Devising Mitigation Strategies With Stakeholders Against Systemic Risks in a Pandemic

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ABSTRACT

Understanding and managing systemic risk has huge importance for disaster risk reduction in our globally connected world.

The COVID-19 pandemic is a prominent case for the global impact of systemic risk. Did so the added urgency of the pandemic systemic risk trigger such paradigm shift?

The use of qualitative modelling of systemic risk has progressed the field, particularly when policy makers need support urgently and want to utilize a range of interdisciplinary expertise. We have extended to disaster risk reduction a method for causal mapping for problem solving and strategy development targeting complex project management. Our approach delivers useful, useable, and used mitigation to systemic risk in a pandemic using participatory modelling with practitioners, domain experts and power-brokers.

Keywords

Systemic risk, Cascading effects, Participatory modelling, Strategy mapping, Vicious cycles, Risk system analysis, Risk mitigation.

INTRODUCTION

There is increasing awareness that understanding and managing systemic risk has tremendous importance for disaster risk reduction in our immensely globally connected world (Goldin, 2014; Ibrahim et al., 2021; Renn et al., 2019; Schweizer, 2021).

The COVID-19 pandemic is a paradigmatic case for the global impact of systemic risk (Abuzayed et al., 2021; Kim et al., 2022; Rizwan et al., 2020; UNDRR & UNU-EHS, 2022). The pandemic impacted the health sector, directly by COVID-19 infections and deaths, and indirectly by disruption of the healthcare system. In addition, COVID-19 stroked forcefully on most societal sectors, such as business, culture, economy, education, employment, energy, entertainment, finance, transport, trade, working patterns, and even on international relations.

An interesting question arises: did the COVID-19 pandemic trigger a significant step forward for assessing and managing systemic risks? A comparison between two authoritative reports on systemic risk by the United Nations Office of Disaster Risk Reduction (UNDDR) provides clues.

The Global Assessment Report on Disaster Risk Reduction 2019, GAR2019, reviewed extensively the state of the art of the science of systemic risk before COVID-19 created havoc (UNDRR, 2019). GAR2019 did also alert extensively about the imminent risk of major pandemics (op. cit., p. 106-112).

The crucial impact of systemic risk on key agendas for mankind was clearly stated in GAR2019: "The systemic risks … are embedded in the complex networks of an increasingly interconnected world. The behavior of these networks defines quality of life and will shape the dynamic interactions among the Sendai Framework, the 2030 Agenda, the Paris Agreement, New Urban Agenda and the Agenda for Humanity. Ultimately, the behavior of these networks determines exposure and vulnerability at all scales." (ibid, p32).

As perceived in 2019, the challenges ahead were huge and a paradigm shift was urgently needed: "Assessment and management methodologies for systemic risks that have been conceived are still in early gestation, and are not yet part of the current operations of twenty-first century risk management institutions. Nonetheless, there is a growing sense of urgency for a paradigm shift…" (ibid, p44).

Three years later, after COVID-19 had started receding, the Global Assessment Report on Disaster Risk Reduction 2022, GAR2022, reviewed extensively again the state of the art of systemic risk (UNDRR, 2022). GAR2022 discussed systemic risk in many settings, including COVID-19.

As to the utility of pandemic models, GAR2022 states: "Lessons learned from the COVID-19 pandemic show that the success rates of models were uneven in predicting the spread of the disease within and among countries. Decision makers went from an over-reliance on models to extreme skepticism about their utility." (op. cit., p204).

The conclusion in GAR2022 concerning assessment and management of systemic risk is the same as in GAR2019: "The science of systemic risk and systemic risk management is still in a primordial state." (ibid, p146).

Hence, mainstream research, which is based on quantitative modelling of systemic risk, has not progressed significantly since the publication of GAR2019 in terms of achieving useful, useable, and used results (i.e., impactful and practical model-based mitigating strategies toward systemic risk).

This contribution sounds a cautious optimistic note regarding the state of the art of systemic risk assessment and management:

1. The methodology for causal mapping for complex problem solving and strategy development, including systemic risks in complex projects, originating in the 1980-1990'ies (Eden, 1989, 1993; Eden et al., 1983; Williams et al., 1997), has been extended by the Systemic Pandemic Risk Management (SPRM) project to assess and manage systemic risks in pandemics. The methods and results of the SPRM project, including its usage in practice by SPRM stakeholders, have been reported in several publications (Gonzalez et al., 2021; Gonzalez & Eden, 2022).
2. Practitioner stakeholders from the SPRM project have adopted the project's method for assessment and management of systemic risks to an emergent pandemic situation (the Omicron wave) and, later, even to other threats and crises involving systemic risk. (Cf. Abildsnes et al., 2023, a practitioner paper in this conference.)
3. The IBM Center for the Business of Government has released a report on strategy mapping where the use of the SPRM project methods by municipalities and hospitals in Norway is showcased (Bryson et al., 2023, p24-30).

The causal mapping methodology for complex problem solving and strategy development is known as "strategy mapping". The mapping of causes and effects is qualitative, but since the causal models are directed graphs (Harary et al., 1965), powerful analysis tools can be applied to identify and rank goals, actions and strategies (Ackermann & Eden, 2011, p12).

Systemic risk has played an important role in the discipline of management of complex projects since the 1990'ies. Systemic risk is clearly implied in the quote "a risk event in one area/category may cause, or contribute to the likelihood of a risk event somewhere else; e.g., a supplier going out of business having an impact on a particular aspect of the engineering arena, or a change in government affecting funding allocations. Thus, risks can be seen as a network of interrelated possible events, which may be referred to as 'risk systemicity'." (Ackermann et al., 2007, p2). Strategy mapping to debrief project failures, or to assess and manage systemic risk in complex projects, has successfully engaged practitioners, domain experts and power-brokers/decision-makers (see e.g., Ackermann et al., 2007; Ackermann et al., 2014; Williams et al., 1997).

Why has the potential of the strategy mapping method for disaster risk reduction been overlooked by mainstream risk scholars?

This contribution tries to answer this important question while attempting to bridge and create synergy across different schools of thought. This may help making systemic risk assessment and management a key part of the current operations of 21st century risk management institutions (as forcefully requested in UNDRR, 2019, p44).

This paper is organized as follows:

Section THE SPRM PROJECT summarizes the method and the results of the Systemic Pandemic Risk Management project. The overview establishes the platform on which the remainder of this contribution rests.

In section ADEQUACY OF MODELLING PURPOSE we contend that to achieve useful, useable and used mitigations strategies to complex and urgent risk situations beyond its use in pandemics, the modelling process must be fast and it must involve power-brokers from scratch, in addition to practitioners and domain experts. This requirement means that the analysis of the risk system will need to be transparent and feel relevant to stakeholders.

Section REVIEW OF SYSTEMIC RISK DEFINITIONS calls attention to the many different definitions of the term 'systemic risk' in the literature, implicitly suggesting different perspectives for modelling and, thus, bias the attention toward specific modelling methods. We argue that the reason why strategy mapping of systemic risks has been overlooked in the mainstream disaster risk community is the way systemic risk has been defined by mainstream disaster scientists. We show that the different definitions do, however, share the awareness that the outcomes of risks are risks themselves. Hence, we support the concise definition of systemic risk based on the commonality that the outcomes of risks are risks themselves (see Ackermann et al., 2007, p2).

