates a closed complex system, which is
conceptualized through Causal Loop Diagrams (CLD), feedback loops and SDA variables. The system
environment is the situation that threatens to create, is creating or has created serious disruptions in
society, depending on the context.

To demonstrate a practical application, the method is used to develop recommendations for
improving an existing societal safety system in case of dam failure of a hydroelectric power station
owned by Landsvirkjun, the National Power Company (NPC) in Iceland.

1.1. **Industrial and natural disaster risk management**

The proposed safety system is rooted in risk management for both industrial accidents and natural
disasters. Industrial accident risk management is characterized as follows (Rasmussen 1997):

- “An industrial accident depends on loss of control of physical processes capable of injuring
  people and damaging property leading to possible injuries, contamination of environment, and
  loss of investment;
- Industrial accident risk management is a control problem that focuses on maintaining a
  particular hazardous, productive process within the boundaries of safe operation;
- Industrial accident risk management systems are socio-technical systems that represent a
  control structure involving all levels of society, including government, regulators,
  associations, company, managers, staff and system operators.”

Despite a broad socio-technical view from government to the engineers, Rasmussen’s perspective looks
only at the impact on the industry in question. When the impact of an accident extends beyond the
physical borders of the industrial installation, then even more actors are involved to deal with rescue,
relief and diverse recovery needs of a larger affected population. A disaster is defined as a serious disruption of the functioning of a community or society. It involves widespread human, material, economic or environmental losses and impacts, exceeding the ability of the affected community or society to cope by using its own resources (UNISDR 2009). Therefore, if an accident has serious negative impact on the society it is in, the accident is a disaster.

According to the United Nations, disaster risk management is defined as the systematic process of using administrative directives, organizations, operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster (UNISDR 2009). Adopting the view that disaster risk management is a control function allows one to rephrase UNISDR's definition of risk from “… in order to lessen the adverse impacts of hazards and the possibility of disaster” to “… in order to control processes adversely impacting the people, structures and the natural environment”. While it can be argued that not all aspects of a natural disaster are controllable, the proposed concept addresses those that are.

2. Disaster-Function Management System

The general assumptions for a Disaster-Function Management System, based on a system dynamics approach, are listed below, followed by more detailed descriptions.

1. Each disaster-related objective (DRO) is set within a single feedback loop (FBL) system, where the transformation processes are project processes (section 2.1).
2. General activities to reach each DRO are known and are sources of projects (section 2.2).
3. The relationships between each related pair of DROs are defined, based on the general activities, and depicted in a Causal loop diagram (CLD), (section 2.3).
4. Three FBL’s are contained in the CLD, representing a normal society, a disrupted society and an improving society (section 2.3).
5. Flow variables are defined as projects completed within one single FBL system that are a source for projects in another single FBL system (section 2.4).
6. Stock variables are incomplete projects for a DRO, created by assumptions 2 and 5 above (section 2.5).
7. Connecting variables carry information from one single FBL to another (constants, algebraic or graphical relationships), (section 2.6).
8. System excitation variables drive the overall need for the system in the form of hazard and damage variables (section 2.7).

2.1. Single feedback-loop disaster-function system

The purpose of a disaster function is to ensure that a disaster-related objective is met. Fig. 1 below portrays a disaster function as a single feedback-loop system. The purpose of the system is to create and complete projects that collectively meet the given objective. The environment creates a need for new projects, a source creates new projects at an inflow rate of new projects, and the transformation process completes projects at an outflow rate. The difference between the inflow and outflow rates is the number of incomplete projects within the system at any given time. The finished projects are placed into the environment, which provides feedback to the source, creating new or adapted projects. Input and output control factors affect the input and output flow rates, such as risk awareness, political interest, funding, time, resources, level of education, and unexpected problems.

The environment’s conditions create threats of unwanted impact processes and actual processes, such as accidents or "collisions" between natural phenomena, such as earthquakes, floods and volcanic eruptions and objects. The analysis of such future events is commonly termed “risk analysis”, where risk is defined as a combination of the probability of an event and its consequences. However, this definition is too simplistic for a complex scenario like a disaster; indeed, it is too simplistic even for an accident (Montewka et al. 2014). The risk perspective proposed by Montewka et
al. considers risk as a set encompassing: plausible scenarios leading to an accident, the likelihoods of unwanted events within the scenarios, the consequences of the events and description of uncertainty. This is a more appropriate definition of risk for disasters. Understanding the environment (i.e., the risk) is the first of the eight disaster-related objectives.

Fig. 1. A disaster function as a single feedback-loop system

To illustrate environmental variables, earthquake risk is discussed from the perspective of Loss Estimation methodology (see, for example, Whitman et al. 1997, McCormack and Rad 1997, Earthquake Spectra 1997, Natural Hazards Review 2006). Exposed objects are characterized through aggregation by relevant attributes in inventory databases. Earthquake processes are characterized by parameters and equations. Additional factors, such as environmental factors, provide increased detail and accuracy. Table 1 provides examples of variables used for a loss estimation tool developed for earthquakes in California, USA, (EPEDAT, Early Post-Earthquake Disaster Assessment Tool, Eguchi et al. 1997).

Table 1. Examples of variables defining a system environment

<table>
<thead>
<tr>
<th>Exposed objects</th>
<th>Earthquake processes</th>
<th>Environmental factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings (age, material)</td>
<td>Magnitude</td>
<td>Soil type (soft, hard)</td>
</tr>
<tr>
<td>Special facilities (functionality)</td>
<td>Epicenter</td>
<td>Amplification factors (soil water</td>
</tr>
<tr>
<td>Infrastructure (location)</td>
<td>Causative fault and type</td>
<td>content)</td>
</tr>
<tr>
<td>Population (by time of day)</td>
<td>Rupture length, area and location</td>
<td></td>
</tr>
</tbody>
</table>

Different combinations of system environment variables give rise to different disaster scenarios. Vulnerability functions are used to describe the impact of varying intensities of ground motion on the exposed objects, such as fragility curves, damage distributions, and Damage Probability Matrices. The development of such functions can be through expert opinion (such as ATC 1985), empirical analysis of past earthquake data (e.g., EQE 1995 and 1995a, Thorvaldsdóttir 2006), or a combination of techniques (e.g., Mansouri et al. 2010). The interest of the analyst or user determines the estimation of unwanted events within the scenario and their consequences. For example, the number of dead, injured and displaced persons can be estimated from building damage data. Examples of environment variables, processes and unwanted events for earthquakes, volcanic eruptions and flooding are given in Table 2.

