between subsystems.

In the event of a disruption occurring in some CI, the interdependencies among CIs pave the way for secondary disruptions in other CIs, called cascading effects (Franchina, Carbonelli, Gratta, Crisci and Perucchini, 2011) or cascading failures (Katina and Keating, 2015). The literature has identified several types of interdependencies (see ref. Ouyang, 2014, Table 1 and examples E1-E10, on p45-46)

Owing to the extreme complexity of the CI system, many different approaches, targeting different purposes, exist for analyzing cascading effects. No single approach does full justice to the problem's complexity. To the best of our knowledge, the most recent extensive review of modeling and simulation of interdependent CIs was performed by Ouyang (2014). A useful model is designed for a purpose, viz. answering specific questions, hence the model simplifies the description of reality to preserve what is relevant for the model's purpose, excluding what is irrelevant. Ouyang's review covers six modeling categories for different purposes, viz. empirical approaches, agent-based approaches, system dynamics-based approaches, economic theory-based approaches, network-based approaches, and miscellaneous modeling approaches.

One modeling category is not included among Ouyang's review, viz., desktop-based expert assessment of CI interdependencies and cascading failures, most certainly because peer-reviewed publications of such activities are missing. A desktop exercise (a.k.a. tabletop exercise) is conducted with participants sitting around a table, addressing a fictional scenario. Desktop exercises concerning risk assessment in CIs are also model-based, since they are synthesis of the mental models of practitioners representing each of the CIs as well as the mental models of people with cross-cutting expertise on CIs. The distance from the synthesized mental model for risk assessment to conducting a simulation (i.e., figuring out the consequences of the model) is short. It is in principle possible to extend the modeling exercise to figure out the consequences. Another, more powerful option, is the one we follow in this paper: using the expert estimates in a system dynamics simulation model.

Desktop-based expert assessment of CI interdependencies and cascading failures are typically performed by organizations having homeland security as mission. Hence, such assessments are important. But then, the research question arises: To what extent can expert practitioner assessments account for the aggregate impact of the cascading failures upon a disruption affecting a critical infrastructure? Indeed, since CIs are interdependent, a disruption affecting a given CI will propagate along multiple feedback loops, causing primary, secondary, tertiary, etc. cascading failures (kind of "ripple effect"). Is this ripple effects moderate, in the sense that it gets quickly damped and the contribution of the primary cascading failures dominate? Or can the aggregate contribution of higher order cascading failures make the ripple effect quite considerable, especially if the duration (or the intensity) of the original disruption is large?

To address the research question, we provide the necessary background information in section "Details of the assessment in the Norwegian desktop exercise"; in section "Expert assessment of cascading failures" we review recent work (Laugé, 2014, Laugé, Hernantes and Sarriegi, 2015) that will allow us develop a quantitative simulation model to answer the research question; in section "System Dynamics model" we explain the key equations of the simulation model and the validation process (the full description of the model is given in the appendix). In section "Assessment of the reliability of expert estimates" we present the simulation results; they provide evidence that expert estimates of cascading failures become less accurate when the length of the disruption triggering the cascading failures increases. In the final section, we provide an interpretation of our findings; in addition, we discuss the robustness of our findings, given the limitations of our study.

DETAILS OF THE ASSESSMENT IN THE NORWEGIAN DESKTOP EXERCISE

In this section, we review the findings of the expert assessment of cascading failures in a risk analysis of a cyber-attack on the Norwegian telecommunication CI sector (DSB, 2015). The corresponding desktop exercise was coordinated by the Norwegian Directorate of Civil Protection (abbreviated DSB, from the initials in the Norwegian name). The risk analysis of a cyber-attack was part of the "National Risk Analysis 2014", considering disasters that may affect the Norwegian society.

Two one-day seminars were conducted. Seminar 1, done in Oslo 12th June 2014, assembled 30 expert participants representing the following CI sectors: energy supply; transportation systems; emergency/security services; water supply; financial sector; health sector; and telecommunication sector. The scenario of seminar 1 was a cyber-attack causing complete disruption lasting 5 days of the ICT CI's transport network in Norway. The leading question posed at seminar 1 was: How will the critical functions in *your own CI sector* be affected by the disruption in the telecommunication sector.

The experts representing a given CI were asked to describe how the disruption in the telecommunication critical infrastructure would impact the performance of their own CI. The detailed answers were afterward mapped to a qualitative scale of values [small, medium, large] for the impact. Thus, the desktop exercise elicited expert

Type	**Variable Name and Description**
	• CI Breakdown ICT • Effect of CIj Failure on CIi • Effect of CIj Failure on CIi ICT