In section HOW CAN SYSTEMIC RISKS BE IDENTIFIED? we argue that that the key issue making risk systemic is dynamic complexity. Dynamic complexity arises because the causal interdependencies among risks create feedback. Most systems of interest for disaster risk reduction are tightly coupled and therefore have huge dynamic complexity, which makes them extremely difficult to manage.

In CONCLUDING REMARKS, we summarize our conclusions and suggest a research avenue to connect strategy mapping of systemic risk to models based on analytical approaches and quantitative simulation.

THE SPRM PROJECT

For the benefit of the reader, we here summarize the method and the results of the Systemic Pandemic Risk Management project as an example of a method that can be used for the management of systemic risk generally.

The SPRM project has developed methods and tools to assess and mitigate the direct and indirect risks to the health and social care system arising from a major pandemic, such as COVID-19. The crucial challenges to strategy development for preparedness and response are posed by systemic risks.

The SPRM project started 1st September 2020 and will be completed 30th June 2023. In its final phase, end-users in Norway and Sweden conduct an extended validation of the project's methods and tools, acting as strategy mapping facilitators, using preparedness and resilience towards a future major pandemic as the focus of their systemic risk assessment and management.[1]

The SPRM project employs strategy mapping using participatory modelling workshops with carefully selected participants, using the causal mapping software *Strategyfinder*™. *Strategyfinder* is a software platform for helping groups collaboratively work in person or virtually on messy problems, develop strategies, and manage risks. With it, groups propose and explore what causes what – means and ends – so that agreements can be negotiated with a full understanding of the expected outcomes and unexpected ramifications.

Previous work on systemic risk in pandemics has described the approach (Eden & Gonzalez, 2023; Gonzalez et al., 2021; Gonzalez & Eden, 2022). The method is illustrated in a video (Eden & Page, 2021). A manual on Systemic Risk Management is available on demand (Eden, 2023). A down-to-earth report providing an overview of strategy mapping with applications in practice, including pandemics, and evaluation of methods and tools for strategy mapping is found in (Bryson et al., 2023). The institution which has commissioned the report, the IBM Center for the Business of Government, defines its mission as connecting research to practice, applying scholarship to real world issues and decisions for government.

When a new major disaster strikes, the number of poorly known, and therefore difficult to quantify factors is vast. Hence, an agile response to the disaster cannot proceed from scratch in terms of quantifiable relations. The definition of risk provided by Lupton (2013) seems adequate: risk is "a phenomenon that has the potential to deliver substantial harm, whether or not the probability of this harm eventuating is estimable". Accordingly, and for a long time to come, modelling of systemic risk for the purpose of devising mitigating strategies must take off from a platform that can handle non-quantifiable risks.

The strategy mapping workshops of the SPRM project followed facilitated stages of 1-2 workshops each: Selection of participants; map of risks with causal influences; analyzing and validating the systemic risk model; strategy/action development.

[1] The company Stepchange AS leads the SPRM project. Project partners are the municipality of Kristiansand; the Sørlandet Hospital; the Centre of Integrated Emergency Management (CIEM), University of Agder; the Center for Disaster Medicine and Traumatology (KMC), Sweden; and the Center for Research and Training in Disaster Medicine, Humanitarian Aid and Global Health (Università del Piemonte Orientale), Italy.

Selection of participants

Strategy mapping workshops integrate fragmented expert knowledge as networks of causality through participatory modelling. Getting the right participants is crucial to the success of strategy mapping, whether the objective be positive goals (e.g., an enterprise seeking competitive advantage) or avoiding negative goals (e.g., mitigation strategies against systemic risk in natural or man-made disasters). Also, to increase the probability that the strategies be implemented, the workshops must include power-brokers, i.e., people with the power to act (or at least, able to influence those with the power to act). As far as possible, the participants should have personal stake in the problem. Power-brokers may not be stakeholders to start with, but the process may persuade them to become stakeholders and care about the problem and its solutions. Involving stakeholders from an early stage in the research process builds strong ownership of the findings (Ackermann & Eden, 2011; Cronbach et al., 1980).

The method to identify and select the best mix of participants for the systemic risk workshops in the SPRM project has been described in (Gonzalez et al., 2021, p6-7, Section Identifying and Selecting Appropriate Interdisciplinary Roles). A short description follows.

Having the municipality of Kristiansand and the Sørlandet Hospital SPRM projects, it was natural to conduct a facilitated workshop with staff from Kristiansand municipality and the Sørlandet Hospital who gathered onto a *Strategyfinder* view all of those who could make a good contribution (producing a proposal to involve over 70 participants). Thereafter, for each proposed participant the reason they should be a participant was explicated – what views do they offer. The person's name (or role) was linked to their offering. Thereafter, 13 advisors, including the five persons from the initial gathering augmented with additional experts from Norway, Sweden, Italy, and the UK, were invited to i) comment on the list of participants and seek to narrow down/prioritize, ii) add new ideas for participants, and iii) add missing topics and link participant suggestions to the new topics. Then, using the *Strategyfinder* analysis tools, the participants were scored for each topic based on i) the number of topics that the respondents saw that the potential participant was able to contribute to, ii) the number of respondents prioritizing the potential participant, and iii) the number of topics that the map indicated a potential participant might contribute to. The fifteen top recommended participants selected for the strategy mapping workshops below. (The total number of participants were sixteen: we added the role of a "remarkable person", a person likely to create an 'aha' from other participants by taking an intelligent, well-argued, but 'off-the-wall' surprising perspective.)

Systemic risk workshop – Map of risks with causal influences

A description of the first systemic risk workshop is found in (Gonzalez et al., 2021, p7-9). A short description follows.

Participants worked independently, adding risks to *Strategyfinder* within the health care sector and externally in sectors being affected by and affecting the health care sector. They added the risks blindly (not seeing the risks added by the other participants).

After making the screen with all the proposed risks made visible to all, the participants added any additional risks and arrows representing causality. A single arrow from A to B, A→B, means A causes B. E.g., 'increased infection rates …' causes 'delays in ordinary medical education'. A double arrow between C and D, C↔D, means C causes D, and D causes C. e.g., 'increased infection rates …' causes 'local outbreaks in hospitals', and vice versa. Cf. Figure 1.

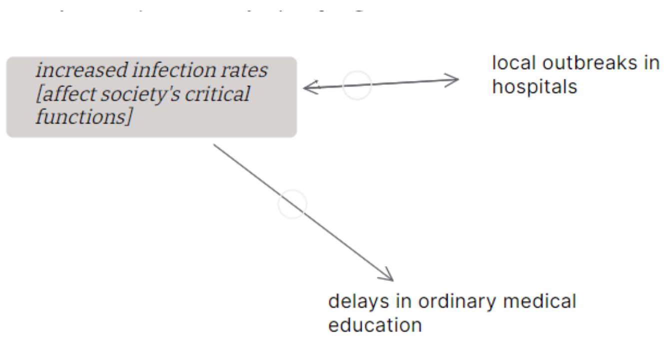

Figure 1 Arrows expressing causality (see main text for details)

In the time between the first and the second systemic risk workshops, the SPRM analysts employed *Strategyfinder* to detect and classify vicious loops and to identify sub-systems (clusters of risks), to create views of the systemic risk model and to prepare tasks for the second workshop.