Table 2. Environment variables

<table>
<thead>
<tr>
<th>Natural parameters</th>
<th>1. Earthquake &amp; Building</th>
<th>2. Eruption &amp; Person</th>
<th>3. Flood &amp; Electrical system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak ground acceleration, duration of strong ground shaking</td>
<td>CO&lt;sub&gt;2&lt;/sub&gt; emissions, lava viscosity</td>
<td>Discharge, stage</td>
<td></td>
</tr>
<tr>
<td>Height, building material</td>
<td>Age, health</td>
<td>Water tightness</td>
<td></td>
</tr>
<tr>
<td>Site condition, ground water level</td>
<td>Wind, topography</td>
<td>Temperature, topography</td>
<td></td>
</tr>
<tr>
<td>Ground acceleration causes liquefaction in soil, causing it to lose bearing capacity.</td>
<td>No winds in low areas cause pockets of heavy CO&lt;sub&gt;2&lt;/sub&gt; gas, pushing out O&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Freezing temperature reduces seepage into ground, raising stage level to reach electrical equipment.</td>
<td></td>
</tr>
<tr>
<td>Collapse</td>
<td>Suffocation</td>
<td>Short circuiting</td>
<td></td>
</tr>
</tbody>
</table>
2.2 Disaster-function activities

Basic activities performed within each disaster-function (DF) are listed below. These activities are used as a basis of discussion for the development of the complex system in section 2.3. The bulleted items are example references.

DF1 Disaster Risk Analysis Function: to understand disaster risk, its components and context
DF1.1 Develop natural process parameters, such as peak values, temporal changes, geographical variations and probability of occurrence.
DF1.2 Classify, characterize and inventory objects exposed to a hazard, such as structures, people and services.
DF1.3 Develop damage models and determine vulnerability factors.
DF1.4 Develop probabilistic or deterministic scenarios, consisting of direct damages, losses and human impact, and cascading damages and consequences, such as loss of function and service disruptions, from a human, material, economic or environmental perspective.

DF2 Mitigation Function: to measurably reduce known disaster risk
DF2.1 Identify opportunities for reducing risk through land-use planning, building codes,
construction inspection, public education in making homes and work places safe, financial insurance, service backup systems and other measures.
DF2.2 Analyze each option, based on cost, estimated time of completion, resources required,
effectiveness as in level of risk reduced, benefits per beneficiary and other relevant aspects.
DF2.3 Compare benefits of different options and different combinations of options and select an option or combination.
DF2.4 Implement and monitor actual reduced risk and reevaluate choice against anticipated reduction.
- Building codes provide structural engineering design provisions to limit risk (UBC 1994).

DF3 Operations Preparedness Functions: to prepare operations for dealing with future disasters.
DF3.1 Develop standard operating procedures for assessment and coordination for impact, rescue,
relief and recovery operations.
DF3.2 Establish facilities and communications networks and procure equipment.
DF3.3 Write contingency plans based on DF1.4 scenario.
DF3.4 Train personnel and test plans.
- ATC-20, a field manual ready to be used when disaster strikes, provides guidance to evaluate damages (ATC 1991).
- INSARAG Guidelines for urban search and rescue (INSARAG 2012).
- Farmers’ Natural Disaster Insurance Fund Act on payout procedures to compensate farmers in Iceland (FNDIF 2010).

DF4 Impact Operations Function: to react to damaging and potentially damaging processes.
DF4.1 Monitor natural processes and damaging processes, diagnose current situation and forecast possible turn of events and turn existing impact contingency plan into an operations plan.
DF4.2 Protect population to avoid the need for rescue operations through warnings, directives,
closing off areas, and evacuations, to the extent possible.
DF4.3 Protect property by redirecting natural processes, such as sandbagging, digging diversion trenches, cooling lava and control of reservoir spillways.
DF4.4 Halt or reduce on-going damaging process by intervening, such as stopping leaking gas lines,
putting out fires, avoiding potential explosions, and shoring damaged structures.
- ATC-20, a field manual ready to be used when disaster strikes, provides guidance to evaluate damages (ATC 1991).

DF5 Rescue Operations Function: to save lives of those caught in damaging processes
DF5.1 Perform reconnaissance missions to gain overview and convert rescue contingency plan to operations plan.
DF5.2 Search for, locate, access, medically assist and secure the safety of people.

DF5.3 Transport victims, and hand them and associated information over to medical facilities or other parties.

DF5.4 Perform support operations, such as crowd control and closing off of areas.

• INSARAG Guidelines for urban search and rescue (INSARAG 2012).

DF6 Relief Operations Function: to provide any temporary measures

DF6.1 Perform needs assessments to gain overview and convert relief contingency plan to operations plan.

DF6.2 Sustain life and provide temporary relief by ministering to basic needs, such as shelter, water, food, cooking facilities, heat, clothing, fuel, physical and mental health, and financial assistance.

DF6.3 Make temporary repairs to homes, roads and bridges, etc.

DF6.4 Make temporary repairs for temporary renewal of services, such as intermittent power supply.

• Contingency plans developed from International Federation of Red Cross and Red Crescent Societies Disaster Response and Contingency Planning Guide (IFRC 2007).

DF7 Recovery Operations Function: to implement final measures to return a community to normalcy

DF7.1 Perform situation assessment to gain an overview and convert a contingency plan to an operations plan.

DF7.2 Restoration processes: remove rubble and clean up the affected area, reunite family members and bury deceased, fully restore services and reconstruct the physical environment.

DF7.3 Reform processes: renew urban planning and revise building codes.

DF7.4 Reestablish livelihoods, and support the physical and mental rehabilitation of people, their hope and zeal for the future.

• Farmers’ Natural Disaster Insurance Fund Act on payout procedures to compensate farmers in Iceland, and the payout to farmers due to the 2010 Eyjafjallajökull volcanic eruption (FNDIF 2010).

DF8 Systematic Learning Function: to systematically learn from recent events and implement changes

DF8.1 Have guidelines available prior to the next event ready for performing systematic learning, both identifying lessons and implementing them.

DF8.2 Review existing knowledge and methods to develop disaster scenarios (DF1), based on the actual event, evaluate the need for changes and make them.

DF8.3 Review existing knowledge and methods, determine mitigating options and implement them (DF2), based on the actual event, evaluate the need for changes and make them.

DF8.4 Determine the effectiveness and efficiency of the operations (DF4-7) relative to the actual damaging process and consequences and use it to review existing procedures, training, facilities, and equipment, based on the evaluation of the current system (DF3), identify necessary changes in operational procedures and make them.

• IFRC (2014) website includes numerous case studies showing how to learn from disasters.

2.3. Complex disaster-function system

Multiple single feedback-loop systems create a complex disaster-function system. A Causal Loop Diagram is used to depict the complex disaster-function system (Fig.2). The numbers in Fig.2 refer to the eight disaster-functions. The development of the CLD was guided by noting how changes in one disaster-function affect others, using the activities in section 2.2 as a basis of logic. The arrows are positive when an increase in the original disaster-function results in an increase in the influenced disaster-function, and negative when an increase or decrease in the original disaster-function has an opposite effect on the influenced disaster-function. An arrow will be positive or negative depending on the information chosen to describe the relationship. The information used to describe causes and effects among disaster-functions is described in Table 3.
Table 3 Cause and effect within the CLD of Figure 2 and arrow direction

<table>
<thead>
<tr>
<th>Narrative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increasing knowledge of risk processes (1+) improves range of possibilities to mitigate risk (2+). Positive</td>
</tr>
<tr>
<td>2. The more that is mitigated (2+), the lower the risk becomes (1-). Negative</td>
</tr>
<tr>
<td>3. The more that is mitigated (2+), the less need for contingency plans (3-). Negative</td>
</tr>
<tr>
<td>4. Increasing knowledge of risk processes (1+) improves ability to create relevant and objective contingency plans (3+). Positive</td>
</tr>
<tr>
<td>5. The clearer the objectivity of a plan (3+), the clearer the required type of risk information needed (1+). Positive</td>
</tr>
<tr>
<td>6. The better the contingency plans (3+), the less time will be spent on developing operational plans during an event (4-, 5-, 6-, 7-). Negative</td>
</tr>
<tr>
<td>7. The more effective the impact operations (4+), the less lives are threatened and the less need for rescue (5-). Negative</td>
</tr>
<tr>
<td>8. The more effective impact operations (4+), the less need for temporary relief (6-). Negative</td>
</tr>
<tr>
<td>9. The more effective impact operations (4+), the less damage and the less need for recovery (7-). Negative</td>
</tr>
<tr>
<td>10. The more people are rescued (5+), the more need for temporary relief (6+). Positive</td>
</tr>
<tr>
<td>11. The more people are rescued (5+), the greater need for rehabilitation (7+). Positive</td>
</tr>
<tr>
<td>12. The better temporary relief considers recovery aspects (6+), the less new issues arise during the recovery time (7-). Negative</td>
</tr>
<tr>
<td>13. The longer the recovery time (7+), the more attention is needed to temporary relief (6+). Positive</td>
</tr>
<tr>
<td>14. The more operations needed (4+, 5+, 6+, 7+), the greater the need to learn from them and improve (8+). Positive</td>
</tr>
<tr>
<td>15. The better lessons are identified (8+), the better the changes to pre-operation activities will be (1+, 2+, 3+). Positive</td>
</tr>
<tr>
<td>16. The more precise information about past disasters is generated as part of a risk analysis objective (1+), the more likely that forecasting during impact operations will be beneficial (4+). Positive</td>
</tr>
<tr>
<td>17. Knowledge generated during activities to mitigate risk about building codes (2+) reduces the effort required to reach recovery objectives (7-). Negative</td>
</tr>
</tbody>
</table>

Fig. 2. Causal Loop Diagram for a complex disaster-function system of eight disaster functions.

From the CLD in Fig. 2, three main feedback loops are derived:

- Normal Loop (DF1, DF2 and DF3): corresponding to a normally functioning society that lives with the threat of possible damaging processes and disruption
- Disrupted Loop (DF4, DF5, DF6 and DF7): corresponding to on-going damaging processes and a disrupted society
- Improvement Loop (DF8, Normal Loop and Disrupted Loop): corresponding to a recovered society, intending to learn from its disruptive experience and improve on its previous ways of normal functioning.

The Normal Loop represents feedback amongst risk analyzers, mitigators, and operation preparedness planners—the three pre-operations disaster-functions (Fig 3), pertaining to lines 1-5 in Table 3. For example, risk analyzers may identify a flood threat and inform mitigators. However, the mitigators require specific information, so mitigators give feedback to the analyzers if the risk needs to be analyzed in more detail from the mitigation perspective. The same goes for the preparedness planners in that risk analyzers inform planners, who give analyzers feedback to ensure that the risk information...
is relevant to preparedness activities. Once the mitigation efforts are completed, information about the resulting situation is sent to the analyzers to update risk information and to planners to adapt the preparedness plans to the reduced risk level.

The Disrupted Loop represents feedback amongst the four operations functions, pertaining to lines 7 to 13 in Table 3. For example, a flood event may be initiated by a weather forecast, leading to impact operations, such as warnings about increased rain and river flooding, increased monitoring of weather forecasts and river discharge, sandbagging to contain rivers, digging trenches to redirect rivers, and telling people to evacuate. Successful impact operations are key to reduce the need for other operations. Highly effective impact operations eliminate the need for rescue operations. However, if impact operations are not performed or are not successful in avoiding impact on people, then rescue operations may be required. The more that people evacuate or are saved, the greater the need for temporary activities, such as providing shelter. The more successful the impact operations have been, the less recovery effort is needed for uniting families, burials, urban planning, reconstruction and rehabilitation, etc. The relationship between rescue and recovery will depend on the type of the event. For example, a sunken ferry may mean that all the people in the event require rescuing, while in a large earthquake, only a small portion of the affected population may need rescuing. The relationship between relief and recovery is strong, since relief is necessary until recovery is complete.

The Improvement Loop captures the entire CLD and links the two loops mentioned earlier into a single loop (Fig 5). It represents learning within society that takes experience from the Disrupted Loop to improve the Normal Loop. The transformative activities in the Improvement Loop are those of the Systematic Learning Function. It is a balanced loop because the more society is disrupted, the more it needs to change; the more it changes, the better society will function; and the better society functions, the less it will be disrupted. The Improvement Loop will provide a new and improved normal society, which when excited by the environment, will be relatively less disrupted and cope better than before.
Rows 6, 16, and 17 in Table 3 describe arrows that go from one feedback loop to another. All these arrows go from the Normal to the Disrupted Loop. Arrow 6 is from operations preparedness (DF3) to the four operations functions (DF4-7). The basis for row 6 is that the level of operations preparedness influences the success of operations. Row 16 is from risk analysis (DF1) to impact operations (DF4). Row 17 is from mitigation (DF2) to recovery (DF7). The basis for rows 16 and 17 is that projects aimed at risk analysis and mitigation produce significant information usable in impact operations and recovery.

2.4 Connecting, flow and stock variables

Connecting variables are values that travel between the different parts of a system. A connector can be developed either because it is useful in both stocks, or because the second stock cannot create it. An example of the former is a risk analyst who calculates peak ground acceleration and sends the values to mitigators to analyze mitigation options. An example of the latter is an engineer who studies the load bearing capacity of a building to avoid the risk of collapse. The design engineer is not interested in how the building collapses; however, such information may be important for rescue teams for planning purposes, which might not have the education to develop collapse patterns. The direction of information sharing in Table 4 indicates travel patterns for connecting variables.

Flow variables are information produced by one disaster function transferred (flow) to another that creates the need for new projects in the latter. According to SDA, flow variables are information that flows between stocks. Key flow variables derived from the activities described in section 2.3 are listed in Table 4, column 2. The information in Table 4, column 2 corresponds to the arrows in Fig. 2 that point away from the boxes.

Stock variables describe the state of the system by stating the amount of incomplete projects. Projects are created based on activities (section 2.2) and flow variables (Table 4). Based on this assumption all stocks are empty when all objectives have been met. As a stock decreases, the level to which an objective is met increases. As new projects are created, the level to which an objective is met decreases.