Systemic risk workshop – Analyzing and validating the systemic risk model

The workshop promoted a process of understanding, editing, refining, and adding to the systemic risk model. The activities included validation of important views (checking causality, adding missing risks and their causality using *Strategyfinder*). To undertake this validation process, the group examined and validated risk sub-systems; this involved the participants proposing and arguing their case for deleting risks (unusual outcome) and changing causal links.

In a major pandemic like COVID-19, the interactions between the risks create a network of associated risks and outcomes, where the outcomes of risks are risks themselves, and where the resulting consequences can be highly complex. Risks are a system where a single risk can cause a plethora of other risks, and, very importantly, cause interacting vicious cycles of risks.

Feedback loops can be either balancing or reinforcing. Balancing feedback occurs when a change in a member of the loop is fed back in a manner that tends to reduce the change. Balancing loops can be characterized as goal-seeking or stabilizing processes. Reinforcing feedback occurs when a change in a member of the loop is fed back in a manner that tends to amplify the change. Reinforcing loops are sources of growth or accelerating collapse, depending on whether the disturbances amplify growth or decay. Reinforcing loops can be destabilizing if they reinforce undesired consequences, such as risks (in that case, the reinforcing feedback loops are often called ‘vicious cycles). (Sterman, 2000, p12-13, 138-141)

If vicious cycles are not properly mitigated, the consequences of risks escalate over time causing inner-sector and inter-sector cascading effects, and thereby increasingly threatening the loss of control. Figure 2 shows an example of a vicious cycle.

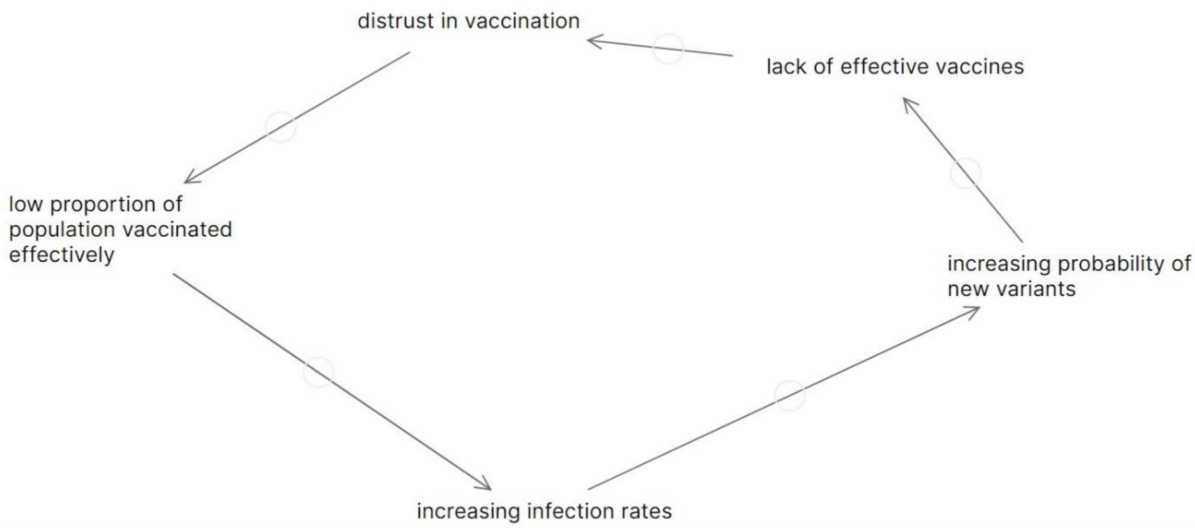

Figure 2 A causal map expressing likely cause-effect relationships forming a reinforcing feedback loop of risks (a vicious cycle). Distrust in vaccination causes low proportion of people vaccinated effectively, which causes increase of infection rates, which increases the number of virus variants, which makes vaccines less effective, which creates even more distrust in vaccination.

Figure 3 shows an overview of the subsystem topics (red) that emerged from the analysis and validation of the pandemic risk system and the two key outcomes of interest (black: pandemic infection rates and indirect death caused by the pandemic, which obviously are core risk outcomes of the pandemic).

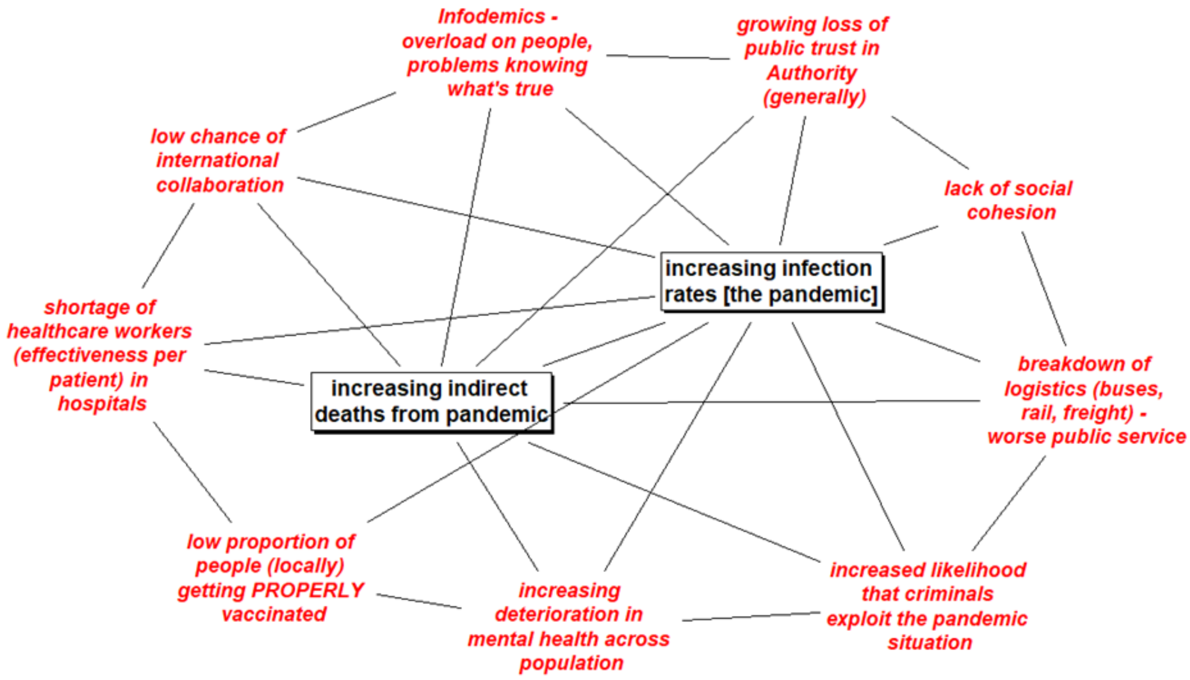

Figure 3 The nine interlinked risk subsystems topics having most impact on the pandemic infection rates and on indirect deaths from the pandemic.