Column 3 in Table 4 tracks whether the project is developed within a feedback loop (Normal, Disrupted or Improvement) or moves between loops (BL). Variables flowing between these feedback loops imply a time delay—for instance, making an operations plan now to be used later when a disaster occurs, or compiling information during a response to be used for systematic learning later.
Table 4. Key flow and connecting variables

<table>
<thead>
<tr>
<th>Disaster function</th>
<th>Flow and connecting variables (Row # in Table 3 are in parenthesis)</th>
<th>Loop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Risk analysis</td>
<td>1. Send scenario information to mitigators (1)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>2. Send scenario information to preparedness planners (4)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>3. Send scenario information to impact operators (16)</td>
<td>BL</td>
</tr>
<tr>
<td>2. Risk mitigation</td>
<td>1. Send information on actual reduced risk to risk analyzers (2)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>2. Send updates on reduced risk to preparedness planners (3)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>3. Have information ready to send when recovery operations are activated (17)</td>
<td>BL</td>
</tr>
<tr>
<td>3. Operations</td>
<td>1. Have plans, templates and information ready when impact operations are activated (6)</td>
<td>BL</td>
</tr>
<tr>
<td>preparedness</td>
<td>2. Have plans, templates and information ready when rescue operations are activated (6)</td>
<td>BL</td>
</tr>
<tr>
<td></td>
<td>3. Have plans, templates and information ready when relief operations are activated (6)</td>
<td>BL</td>
</tr>
<tr>
<td></td>
<td>4. Have plans, templates and information ready when recovery operations are activated (6)</td>
<td>BL</td>
</tr>
<tr>
<td>4. Impact</td>
<td>1. Send real-time impact information to rescue operators (7)</td>
<td>D</td>
</tr>
<tr>
<td>Operations</td>
<td>2. Send real-time impact information to relief operators (8)</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>3. Send real-time impact information to recovery operators (9)</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>4. Send information about impact operations to learning staff (14)</td>
<td>BL</td>
</tr>
<tr>
<td>5. Rescue Operations</td>
<td>1. Send real-time rescue information to relief operators (10)</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>2. Send real-time rescue information to recovery operators (11)</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>3. Send information about rescue ops to learning staff (14)</td>
<td>BL</td>
</tr>
<tr>
<td>6. Relief Operations</td>
<td>1. Send real-time relief information to recovery operators (12)</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>2. Send information about relief operations to learning staff (14)</td>
<td>BL</td>
</tr>
<tr>
<td>7. Recovery</td>
<td>1. Send real-time recovery information to relief operators (13)</td>
<td>D</td>
</tr>
<tr>
<td>Operations</td>
<td>2. Send information about recovery operations to learning staff (14)</td>
<td>BL</td>
</tr>
<tr>
<td>8. Systematic</td>
<td>1. Send identified lessons to risk analyzers (15)</td>
<td>I</td>
</tr>
<tr>
<td>learning</td>
<td>2. Send identified lessons to mitigators (15)</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>3. Send identified lessons to preparedness planners (15)</td>
<td>I</td>
</tr>
</tbody>
</table>

FBL: Feedback Loop, N: Normal Loop, D: Disrupted Loop, I: Improvement Loop, BL: between loops

2.5. System excitation

Hazardous (natural or accidental) and damaging processes in the environment (section 2.1), or the threat thereof, activate a DFM system. These processes occur regardless of the existence of a DFM system and are exogenous excitation variables. Two of the disaster functions are directly affected by these variables: Risk Analysis (DF1) and Impact Operations (DF4), (Fig. 6). Risk analyzers monitor hazardous processes to understand and develop risk variables and probabilities, which in turn feed information to Mitigation and Operations Preparedness Functions (i.e., the Normal Loop). Impact operators monitor both hazardous and damaging processes (hazard variables, EX1 and damage variables, EX2) and activate Rescue, Relief and Recovery Operations Functions (i.e., the Disrupted loop).

Fig. 6. Excitation variables pointing to the disaster functions they activate

The Normal Loop can theoretically exist on its own if no disaster ever occurs, but potential activation of the Disrupted Loop makes its sole purpose obvious. The Disrupted Loop can be considered the core loop since its actions can exist as a system without the other two loops, meaning, one can respond without any preparedness and without improving the system for possible future events. The activation of the Disrupted Loop activates the Improvement Loop. The Improvement Loop can only be activated if a disruption has occurred. Therefore, circumstance will dictate which loops are active at any given moment.
3. Results

The following management steps are proposed for safety officers and disaster managers in order to set up and manage a societal safety system:

For the given context:

1. Determine the general problem scenario (section 2.1) and excitation variables (section 2.7).
2. Define relevant objectives to be met, based on context. Either the normal, disrupted or the improvement loop will be the focus for the work to be done (section 2.3), but activities from multiple loops may be relevant.
3. Determine amount of projects to be completed (stock variables) according to the objectives defined in step 2:
   a. Activities to be performed (section 2.2)
   b. Flow variables to be produced (Table 4).
4. Identify actors who can complete the projects in step 3. These actors determine which connecting variables are needed.
5. With the actors and for the given context:
   a. Review and elaborate the projects determined in steps 3.a and 3.b
   b. Design and establish collaboration and coordination mechanisms to ensure the production and sharing of information, based on Table 4, and on connecting variables identified by actors. Take into consideration time delays and overlapping activities indicated by Table 4, column 3.
   c. Add any missing actors identified in this process
6. Evaluate progress towards meeting the relevant objectives by monitoring the completion of the projects.

An application of the above is context driven and an iterative process. Steps 1 to 4 can be performed as a first estimation by safety officers and disaster managers. Steps 5 and 6 include specialized actors, who produce detailed information, such as the examples in Tables 1 and 2, and in Table 9.

4. Practical application: Evaluating an existing system

In cases where a societal safety system exists to any degree, the proposed method can be used to evaluate the system and recommend changes. Evaluating how well an existing system meets disaster-related objectives involves determining which system projects should be produced for the given context, and comparing the expected projects to the actual projects. Missing or incomplete projects are signs of a dysfunctional system. An evaluation of the connecting variables indicates on the level of detail and scientific rigor used within the system. Six steps for evaluating an existing system are:

1. Collect data to build a disaster risk scenario, which the system is being tested against:
   a. Exposure, hazard, damaging processes and complicating factors.
2. Define relevant objectives
3. Determine the projects that should be completed: activities and flow variables.
4. Collect information about the actual projects and compare it with step 3 to determine incomplete or missing projects.
5. Collect information about connecting variables.
6. Analyze and recommend improvements.

An evaluation of a system for a dam in Kárahnjúkar Hydropower Plant in NE Iceland, owned by Landsvirkjun, the National Power Company of Iceland (NPC), is presented below.
4.1 Scenario

The power plant was built in 2003-2007 and has a maximum output of 690 MW. The main reservoir, Hálslón, is approx. 57 km² and has live storage of 2,100 million m³ of water. Dam failure would cause severe flooding downstream, in the farming community of Fljótsdalshérað. Based on a ruling from the Minister for the Environment on 20 December 2001, the NPC was ordered to make a preparedness and response plan for an emergency situation due to a dam failure. The NPC had long since developed a response plan to protect its own exposed property and critical activities (Henje and Sighþórsdóttir 2002), but this ruling was directed at protecting the property of others. The plan was to include:

1. Main plausible emergency circumstances
2. Area, population, and valuable assets at risk
3. Operations to react to such a situation
4. Operations to warn, protect, control, evacuate and take other actions considered necessary to protect life and valuable assets.

A dam failure would affect the NPC, its clients, the environment, the national economy, and the property owners, tourists and farming community downstream of the dam. The test is limited to effects on the farming community.