The subsystems offer partial views of the complete risk model clustered according to the topic labels – each sub-system represented many risks and their causal links, with some common risks across sub-systems. *Strategyfinder* helps identify such clusters using analysis tools for network centrality (such as 'degree-centrality', 'betweenness centrality' and 'closeness centrality').

A line between subsystems, or between a subsystem and an outcome, typically summarizes numerous links expressing causality among numerous risks and the effects of the causality can be bidirectional (in other words, that there are feedback loops acting across the subsystems).

Figure 4 shows a small extract, consisting of only 14 risks, of the risk subsystem 'shortage of healthcare workers (effectiveness per patient) in hospitals' appearing on Figure 3. The risk extract on Figure 4 has 10 simple vicious cycles, and several nested vicious cycles. Nested vicious cycles are composed of several single vicious cycles which are interconnected. E.g., #8↔#4↔#7 is a nested vicious cycle composed of the single vicious cycles #8↔#4 and #4↔#7. The two vicious cycles become nested because they share the risk '#4 local outbreaks in hospitals'. Nested vicious cycles compound the negative effects arising from reinforcing feedback.

Key for strategy development is mitigating the most potent risks, i.e., those participating in the highest numbers of vicious loops (Eden, 2023; Gonzalez et al., 2021, section Analysis for Prioritising Risk Mitigation).

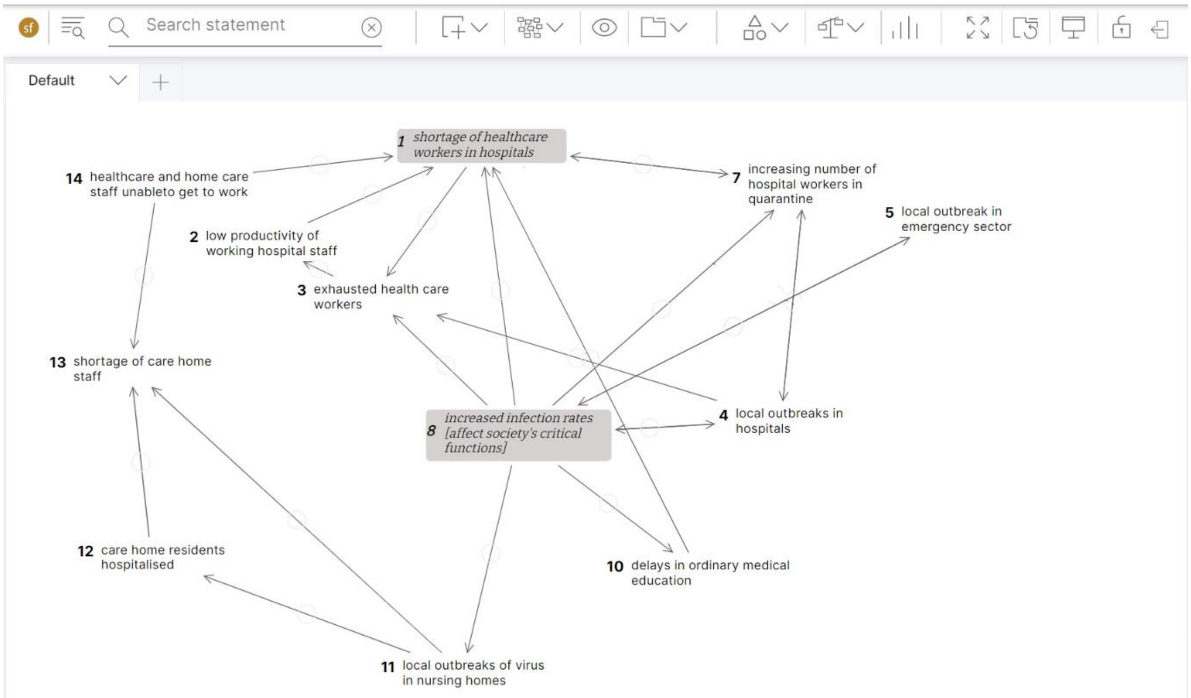

Figure 4 A small extract of the subsystem clustering risks of relevance of shortage of healthcare workers. The two risks displayed on gray background are negative goals (Eden & Gonzalez, 2023) affected by highly potent risks. Mitigations strategies directly or indirectly targeting these negative goals will attack a high number of vicious cycles.

Systemic risk workshop – Strategy/Action Development

All the identified subsystems of risks contain numerous vicious cycles. Hence, the most effective pandemic mitigation strategy should ideally consist of portfolios of strategies for each and all the risk subsystems.

In real life, one must consider the availability of resources and trade-offs: there will never be enough resource to implement all desired mitigation strategies. *Strategyfinder* has a rating tool allowing the workshop participants to range issues for the importance on a scale 0…10. Using such rating tool, the experts ranked the priorities of devising mitigation strategies for the risk subsystems shown on Figure 3. The risk subsystem 'shortage of healthcare workers … in hospitals' was the highest ranked.

In the strategy/action development workshop the participants were asked to make their own suggestions about potential mitigating actions/strategies and link those statements to the potent risks, the negative goals, shown on 4, they expect to mitigate. Several mitigation strategies were proposed. Again, since resources always are limited in real life, the best strategies should be prioritized. Arguably, the best strategies are those that are evaluated as both impactful and practical. When everyone has made their suggestions and the facilitator has reviewed them with the group, *Strategyfinder* allows each participant to evaluate the options using the 'preferencing' tool. Evaluation occurs by constraining choice: each participant is given several blobs, say, green for impact and blue for practicality. The participants independently and anonymously attach the blobs to the proposed mitigating strategies.

Figure 5 shows the two strategies (purple) which got the highest numbers of blobs for both impact and practicality. (Of course, one can reconsider proposed strategies high in impact, but low in practicality to find out whether there are ways to make them more practical.)

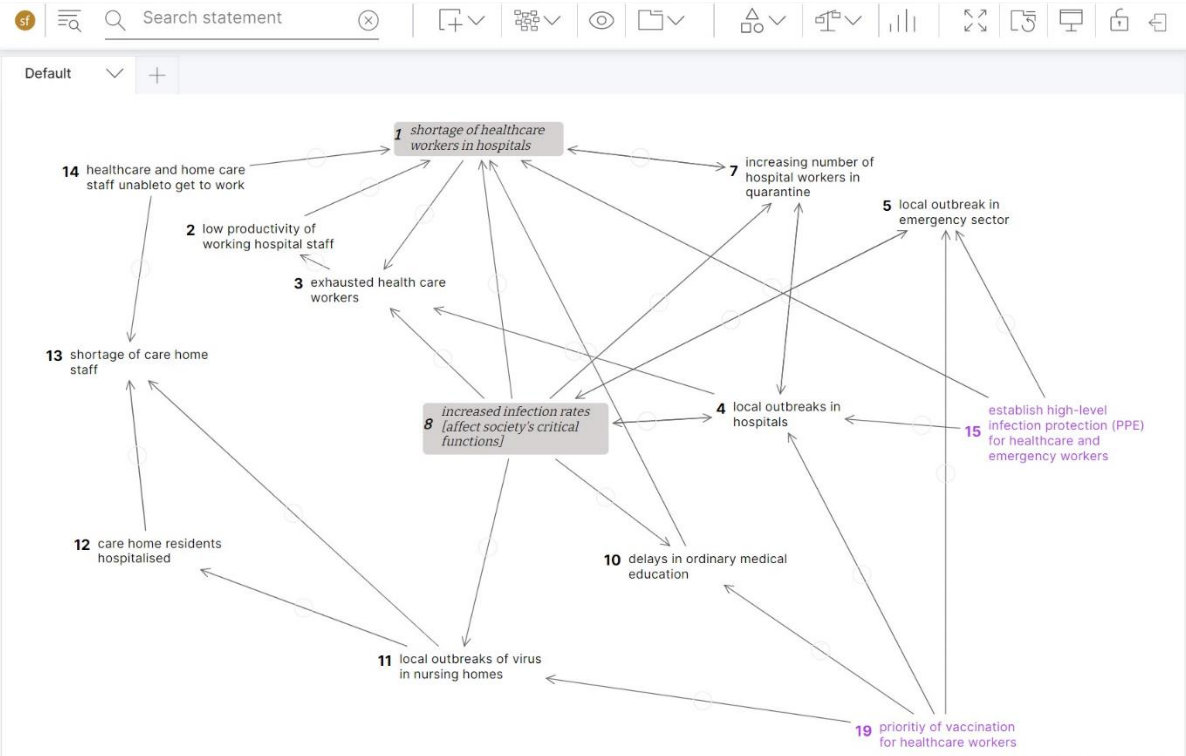

Figure 5 The small extract of the subsystem clustering risks of relevance of shortage of healthcare workers showing two strategies (in purple) evaluated as both impactful and practical by the expert workshop participants. Note that the strategies attack the potent risks (on gray background) through several paths, thus increasing the probability of mitigating the risks.

Finally, the participants were asked to identify responsibility for the mitigating strategies. The outcome of the strategy session was a document with portfolios of strategies, the rationale in terms of the causal implications, and the responsibility for each strategy.

Assigning responsibility for the implementation of the strategies increases the probability that the agreed strategies get used. Spelling out the rationale of the strategy helps the person responsible for the implementation of the strategy to monitor the performance of the strategy (to what extent the strategy achieves the intended effect). Corrective actions and learning become possible.

For further details about the strategy/action development workshops see (Gonzalez et al., 2021, p10-13).

ADEQUACY OF MODELLING PURPOSE

Models should be assessed with respect to their adequacy or fitness for a particular purpose (Parker, 2020; Thompson, 2022).

Useful and useable mitigations strategies for responding to a complex and urgent risk situation, such as a pandemic, must be based on a *fast process*. Disasters do not follow scripts and emerging risks are not quantifiable, at least not within the time scale needed for quantitative models to sufficiently account for the systemic risk and the relations among the risks that must be considered. Hence, such a fast process is necessarily *qualitative concerning cause-effect relationships*. But there is quantitative information in the causal network structure (e.g., potency of risks) which can be computed by network analysis tools and algorithms, and used to identify the most powerful mitigation strategies.

The mitigation strategies must be quickly identified, and they must be both practical and impactful. The process of model development, model validation, model analysis and identification of the mitigation strategies must involve power-brokers – those with the power to act or, at least, to influence those with the power to act – to ensure ownership of the model and the strategies derived from it. Since most power-brokers are extremely busy, the modelling process and the identification of the mitigation strategies must involve relatively small amounts of the power-brokers time. This requirement means that the analysis of the risk system will need to be transparent and relevant. (Eden & Gonzalez, 2023).

Qualitative models based on causal strategy mapping as described in this contribution are transparent and create ownership. Quantitative models are less transparent for practitioners and power-brokers, and, hence, do not (yet) achieve the necessary ownership among practitioners and power-brokers for practical use.

We do not dispute the value of quantitative systemic risk modelling approaches (stochastic simulation, multi-agent systems modelling, non-structural time-series modelling, structural modelling like system dynamics, etc) to inform and support, discussed in (UNDRR, 2019). But it is an impossible task to fast enough develop mitigation strategies against systemic risk based only on full-scale numerical models. It would require determining within days or weeks the relationships – be it empirical, analytic, or stochastic – in systems of hundreds of risks causally connected through even more hundreds of relationships. Hence, the purpose of quantitative modelling of systemic risk cannot primarily be the development of mitigation strategies toward systemic risk in near real time. It is also important to acknowledge the weaknesses in quantitative modelling which are often not appreciated or understood by policy-makers (Thompson, 2022).

REVIEW OF SYSTEMIC RISK DEFINITIONS

There are numerous definitions of systemic risk valid for the tightly coupled systems representing the interdependencies of our societies. Despite their differences, they share the awareness that the outcomes of risks are risks themselves, owing to the causal interactions between the risks. We proceed to review often-quoted definitions of systemic risk, highlighting such common awareness of the risks' interdependencies. In doing so, it is unavoidable, and many scholars do explicitly acknowledge it, that the management of systemic risk requires systems thinking (Centeno et al., 2015; Jacobzone et al., 2020; Sillmann et al., 2022).

Several scholars assert that the concept of systemic risk originated in the financial sector and economics (e.g., Kim et al., 2022, p2; Schweizer, 2021, p90). We do not dispute that the disaster risk reduction community firstly became aware of systemic risk through publications in the financial sector and economics. But, as mentioned on p2, systemic risk has played an important role in the discipline of management of complex projects since the 1990'ies. The fixation by the disaster risk community on the sole origin of systemic risk in the financial sector and economics risk implies also that most attention has been directed to system risks analysis methods employed in those sectors. Arguably, this fixation has biased the disaster risk reduction community, leading their scholars to overlook the alternative approach for modelling systemic risk originating in the discipline of management of complex infrastructure projects.

The financial sector became also concerned with systemic risk in the 1990'ies. An early publication recognizes that the outcomes of a trigger event are chains of linked risks, in other words, that the outcomes of risks are risks themselves. Systemic risk is the "the risk of a chain reaction of falling interconnected dominos." (Kaufman, 1995).

In the financial sector and economics discipline, Kaufman & Scott (2003) characterize systemic risk as "the probability of breakdowns in an entire system, as opposed to breakdowns in individual parts or components, and is evidenced by co-movements (correlation) among most or all the parts". Here again, 'co-movements (correlation) amongst the parts' acknowledges the interdependence of the risks, and so the cascading effects that can lead to system breakdown. The term 'cascading effects' implicitly acknowledges a chain of causal connection between risks, in other words, that the outcomes of risks are risks themselves.

Schwarcz (2008, p198) reviews definitions of systemic risk in the financial sector and economics: "a common factor in the various definitions of systemic risk is that a trigger event, such as an economic shock or institutional failure, causes a chain of bad economic consequences – sometimes referred to as a domino effect" – clearly acknowledges that the outcomes of risks are risks themselves.

We now consider some of the views beyond the financial focus. Centeno et al. (2015, p68), discussing global risks, define systemic risk as "the threat that individual failures, accidents, or disruptions present to a system through the process of contagion". 'Contagion' implies that the interdependencies among risks act as causal paths for the outcomes of risks, which become risks themselves. Centeno et al. also recognize that feedback loops are a key characteristic of the systemic nature of risks. Indeed, interdependency of risks implies causality. Causal paths in tightly coupled systems result mostly in numerous feedback loops.