The river, the dams, the flood zone, and the objects in the flood zone frame the scenario. The details of the scenario are available from the NPC (Landsvirkjun 2009). The river Jökulsá-á-Dal, hereafter termed Jökla-river, is dammed in one place with two saddle dams to create the main storage reservoir Hálslón (Fig. 7). Failure of the smaller saddle dam would affect other areas and is not considered in this scenario. The main dam, Kárahnjúkar Dam, is a 198m high, 700m long earth-dam built across a deep canyon. It has a concreted faced waterside, a gated bottom outlet under the dam, and a spillway. It is one of the highest dams in the world. Desjará Dam, the larger saddle dam, is a 68 m high earth-dam, and has a weak earth-fill flood fuse that will breach if overtopped. Kárahnjúkar Dam and Desjará Dam are not equally vulnerable to ground shaking, relative fault displacement and flood discharge. However, for the sake of simplicity, the information presented is not associated with one dam or the other.

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The river, the dams, the flood zone, and the objects in the flood zone frame the scenario. The details of the scenario are available from the NPC (Landsvirkjun 2009). The river Jökulsá-á-Dal, hereafter termed Jökla-river, is dammed in one place with two saddle dams to create the main storage reservoir Hálslón (Fig. 7). Failure of the smaller saddle dam would affect other areas and is not considered in this scenario. The main dam, Kárahnjúkar Dam, is a 198m high, 700m long earth-dam built across a deep canyon. It has a concreted faced waterside, a gated bottom outlet under the dam, and a spillway. It is one of the highest dams in the world. Desjará Dam, the larger saddle dam, is a 68 m high earth-dam, and has a weak earth-fill flood fuse that will breach if overtopped. Kárahnjúkar Dam and Desjará Dam are not equally vulnerable to ground shaking, relative fault displacement and flood discharge. However, for the sake of simplicity, the information presented is not associated with one dam or the other.

**Fig. 7.** (Based on Fig 1. Sigtryggssdóttir et al., 2013c)

The damaging processes leading to dam failure considered in this test are twofold: river flooding, causing overtopping of the dam, and earthquakes at the dam sites or in the tectonic zone, causing internal erosion. The natural process variables are dictated by the geological conditions (Fig 8). Iceland is a highly volcanic island with over 30 volcanic systems contained within volcanic belts. The volcanic hazard is compounded by the fact that approximately 11% of the country is covered with ice, causing river flooding due to ice melting during volcanic eruptions under icecaps. Jökla-river is fed by a catchment area that is mainly under the NE section of the Vatnajökull-icecap. The dam site is close to the boundary of the Northern Volcanic Belt. Volcanic eruptions under the Vatnajökull-icecap can result in large river flooding (geological term jökulhaup). Iceland is also seismically active. It lies on a tectonic plate boundary, containing two main fracture zones, in North and South Iceland. The plates are moving away from each other at an average rate of 2 cm/yr.
The eruption does not at this point in time affect dam safety and is not expected to since the eruption is atmosphere by The Earthquake Engineer. Holuhraun eruption, commenced north of Vatnajökull
Groundwater, earthquakes, faults and lineaments, crustal movements, leakage (Fig 3., Sigtryggsdóttir et criteria for the dams stayed unchanged, but mitigation processes called for following an environmental impact asses
Fig. 9
The downstream exposed objects are: livestock, equipment, land, and transport infrastructure and buildings associated with farms, summerhouses, abandoned farms used as summerhouses, churches and community halls, 289 residents living on a total of 74 farms, of which 25 are below the expected flood stage. A farming community will have various physical, natural, financial, social and human assets in harm’s way, such as machinery, water and electricity supply systems, fuel storage, pastures, crops, fences, homes, families and workers, to name a few.
Damaging processes causing dam failure are expected to take hours, even days. Floodwater is expected to reach the first farms within 4.7 hours after dam failure. The flood is expected to last 4 days.
Failure of these two dams would affect the same communities downstream.
Two factors complicate the scenario. The first is as follows: During the dam construction in 2004 the topsoil was removed from the dam site. The amount of faulting revealed was more than expected, and new information became available, indicating a possible association of geothermal activity with earthquake risk (Sigtryggsdóttir et al., 2013d). This new information about natural processes called for recalculations of the risk and flood scenario development. As a result, the design criteria for the dams stayed unchanged, but mitigation of relative fault displacements under the dams was added (Landsvirkjun 2006). Mitigation efforts could not rule out the possibility of dam failure. Groundwater, earthquakes, faults and lineaments, crustal movements, leakage (Fig 3., Sigtryggsdóttir et al., 2013a), and dam settlement behavior (Sigtryggsdóttir et al., 2013b) are monitored.
The second complicating factor is that during the study an effusive volcanic eruption, the Holuhraun eruption, commenced north of Vatnajökull Glacier, 80 km west of the reservoir (see Fig. 10). This led to increased impact operations to increase assessments of seismic activity, for example, by The Earthquake Engineering Research Center of the University of Iceland. Their monitoring system shows a detectable but miniscule increase of ground motion at the dam site (Olafsson 2014). The current eruption creates a need for health risk analysis due to increased sulfur dioxide in the atmosphere. This calls for information available from risk studies on health hazards of sulfur dioxide.
The eruption does not at this point in time affect dam safety and is not expected to since the eruption is not within the catchment that feeds Jökla-river, but areas close to the eruption have been closed off to protect the public. Fig. 9 shows the location of the Askja Volcano, one of the largest calderas in Iceland (Gudmundsson et al. 2008 Fig. 3, Thorvaldsdóttir and Sigbjörnsson 2015 Fig. 6).
4.2 Relevant objectives

The given scenario calls for the following objectives to be met:

- DF1 Disaster risk analysis.
- DF2 Disaster risk mitigation.
- DF4.1 Monitor natural processes and damaging processes, diagnose current situation and forecast the possible sequence of events and turn the existing impact contingency plan into an operations plan.
- DF4.2 Close off areas.
- DF8.1 Have available guidelines for performing systematic learning, both identifying lessons and implementing them prior to the event.

All three feedback loops are included in this system test, due to the fact that there was a small eruption going on at the time of the analysis.

4.3 Expected projects

The expected projects to be completed for the relevant objectives in section 4.2 are listed in Table 5. They are identified as an activity (DF), flow variable (FLV), or connecting variable (CCV).

Table 5. Relevant projects due to situation at Kárahnjúkar Plant December 2014

<table>
<thead>
<tr>
<th>Activities (numbering based on section 2.2)</th>
<th>Flow (FLV) and connecting (CCV) variables created in one disaster function and create projects in others</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF1.1, DF1.2, DF1.3, and DF1.4</td>
<td>FLV1.1 Send risk information to mitigators</td>
</tr>
<tr>
<td></td>
<td>FLV1.2 Send risk information to preparedness planners</td>
</tr>
<tr>
<td></td>
<td>FLV1.3 Have risk information ready for impact operators</td>
</tr>
<tr>
<td>DF2.1, DF2.2, DF2.3, and DF2.4</td>
<td>FLV2.1 Send risk analyzers information on actual reduced risk</td>
</tr>
<tr>
<td></td>
<td>FLV2.2 Send preparedness planners updates on reduced risk</td>
</tr>
<tr>
<td></td>
<td>FLV2.3 Have information ready for when recovery operations are activated</td>
</tr>
<tr>
<td>DF3.1, DF3.2, DF3.3, and DF3.4</td>
<td>FLV3.1 Have plans, templates and information ready when impact operations are activated</td>
</tr>
<tr>
<td></td>
<td>FLV3.2 Have plans, templates and information ready when rescue operations are activated</td>
</tr>
<tr>
<td></td>
<td>FLV3.3 Have plans, templates and information ready when relief operations are activated</td>
</tr>
<tr>
<td></td>
<td>FLV3.4 Have plans, templates and information ready when recovery operations are activated</td>
</tr>
<tr>
<td></td>
<td>CCV3.1 Send feedback on the relevancy of the risk info to risk analyzers</td>
</tr>
<tr>
<td>DF4.1, and DF4.2</td>
<td>None</td>
</tr>
<tr>
<td>DF8.1</td>
<td>None</td>
</tr>
</tbody>
</table>

4.4 Actual project status

Table 6 portrays the state of the projects listed in Table 5, column 1. The discussion in the table is based on previously mentioned references from Landsvirkjun and Sigtryggsdóttir et al., and references mentioned in Tables 6, 7 and 8 portray the state of projects listed in Table 5, column 2 for dams and for
farmlands, respectively. The last column of these tables shows which feedback loops are associated with each project.