Reichstein et al. (2021, p347) also use the term 'domino effects' to characterize an example of cascading effects originating from a heatwave (forest fires, causing air pollution, which damages public health). Further, on p348, the authors state that realistic models of *interacting risks* are crucial for policymakers and investors.

Flood et al. (2022) acknowledge risk interdependencies while remarking that none of the major agreements – Sendai Framework, the Paris Agreement, and Agenda 2030 – sufficiently address systemic risk: "risks *increasingly have interdependencies and cascading effects* within and across multiple sectors that cannot be addressed through any one of the agreements."

Kim et al. (2022, p2), with respect to pandemics, recognize that the outcomes of risks are risks themselves by stating that the concept of systemic risk “assumes that failure in one sub-unit or cluster of the system will lead to cascading events in other system units”, i.e., that the outcomes of risks are risks themselves. Note, however, many such cascading events can occur within a given sector (inner-sector cascading events) before they trigger events in other sectors (inter-sector cascading events). While COVID-19 did affect numerous societal sectors via cascading events, numerous infections with cascading consequences *within* the healthcare system had happened before the inter-sector cascading effects became worrisome.

Some scholars provide definitions of systemic risk listing many characteristics. Often, some characteristics are duplicates, since they are consequences of attributes already listed.

“Key characteristics that determine the risks associated with COVID-19 have been identified: (i) interdependence, interconnectedness and cascading effects, (ii) non-linear relationships, (iii) feedback loops, (iv) tipping points, (v) being unnoticed, (vi) uncertainty, and (vii) dynamics” (UNDRR & UNU-EHS, 2022).

While most authors consider systemic risk as a system of tightly coupled risks through causality, Schweizer (2021) describes ‘systemic risk’ as exceedingly complex risk *phenomena*. “Human life, societal welfare and the environment are especially threatened by systemic risks such as climate change, epidemics, and financial crises” (op. cit., p78). The key attribute of interdependency in systemic risk, which implies that the outcomes of risks are risk themselves, is declared by “systemic risks are characterized by complexity and interdependency” (op. cit., p78). In the next section, we discuss the special complexity – dynamic complexity – which reigns in tightly coupled systems owing to the feedback caused by causal interdependencies.

Other attributes often mentioned in definition of systemic risk (e.g., transboundariness, tipping points, etc) are context dependent. E.g., transboundariness plays a crucial role in climate change or major pandemics but it would not necessarily do so in wildfires or floods – even if they can cause systemic risk within the affected region.

Synthesizing this material, with our own views, we identify: i) cascading effects, ii) non-linearity and tipping points (a characteristic of non-linearity), iii) un-noticed and uncertainty, and iv) dynamics as key features of systemic risk.

Cascading effects (i) originate through interdependence and interconnectedness, which imply either a causal relation between risks or correlation owing to common causes of risks.

Non-linearity can refer to relationships among system components or to the behavior over time of the system. Non-linear relationships (ii) are the rule in the real world – linear relations are rare. Non-linear behavior over time happens if the system has feedback loops, which are ubiquitous in tightly coupled systems. There are only two kinds of feedback loops, viz. reinforcing and balancing, which both cause non-linear processes (Sterman, 2000, p12-13). Tipping points are related to changes about which feedback loops dominate the behavior of the system over time (cf. op. cit., p305ff).

The attributes of being unnoticed (iii) and uncertainty (vi) are likely the consequence of the insufficient human knowledge regarding the extremely complex systems that humankind must face – many of them heavily shaped by human activities. They relate to dynamic complexity (see next section).

Finally, dynamics (iv) expresses changing behavior over time. Change follows from the impacts of causal connections. The central tenet of system dynamics is that feedback loops capture the causal interactions and shape the overall pattern of behavior over time (Forrester, 1968).

The review of often quoted definitions clearly points that they all recognize that systemic risk originates in systems governed by feedback where the outcomes of risks are risks themselves. This recognition provides a concise definition of systemic risk.

Different definitions of ‘systemic risk’ in the literature, direct attention to the specific issues (e.g., tipping points). Thus, different definitions suggest different perspectives for modelling and, thus, may bias the attention toward specific modelling methods. Part of the reason why strategy mapping of systemic risks has been overlooked in the mainstream disaster risk community can the way systemic risk has been defined by mainstream disaster scientists.

HOW CAN SYSTEMIC RISKS BE IDENTIFIED?

The above concise definition of systemic risk is sufficient to proceed with the strategy mapping method. Strategy mapping of disasters with systemic risk succeeds in engaging practitioners and power-brokers in participatory modelling because they capture the essential characteristics of risk for quickly designing a first line of defense (of mitigation strategies). The troublemakers in such disasters are vicious cycles (feedback reinforcing the risks). The escalation of risks demands strategies that can handle vicious cycles. There are three options to manage vicious cycles: 1) promote balancing feedback loops that mitigate the behavior of vicious cycles; 2) attack risks which are members in vicious cycles to disable or, at least, weaken the vicious cycle; 3) change the direction of causality in reinforcing feedback, so that desired changes are reinforced (mitigating, instead of escalating the risks). Single strategies are not effective enough (Eden, 2023). Instead, portfolios of strategies based on analysis on the potency of risks must be designed (for potent issues, cf. Ackermann & Eden, 2011, p99ff).

Strategy mapping of disasters with systemic risk can rely on Lupton's definition of risk: "a phenomenon that has the potential to deliver substantial harm, whether or not the probability of this harm eventuating is estimable" (Lupton, 2013). This allows creating networks of risk causality in participatory modelling with practitioners and stakeholders, and to design portfolios of strategies from the analysis of feedback loops with a dedicated software (*Strategyfinder*).

Schweizer (2021, p80) raises the crucial question 'How can systemic risks be identified?' and 'How can they be differentiated from other kinds of risks?'. Schweizer suggests the perspective of the OECD (2003) that a risk becomes systemic when a society's essential systems are potentially threatened (op. cit., p79).

We contend that the key issue distinguishing systemic risk is the special kind of complexity known as *dynamic complexity*. It is a most challenging kind of complexity for human understanding. Dynamical behavior governed by feedback *in systems of even few components* can result in dynamic complexity that humans find difficult to understand and acknowledge (Sterman, 2000, p21). Dynamic complexity causes counterintuitive behavior. The management of dynamic complexity often is frustrated by 'policy resistance', i.e., that seemingly 'obvious' solutions fail or even worse the situation (op. cit., 3, 5-12, 21-23).

"Dynamic complexity is characterized by …cause and effect are subtle…the effects over time of interventions are not obvious. Conventional forecasting, planning and analysis methods are not equipped to deal with dynamic complexity." (Senge, 1992)

Dynamic complexity can occur in systems in need of better management even if they do not threat society's essential functions. An example in point is management of complex projects (Sterman, 2000, p55-65).

For a simple definition for systemic risk we proposed (p10): Risks are a system where a single risk can cause a plethora of other risks – risks interact with each other as a system - and so typically there are vicious cycles of risks present in the system.

How many vicious cycles can a major pandemic like COVID-19 trigger? Previous research has shown that there are *millions* of vicious cycles in a pandemic risk model (Gonzalez & Eden, 2022; Gonzalez et al., 2021). In the SPRM project the huge number of vicious cycles is a consequence of about 600 causal connections among ca. 220 risks identified in participatory modelling with practitioners, domain experts and power-brokers, and this related only to mapping the system of risks when focusing on the health and welfare sector.

Recall that a system having only a few feedback loops and low combinatorial complexity already can exhibit dynamic complexity (Sterman, 2000, p21). A major pandemic has *high* combinatorial complexity in terms of the numbers of resulting feedback loops. Hence, the *dynamic complexity* of a major pandemic resulting from millions of feedback loop is *enormous*. In other words, the huge challenges ascribed to systemic risk emerge from its dynamic complexity.

With increasing number of risks and increasing number of relationships among the risks, the number of feedback loops increases exponentially. Thus, natural disasters resulting from major threats affecting humankind are likely to generate as many or even more vicious cycles than pandemics.

CONCLUDING REMARKS

The Global Assessment Report on Disaster Risk Reduction 2019 firmly states a growing sense of urgency for a paradigm shift concerning methodologies for managing systemic risk (UNDRR, 2019, p44).

To achieve impact, the requested paradigm shift must go beyond publishing novel research results. It has long been, and it is still a major challenge accomplishing that research is *useful, useable, and used* (Boaz & Hayden., 2002). A recent review (Oliver et al., 2022), targeting the identification of existing research-policy engagement activities and of impacts of these activities on research and decision making, concludes that most researchers have not reached the point of translating science into practice by making the knowledge useful and used. "Overall, the picture is of a vast and increasing mass of rudderless activity, which is busy rather than effective" (op. cit., p704).

Another recent publication (Reichstein et al., 2021), a feature in the prestigious science journal *Nature* on setting the agenda in research, urges researchers to create models that are more understandable and useful to policymakers. Research needs advocates to promote its use in practice (Boaz & Hayden., 2002, p440).

Our article has sought to present evidence that the SPRM project has had some degree of success in terms of delivering useful, useable, and used research. Key to this success is the transparency of the strategy mapping method and the fact that the process engages practitioners and power-brokers.

Our research has some limitations:

The modelling of pandemic risks must still be considered a proof-of-concept. It is based on an innovation project founded by the Research Council of Norway with international participation. As usual, the funding is limited. Limited resources did influence the extent of ‘experimental’ effort from practitioners, domain experts and power-brokers in the participatory modelling workshops. Since the number of the workshops was limited, the identification of mitigation of strategies had to be restricted to the highest rated subsystem of risks – although, as we state above, urgency means that deciding where to focus effort is a crucial part of any effective method for managing systemic risk, and so this constraint is likely to be realistic.

However, note that the method has been adopted and is being increasingly adopted by practitioners suggests that more evidence about the method’s utility will inspire further progress (Abildsnes et al., 2023; Bryson et al., 2023).

Another limitation is the fact that the method has been applied from a Western, Educated, Industrial, Rich, Developed (‘WEIRD’) standpoint. Therefore, both the participants’ brains and our model are likely to contain WEIRD assumptions that have escaped our notice (Thompson, 2022). Hence, some caution is needed, and more research must be done to understand to what extent our findings would apply in a non-WEIRD context.

Finally, we suggest a possible path to make qualitative causal mapping models a basis for quantitative modelling. Many valuable insights in the discipline of management of complex projects came from legal disputes between project owners and contractors where quantitative simulation models were used to provide insight in the causes of project disruptions (Ackermann et al., 2011). To be useful as instrument in litigation between project owners and contractors, the validity of the simulation model must be appreciated by multiple audiences, especially non-experts. To this effect, a dedicated modelling approach was developed (‘the modelling cascade’), providing a structured, transparent, auditable, formalized process from real world interviews generating a rich qualitative model through two intermediate steps before arriving at a quantitative simulation model (Howick et al., 2007).

We suggest as a potentially promising research avenue to explore whether the ‘modelling cascade’ can be extended to urgent disaster risk mitigation settings. In other words, whether quantitative modelling approaches of systemic disaster risk may piggy-back on qualitative participatory modelling by adapting and extending the ‘modelling cascade’ approach developed for using simulation models in litigation about cost and time overruns of large engineering projects.

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REFERENCES

Abildsnes, E., Paulsen, S., & Gonzalez, J. J. (2023). Improving resilience against a pandemic: A novel technology for strategy development with practitioners and decision-makers, *Proceedings of the 20th International Conference on Information Systems for Crisis Response and Management*, Omaha, NE.

Abuzayed, B., Bouri, E., Al-Fayoumi, N., & Jalkh, N. (2021). Systemic risk spillover across global and country stock markets during the COVID-19 pandemic, *Econ Analysis and Policy, 71*, 180-197. doi:https://doi.org/10.1016/j.eap.2021.04.010

Ackermann, F., & Eden, C. (2011). Making Strategy : Mapping Out Strategic Success, Sage, London.

Ackermann, F., Eden, C., Williams, T., & Howick, S. (2007). Systemic risk assessment: a case study, *J. Oper. Res. Soc.*, *58*(1), 39-51.

Ackermann, F., Howick, S., Eden, C., & Williams, T. (2011). Delay and Disruption in Complex Projects. In R. A. Meyers (Ed.), *Complex Systems in Finance and Econometrics* (pp. 116-135), Springer, Berlin.

Ackermann, F., Howick, S., Quigley, J., Walls, L., & Houghton, T. (2014). Systemic risk elicitation: using causal maps to engage stakeholders and build a comprehensive view of risks, *Eur. J. Oper. Res.*, *238*(1), 290–299.

Boaz, A., & Hayden., C. (2002). Pro-active evaluators -- Enabling research to be useful, usable and used, *Evaluation, 8*(4), 440-453.

Bryson, J. M., Barberg, B., Carroll, A., C., E., George, B., Gonzalez, J. J., Rochester, J., Vandersmissen, L., and Zaki, B. (2023). Addressing Complex and Cross-Boundary Challenges in Government: The Value of Strategy Mapping. The IBM Center for the Business of Government, Washington, DC, USA. Retrieved

January 5, 2023, https://www.businessofgovernment.org/report/addressing-complex-and-cross-boundary-challenges-government-value-strategy-mapping.

Centeno, M. A., Nag, M., Patterson, T. S., Shaver, A., & Windawi, A. J. (2015). The Emergence of Global Systemic Risk, *Annual Review of Sociology, 41*(1), 65-85. doi:10.1146/annurev-soc-073014-112317

Cronbach, L. J., Ambron, S. R., Dornbusch, S. M., Hess, R. D., Hornik, R. C., Phillips, D. C., Walker, D. F., and Weiner, S. S. (1980). Towards Reform of Programme Evaluation, Jossey-Bass, San Francisco, CA.

Eden, C. (1989). Strategic Options Development and Analysis - SODA. In J. Rosenhead (Ed.), *Rational Analysis in a Problematic World* (pp. 21-42). London: Wiley.

Eden, C. (1993). Strategy Development and Implementation - Cognitive Mapping for Group Support. In J. Hendry, G. Johnson, & J. Newton (Eds.), *Strategic Thinking: Leadership and the Management of Change*. London: Wiley.