**Table 6. Project status for activities listed in Table 5, column 1**

<table>
<thead>
<tr>
<th>Completed components</th>
<th>Incomplete or missing components</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF1.1. Information has been produced to understand the natural processes that could lead to dam failure due to internal erosion during an earthquake or overtopping during a flood. DF1.2. The dam characteristics are well understood. DF1.3. Information is available about the movement of earthquake-induced cracks that need restricting. DF1.4. The flood size that will cause dam overtopping and the size of the flood and estimated flooded area downstream have been calculated. Detailed information is provided about the flood path, peak and travel time (in a cross section window) to every building downstream. Information about roads, power lines and water sources is available. A short reference is made to damages to fields and the possibility of farm abandonment.</td>
<td></td>
</tr>
<tr>
<td>DF2.1. Options for mitigating risk of dam failure due to crack movement. DF2.2. Analysis of options for dam failure. DF2.3. Comparison of options for dam failure. DF2.4. Measures have been taken to reduce the risk of damages from relative fault displacement under the dams, such as clearing the site of the dam down to bedrock and filling cracks with concrete paste or with reinforced concrete bolted to the bedrock. Expansion joints with elastic water-stops have also been placed in the concrete to avoid damaging movement.</td>
<td></td>
</tr>
</tbody>
</table>
| DF3.1-DF3.4: The NPC has produced standard operating procedures for impact operations for dam failure:  
  - Plan activation and reconnaissance  
  - Duty officer monitors devices and activates action plan  
  - Reconnaissance officer called out to assess situation  
  - Assess situation, decide response level and take action accordingly.  
  - Notifications  
  - Notify and evacuate staff.  
  - Notify civil protection for evacuation of population downstream.  
  - Information sharing  
  - Provide updates on actual flood and flood peak behavior.  
  - Provide prognosis.  
| DF3.1-DF3.4: From the farmers’ perspective, very limited operations preparedness activities have been performed in Iceland (Thorvaldsdóttir and Sighjörnsson, 2015). DF3.4: An exercise should take place every 5 years. No exercise or training of personnel has taken place since 2009. The evacuation/rescue/mass care plan should be updated every three years. It has not been updated since completion in 2009 (Bjartmarz 2015). |
| DF3.1-DF3.4: The National Police Commissioner has produced an evacuation plan that includes the emergency services (i.e., police, fire, medical, rescue, volunteers) and other services (National Police Commissioner 2009). The plan is based on the disaster scenario from NPC, which includes resources to provide rescue operations and initial assistance to those who are displaced. |
| DF4.1. The NPC monitors the following on a daily basis for the dam area and the nearby volcanic systems (Askja, Kverkfjöll, Snæfell and Vatnajökull):  
  - GPS, microseismic and accelerometric networks  
  - Dam-related parameters are:  
  - Subsidence and displacement of earth fill  
  - Pressure in the concrete coating  
  - Displacements in concrete construction joints  
  - Displacements between concrete coating and dam footing  
  - Changes in distance from bedrock to dam surface  
  - Ground water level and ground water pressure  
  - Seepage through and under the dam  
  - Displacement of faults and cracks in the bedrock below the dams  
  - Dam response to earthquake loading  
| In case of a flood, NPC plans to open the bottom outlet, place the plant into full operation and dispatch work crews. The Holuhraun eruption has increased monitoring and assessment efforts. NPC has tasked various engineering and academic institutions to calculate increased risk due to the current Holuhraun eruption. |

No missing impact activities have been identified in this study.
Table 7. State of flow variables listed in Table 5, column 2, for the dams

<table>
<thead>
<tr>
<th>DF#</th>
<th>Flow variables</th>
<th>FBL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1. Yes, information about the risk was sent to mitigators (designers)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>2. Yes, information about the risk scenario was sent to the preparedness planners (Civil Defense)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>3. Yes, calculations from the original risk analysis are available to be used during an actual flood</td>
<td>N&amp;D</td>
</tr>
<tr>
<td>2</td>
<td>1. Yes, mitigation has taken place, current risk is known</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>2. Yes, planning took place after final mitigation, so updating of plans after mitigation is irrelevant.</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>3. Yes, mitigation measures that took place are available to be used during recovery</td>
<td>N&amp;D</td>
</tr>
<tr>
<td>3</td>
<td>1. Yes, impact operations have been prepared; procedures are ready for activation</td>
<td>N&amp;D</td>
</tr>
<tr>
<td></td>
<td>2. Rescue operations for dam are beyond the scope of this example</td>
<td>N&amp;D</td>
</tr>
<tr>
<td></td>
<td>3. Relief operations for dam are beyond the scope of this example</td>
<td>N&amp;D</td>
</tr>
<tr>
<td></td>
<td>4. Recovery operations for dam are beyond the scope of this example</td>
<td>N&amp;D</td>
</tr>
<tr>
<td></td>
<td>5. Yes, feedback was given on the relevancy of the scenario during the development of impact plans*</td>
<td>N</td>
</tr>
</tbody>
</table>

* Originally this variable was defined as a flow variable, but changed to a connecting variable when making a Stock and Flow Diagram.