Eden, C. (2023). *Strategyfinder - Systemic Risk Management*, Formfinder Software GmbH, Viena:

Eden, C., & Gonzalez, J. J. (2023). The strategic management of disaster risk mitigation. In J. Radianti, T. Gjøsæter, & Y. Murayama (Eds.), *Information Technology in Disaster Risk Reduction ITDRR 2022*, Springer Nature, Cham, Switzerland.

Eden, C., Jones, S., & Sims, D. (1983). Messing About in Problems, Pergamon, Oxford.

Eden, C., & Page, K. (2021). *Systemic Pandemic Risk Management: The First Field Trial of the Method* https://youtu.be/MKoZr8jV6aY

Flood, S., Columbie, Y. J., Le Tissier, M., & O'Dwyer, B. (2022). Can the Sendai Framework, the Paris Agreement, and Agenda 2030 Provide a Path Towards Societal Resilience? In S. Flood, Y. J. Columbie, M. Le Tissier, & B. O'Dwyer (Eds.), Creating resilient futures : integrating disaster risk reduction, sustainable development goals and climate change adaptation agendas. Springer International Publishing, Cham, Switzerland.

Forrester, J. (1968). Principles of Systems, Pegasus Communications, Waltham, MA.

Goldin, I. (2014). The Butterfly Defect: Why globalization creates systemic risks and what to do about it, *Journal of Risk Management in Financial Institutions, 7*(4), 325-327.

Gonzalez, J. J., & Eden, C. (2022). Insights from the COVID-19 Pandemic for Systemic Risk As-sessment and Management. In J. Sasaki, Y. Murayama, D. Velev, & P. Zlateva (Eds.), *Information Technology in Disaster Risk Reduction. ITDRR 2021.* (Vol. 638). Springer Nature, Cham, Switzerland.

Gonzalez, J. J., Eden, C., Abildsnes, E., Hauge, M., Trentin., M., Ragazzoni, L., Berggren, P., Jonson, C.-O., and Abdelgawad, A. A. (2021). Elicitation, analysis and mitigation of systemic pandemic risks. Proceedings of the 18th International Conference on Information Systems for Crisis Response and Management, Blacksburg, VA.

Harary, F., Norman, R., & Cartwright, D. (1965). Structural Models: An Introduction to the Theory of Directed Graphs, Wiley, New York.

Howick, S., Eden, C., Ackermann, F., & Williams, T. (2007). Building confidence in models for multiple audiences: The modelling cascade, *Eur. J. Oper. Res., 186*, 1068-1093.

Ibrahim, S. E., Centeno, M. A., Patterson, T. S., & Callahan, P. W. (2021). Resilience in Global Value Chains: A Systemic Risk Approach, *Global Perspectives*, *2*. doi:https://doi.org/10.1525/gp.2021.27658.

Jacobzone, S., Baubion, C., Radisch, J., Hochrainer-Stigler, S., Linnerooth-Bayer, J., Liu, W., Rovenskaya, E., & Dieckmann, U. (2020). Strategies to Govern Systemic Risks. In W. Hynes, M. Lees, & J. M. Müller (Eds.), *Systemic Thinking for Policy Making: The Potential of Systems Analysis for Addressing Global Policy Challenges in the 21st Century*, OECD Publishing, Paris.

Kaufman, G. G. (1995). Comment on Systemic Risk. In G. G. Kaufman (Ed.), *Research in Financial Services: Banking, Financial Markets, and Systemic Risk* (pp. 47-52), JAI PR, Greenwich, CT.

Kaufman, G. G., & Scott, K. E. (2003). What Is Systemic Risk, and Do Bank Regulators Retard or Contribute to It? *Independent Review, 7*(3), 371-393.

Kim, Y.-k., Yoon, W. C., Lee, J., Poncelet, J.-L., Dolcemascolo, G., & Sohn, H.-G. (2022). A strategic response map for cascading pandemics: Lessons learned from the response to COVID-19 in the Republic of Korea, *Progress in Disaster Science, 13*, 100214. doi:https://doi.org/10.1016/j.pdisas.2022.100214

Lupton, D. (2013). *Risk* (2nd ed.), Routledge, London.

OECD. (2003). Emerging Systemic Risks in the 21st Century: An Agenda for Action, OECD, Paris.

Oliver, K., Hopkins, A., Boaz, A., Guillot-Wright, S., & Cairney, P. (2022). What works to promote research-policy engagement? *Evidence & Policy, 18*(4), 691-713. doi:10.1332/174426421X16420918447616.

Parker, W. S. (2020). Model Evaluation: An Adequacy-for-Purpose View, *Philosophy of science, 87*(3), 457-477.

Reichstein, M., Riede, F., & Frank, D. (2021). More floods, fires and cyclones - plan for domino effects on sustainability goals, *Nature, 592*(7854), 347-349. doi:10.1038/d41586-021-00927-x.

Renn, O., Lucas, K., Haas, A., & Jaeger, C. (2019). Things are different today: the challenge of global systemic risks, *Journal of risk research, 22*(4), 401-415. doi:10.1080/13669877.2017.1409252.

Rizwan, M. S., Ahmad, G., & Ashraf, D. (2020). Systemic risk: The impact of COVID-19, *Financ Res Lett.*, *36*, 1-8. doi:10.1016/j.frl.2020.101682.

Schwarcz, S. L. (2008). Systemic risk, *The Georgetown Law Journal*, *97*, 193-249.

Schweizer, P.-J. (2021). Systemic risks - concepts and challenges for risk governance, *Journal of risk research*, *24*(1), 78-93. doi:10.1080/13669877.2019.1687574.

Senge, P. (1992) The Fifth Discipline: The Art and Practice of the Learning Organization, Century Business, London.

Sillmann, J., Christensen, I., Hochrainer-Stigler, S., Huang-Lachmann, J., Juhola, S., Kornhuber, K., Mahecha, M. D.,. Mechler, R., Reichstein, M., Ruane, A. C., Schweizer, P.-J., and Williams, S. (2022). Briefing note on systemic risk. Retrieved Jan. 5, 2023, https://www.undrr.org/publication/briefing-note-systemic-risk.

Sterman, J. D. (2000). Business dynamics : systems thinking and modeling for a complex world, Irwin McGraw-Hill, Boston.

Thompson, E. (2022). Escape from Model Land -- How Mathematical Models Can Lead Us Astray and What We Can Do About It, Basic Books UK, London.

UNDRR. (2019). Global Assessment Report on Disaster Risk Reduction 2019 (GAR2019). Retrieved Jan. 5, 2023, https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019.

UNDRR. (2022). Global Assessment Report on Disaster Risk Reduction 2022 (GAR2022). Retrieved Jan. 5, 2023, https://www.undrr.org/gar2022-our-world-risk.

UNDRR & UNU-EHS. (2022). Understanding and managing cascading and systemic risks: lessons from COVID-19. Retrieved Jan. 5, 2023, https://www.undrr.org/publication/understanding-and-managing-cascading-and-systemic-risks-lessons-covid-19.

Williams, T. M., Ackermann, F., & Eden, C. (1997). Project Risk: systemicity, cause mapping and scenario approach. In K. Kahkonen & K. A. Artto (Eds.), *Managing Risks in Projects* (pp. 343-352), E&FN Spon, London.