Table 8. State of flow variables listed in Table 5, column 2, for the farmlands

<table>
<thead>
<tr>
<th>DF#</th>
<th>Flow variables</th>
<th>FBL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1. No scenario information has been sent to or requested from people who could analyze it for downstream mitigation, for example, the mayor or the local or national farming association.</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>2. No scenario information has been sent to or requested from people who could write a recovery plan, for example, the mayor, or the local or national farming association, or Ministry of Agriculture</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>3. No information is available about scenario from a farming livelihood perspective, and impact operators have not been identified.</td>
<td>N&amp;D</td>
</tr>
<tr>
<td>2</td>
<td>1. Since no mitigation has taken place, updating risk information after mitigation is irrelevant.</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>2. Since no mitigation has taken place, updating plans after mitigation is irrelevant.</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>3. Since no mitigation has taken place, no special information is available for recovery operations</td>
<td>N&amp;D</td>
</tr>
<tr>
<td>3</td>
<td>1. No plans for impact operations exist for intervening in damaging processes downstream. Unclear about animal evacuation.</td>
<td>N&amp;D</td>
</tr>
<tr>
<td></td>
<td>2. Yes, rescue operations plans are ready, but not practiced or updated. Unclear about animal rescue</td>
<td>N&amp;D</td>
</tr>
<tr>
<td></td>
<td>3. Partial relief operations plans are ready, but not practiced or updated. Unclear about animal relief</td>
<td>N&amp;D</td>
</tr>
<tr>
<td></td>
<td>4. No plans for recovery operations have been prepared.</td>
<td>N&amp;D</td>
</tr>
<tr>
<td></td>
<td>5. No farming stakeholders have given NPC feedback.</td>
<td>N</td>
</tr>
</tbody>
</table>

Table 9. Connecting variables for the dam

<table>
<thead>
<tr>
<th>Direction</th>
<th>Information produced in one DF sent to another DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF1 to DF2</td>
<td>Expected peak ground acceleration at dam sites was calculated</td>
</tr>
<tr>
<td></td>
<td>• Deterministic value: 30% g</td>
</tr>
<tr>
<td></td>
<td>• Probabilistic seismic hazard analysis: 10,000-year return period; upper value acceleration 10% g</td>
</tr>
<tr>
<td></td>
<td>• Earthquakes with epicenters on the faults near the dam sites, (used 5.5-6 M and 26% g)</td>
</tr>
<tr>
<td></td>
<td>• Near field effects 4-5 M, and 40-50% g</td>
</tr>
<tr>
<td></td>
<td>Faults at dam sites</td>
</tr>
<tr>
<td></td>
<td>• Exact location of faults mapped</td>
</tr>
<tr>
<td></td>
<td>• Maximum displacement of faults under dams estimated at 10 cm.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DF2 to DF1</th>
<th>Design peak ground acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• The dams were designed against numerous time series with PGA between 26% - 50%g, well beyond code requirements (code value is less than 10% g for 500-year return period)</td>
</tr>
<tr>
<td></td>
<td>Fault displacement design</td>
</tr>
<tr>
<td></td>
<td>• Mitigation procedures allow for 10 cm displacement under the dams</td>
</tr>
<tr>
<td></td>
<td>• Less than 10 cm displacement causes repairable damages and is not a threat to the dam</td>
</tr>
<tr>
<td></td>
<td>Design flood values with and without damages, and flood fuse capacity</td>
</tr>
<tr>
<td></td>
<td>• Design flood: 1000-year return period, 1400 m³/s flowing into the reservoir. No damages expected</td>
</tr>
<tr>
<td></td>
<td>• Probable Maximum Flood (PMF): 4000 m³/s due to rain and snowmelt. Damages expected. Spillway will be active</td>
</tr>
<tr>
<td></td>
<td>• Flood fuse: A 100m long flood fuse is built into the east end of Desjard Dam. In a larger flood, e.g., due to a...</td>
</tr>
</tbody>
</table>
subglacial eruption, a flood fuse will breach due to overtopping. The flood fuse avoids overtopping of other
dams for up to 6000 m³/s flow into Hálslón Reservoir and thus controls dam failure processes.

<table>
<thead>
<tr>
<th>DF1 to DF3</th>
<th>Planning scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EQ1 earthquake loading creates changes in dam shape, causing overtopping or damage to the concrete coat so that seepage becomes uncontrollable</td>
</tr>
<tr>
<td></td>
<td>EQ2 movement on faults and cracks under dam that damage it</td>
</tr>
<tr>
<td></td>
<td>EQ3 movement on faults and cracks under dam causing internal damage, liquefaction in crack-fills or in sedimentary layers</td>
</tr>
<tr>
<td></td>
<td>EQ4 earthquakes causing cracks in dam, earth fills or concrete coat</td>
</tr>
<tr>
<td></td>
<td>F1 Catastrophic flooding leading to overtopping or breaching, causing damage failure</td>
</tr>
<tr>
<td></td>
<td>F2 Catastrophic flooding causing seepage and removal of material from dam foundation that is impossible to control</td>
</tr>
</tbody>
</table>

Flood behavior if fuse is breached: After breaching has started, it is expected to take one hour to fully breach the fuse. The flood path and speed are clearly outlined, based on amount of water and topography. Estimated maximum discharge is 14,000 m³/s. Peak flood expected to travel from fuse to sea in 8 hours.

Flood behavior if internal dam breaching: After internal breaching has started, the estimated time to breach the dam is 3 hours. Maximum expected discharge is 110,000 m³/s. Peak discharge is expected to reach the sea in 4.5 hours.

Table 6 shows that projects related to dam failure are complete, but some of the projects for farmland are incomplete or missing. Table 7 shows that flow variables for the dam are complete, whereas Table 8 shows that most of the flow variables for the farmlands are incomplete or missing. The tables indicate that the Normal Loop is functioning with respect to the dam, but dysfunctional with respect to the farming community. Table 9 shows the possibilities available to produce a detailed risk analysis for the farmlands, if a detailed farmland exposure analysis were performed.

Recommendations for system excitation variables, projects and feedback loops are as follows:
1. The system excitation variables, i.e., seismic and volcanic activity, and dam response (Table 6, row 4), are closely monitored for continuous updating on the risk and system activation.
   **Recommendations:** None
2. Projects relating to dam failure, mitigation of dam failure to the extent possible, and regarding impact operations for the Holuhraun eruption are complete (Table 6, column 1). The level of detail of the connecting variables (Table 9) gives confidence in the quality of work. From the perspective of the dam, the only missing project is a set of guidelines on how to perform systematic learning.
   **Recommendation:** Prepare guidelines on how to learn from the past, in case a critical event does happen, to ensure that systematic learning does take place within the company.
3. A risk analysis for the farmland in the downstream area is incomplete, and mitigation efforts are not considered. Operational preparedness activities relate only to emergency services, i.e., warning, evacuation (impact operations), rescue operations and relief in the form of mass care for people (Table 6, column 2). The planning scenario information (Table 9, last row) allows for a detailed disaster scenario for the farmlands, and consequential mitigation and operational planning from a farming perspective.
   **Recommendation:** Establish projects to deal with objectives #1, 2, and 3 from the perspective of framers and other stakeholders in the downstream area.
4. The only feedback loop that could have been active in December 2014 was the Normal Loop, since no damages had occurred to activate the Disrupted or Learning Loops. Missing information in relation to the Normal Loop (Table 7) indicates that the loop is dysfunctional from a farming perspective. A dysfunctional loop from any perspective indicates that the system itself is dysfunctional.
   **Recommendation:** Establish a functioning Normal Loop, specifically including the farming perspective.

Safety officers and disaster managers can perform evaluation tests, such as above, to determine the need to improve existing collaboration and coordination mechanisms. The result of the above test is that the current system is dysfunctional, as it does not meet all the relevant objectives calling for effort

4.5 Analysis and recommendations

Table 6 shows that projects related to dam failure are complete, but some of the projects for farmland are incomplete or missing. Table 7 shows that flow variables for the dam are complete, whereas Table 8 shows that most of the flow variables for the farmlands are incomplete or missing. The tables indicate that the Normal Loop is functioning with respect to the dam, but dysfunctional with respect to the farming community. Table 9 shows the possibilities available to produce a detailed risk analysis for the farmlands, if a detailed farmland exposure analysis were performed.

Recommendations for system excitation variables, projects and feedback loops are as follows:
1. The system excitation variables, i.e., seismic and volcanic activity, and dam response (Table 6, row 4), are closely monitored for continuous updating on the risk and system activation.
   **Recommendations:** None
2. Projects relating to dam failure, mitigation of dam failure to the extent possible, and regarding impact operations for the Holuhraun eruption are complete (Table 6, column 1). The level of detail of the connecting variables (Table 9) gives confidence in the quality of work. From the perspective of the dam, the only missing project is a set of guidelines on how to perform systematic learning.
   **Recommendation:** Prepare guidelines on how to learn from the past, in case a critical event does happen, to ensure that systematic learning does take place within the company.
3. A risk analysis for the farmland in the downstream area is incomplete, and mitigation efforts are not considered. Operational preparedness activities relate only to emergency services, i.e., warning, evacuation (impact operations), rescue operations and relief in the form of mass care for people (Table 6, column 2). The planning scenario information (Table 9, last row) allows for a detailed disaster scenario for the farmlands, and consequential mitigation and operational planning from a farming perspective.
   **Recommendation:** Establish projects to deal with objectives #1, 2, and 3 from the perspective of framers and other stakeholders in the downstream area.
4. The only feedback loop that could have been active in December 2014 was the Normal Loop, since no damages had occurred to activate the Disrupted or Learning Loops. Missing information in relation to the Normal Loop (Table 7) indicates that the loop is dysfunctional from a farming perspective. A dysfunctional loop from any perspective indicates that the system itself is dysfunctional.
   **Recommendation:** Establish a functioning Normal Loop, specifically including the farming perspective.

Safety officers and disaster managers can perform evaluation tests, such as above, to determine the need to improve existing collaboration and coordination mechanisms. The result of the above test is that the current system is dysfunctional, as it does not meet all the relevant objectives calling for effort
towards all six steps in Section 3. Steps to create a functional system using a system dynamics approach require a Stock and Flow Diagram. A Stock and Flow Diagram for a social safety system is presented in two parts in Figs.10 and 11. Fig.10 shows the Normal Loop. Fig.11 shows the links of the Normal Loop to the other two relevant to the situation at Kárahnjúkar Power Plant in December 2014. The diagram is based on the activities and variables in Table 5 and created using Vensim® PL software. Incomplete projects are used as stocks, as prescribed in the theoretical discussion herein. Additional stocks are included to ensure that flow variables are between stocks. Acceptable loss is used to create negative (balanced) feedback loop between Risk Analysis and Mitigation, the goal being that exposed losses are continually reduced till the losses are at least the same as acceptable losses. State of current operations system is used as a bench mark for operations preparedness projects, however, does not provide a goal for a negative feedback loop. The Impact Operations is an open loop since the operations were still on-going in December 2014, and so is System Learning since the learning process has not started.

Fig.10 A Normal Feedback Loop presented in a Stock and Flow Diagram.
The links between the Normal Feedback loop to active parts of the Disrupted and Changing Loops relevant for a social safety system in December 2104 at Kárahnjúkar Power Plant, presented in a Stock and Flow Diagram

5. Discussion

The results of the practical application show that the actual societal safety system for a dam failure at Kárahnjúkar Power plant has well defined excitation variables, detailed projects associated with dam failure, projects related to emergency services, although never practiced or updated. However, projects for the downstream farmland area are incomplete or missing. The main system weakness lies in recommendation 4, i.e., in the dysfunctional Normal Loop. Dysfunctionality can be attributed to, for example, lack of system management or lack of stakeholder involvement. This leads to the question, who are the stakeholders that should be involved? Stakeholders can be grouped as follows (Checkland and Poulter 2010):

- Customers or beneficiaries benefitting from the system
- Actors working within the system
- Owners of the system

In the case of dam failure at the Kárahnjúkar Power Plant, the relevant stakeholders include:

1. Customers or beneficiaries: the communities suffering widespread human, material, economic and environmental losses and impacts, to the extent that they exceed the communities’ ability to cope by using their own resources. Here, this means the farmers living downstream, tourists in the area and property owners of roads, power lines, etc.
2. Actors: a. the NPC, which seeks to maintain safety by careful dam design, monitoring of natural and damaging processes, warning, damage control, impact procedures, such as notifying
emergency services of pending or actual damages and flood behavior; b. the Earth Science Group
of NPC, established to monitor and evaluate geohazards. The group comprises NPC project staff,
designers, contractors, earthquake engineers, structural engineers, geophysicists, and geologists; c.
the local mayor whose community has become seriously disrupted; d. local chief of police,
responsible for civil protection in the locale; e. the National Police Commissioner, responsible for
civil defense at the national level, both of which fall under the Ministry of Interior; and f. actors
dealing with farming livelihoods, such as agricultural associations, farming insurance funds, food
and veterinarian authorities; g. the Ministry of Agriculture is also a relevant actor due to the impact
on farming communities.
3. Owners: a. it is logical to assume that the Minister for the Environment is one of the owners as that
ministry ruled in the decree of 20 Dec. 2001, calling for plans to be written; b. the Ministry of the
Interior is legally responsible for civil protection; c. the Ministry of Agriculture is assumed to be
an owner of a system that pertains to agricultural agencies and farmers; d. the NPC that owns the
power plant.
The above discussion identifies a wide range of stakeholders, from the top ministerial level to ground
level activities. This is similar to the concept of accident safety control structures (Leveson 2015, Figs
1, 2, and 6). Three ministries are stakeholders. This raises questions on whether poor coordination at
the ministerial level can be attributed to gaps and overlaps of ministerial mandates and led to the
dysfunctional Normal Loop. The next logical step in further understanding the weakness of the
Icelandic system would therefore be a stakeholder analysis at the ministerial level in order to clarify the
system owners and their contributions to system projects.

6. Conclusion
This paper presents a theoretical foundation for societal safety system based on system dynamics and
Disaster-Function Management. It describes an approach to identify projects and guide the
coordination of multiple actors toward a set of safety objectives. The method is partly prescriptive with
six management steps, but the steps are iterative in nature and provide an avenue for safety officers and
disaster managers, along with the other actors involved, to develop management techniques that best
suit the problems at hand. The method can also be used for other sets of objectives. However, then the
Causal Loop Diagram needs to be redrawn based on the logical relationship of the objectives, and
variables re-established.
An example application used the steps to judge whether an existing system sufficiently meets
the disaster-related objectives, or whether a more robust system is needed. The application was
preformed by the authors and based on collected data; a full analysis of the system requires actor
participation. Future steps to developing well functioning systems include developing Stock and Flow
Diagrams and modeling a complete DFM system. Building such work on existing Loss Estimation
models is a logical approach. Further development of the method is needed to ensure the incorporation
of different stakeholder-type perspectives, such as those of system owners, actors and customers, into
the proposed method.

Acknowledgements
The contribution of Dr. Óli Grétar Sveinsson Director, Executive Vice President of Landsvirkjun
National Power Company, is greatly appreciated. Puja Acharya is thanked for her assistance in
generating figures. The authors gratefully acknowledge the research grant from the University of
Iceland Eimskip Fund.
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