Rearranging the Deck Chairs: A Simulation Model of Behavioral Resource Utilization Under Crisis

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ABSTRACT:

Under what circumstances could seemingly trivial mitigation activities, i.e. "rearranging the deck chairs", or any possibly preventative activity during a crisis be helpful in reducing negative outcomes? How can the actions of the people during an evolving and crisis materially affect the both the physical and behavioral dynamics of the crisis, and how do humanitarian coordinators balance those actions with the immediate value of fleeing? This work presents a methodological framework for answering these questions via the development of a compartmental differential equation model that explores the interplay of stress response and action efficacy in group survivability during a crisis. This framework illustrates that calming, but even marginally effective, mitigation activities can stabilize or improve crisis outcomes. However a similarly calming, but totally non-effective, mitigation can severely worsen outcomes.

KEYWORDS:

Disaster Management, Capacity Management, Humanitarian Operations, System Dynamics Modeling, Methodology

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1. Introduction and Background

The phrase “Rearranging the deck chairs” is typically used metaphorically in the sense of “to occupy oneself with some trivial activity while ignoring something much more important.” It is intended to call to mind the futility of the activity of rearranging the deckchairs on the Titanic as it sunk into the North Atlantic Ocean on the frigid early morning of April 15, 1912. While the phrase itself was not likely first used until nearly 60 years after the sinking of the Titanic, its usage as a short hand for performing trivial work that misses the wider scope of an unfolding crisis (Martin, 2022; “Rearranging the Deck Chairs on the Titanic,” 2001).

However, during an actively unfolding crisis, the ability to identify activities as *trivial* versus *essential* can be unclear, and more than just mitigate a crisis, some activities could outright prevent the crisis or even recover from it.

Under what circumstances could “rearranging the deck chairs” or any possibly preventative activity during a crisis have been helpful in reducing deaths?

How can the actions of the people during an evolving and crisis materially affect the both the physical and behavioral dynamics of the crisis, and how does a manager balance those actions with the immediate value of fleeing?

This work endeavors to build an endogenized framework that can be used to explore this fine-line between the trivial and the essential in an unfolding crisis. This is done via the development of a compartmental differential equation model that explores the interplay of stress response and action efficacy in group survivability during a crisis.

The exploration of the behavior of this model highlights that calming, but even marginally effective, mitigation activities can stabilize or improve crisis outcomes. However, a similarly calming, but totally non-effective, mitigation can *severely* worsen outcomes

This work provides framework for future examination of balancing the expenditure of human resources as a function of both effect of actions on offsetting system decay and how those actions affect the stress response of those in the evolving crisis.

2. Dynamic Hypothesis

An exogenous event kicks off a crisis that actively erodes a system's ability to support life. Those in this eroding system have three options with their limited time:

- Do nothing (remain idle)
- Work to mitigate the crisis, possibly buying time (or even preventing or reversing further degradation of the situation)
- Flee (evacuate)

Fleeing has the immediate effect of removing people from harm, though it may be inefficient, resulting in more harm than good. Concern for safety is a function perception of the current system's capability to resist the crisis, and also perception of activities around each person. Viewing evacuation is stressful, while mitigation activities are presumed to be less so (or even calming). As discussed in many prior works, low levels of stress can increase efficacy of evacuation efforts, while high levels of stress can lead to a less efficacious evacuation (Teigen, 1994; Yerkes & Dodson, 1908).

Table 1. Central State and Outcome Variables of the Dynamic Hypothesis

Parameter	Units	Category
Concern for Safety	Dmnl	Stock (State Variable)
Capability to Resist Crisis	Dmnl	Stock (State Variable)
People exposed to Crisis	People	Stock (State Variable)
Evacuated (Survived)	People/Hour	Flow (Outcome)
Evacuated (Died)	People/Hour	Flow (Outcome)

The key state variables of this system can be separated out into two categories: Behavioral (*Concern for Safety* and *Capability to Resist Crisis*) and physical (*People Exposed to Crisis*). These are modeled using differential equation methods and subsequent diagram generally will use the visual language of compartmental models discussed in System Dynamics literature (Morecroft, 2015; Sterman, 2000). For example, the key stocks *Concern for Safety* and *Capability to Resist Crisis* are modeled in terms of structures that affect the change of these state variables over time from their initial values.

$$\frac{d}{dt}(Concern\ for\ Safety) = \ Change\ in\ Concern\ for\ Safety \qquad (1)$$

$$\frac{d}{dt}(Capability\ to\ Resist\ Crisis) = \ Crisis\ Mitigation - Crisis\ Progression \qquad (2)$$

For both of these, they are normalized to a value of 1 with no units. This allows for the exploration of the model behavior in subsequent sections to focus on the outcomes and sensitivities to relative changes in values versus the absolute definitional and functional forms of these otherwise highly qualitative, but still essential, concepts.

The *Crisis Progression* is the exogenous event that triggers the behavior in this model framework. After a certain time, the Capability to Resist Crisis stock begins a first order decay, at a rate defined by the *Crisis Progression Rate* parameter. This first order decay is a modeling decision used here to capture the rapid and sudden onset of a crisis, like that from a natural disaster. Other formulations are of course possible, but outside the specific dynamics being explored here.

$$\begin{aligned} & Crisis\ Progression = if\ then\ else(Time > \\ & \qquad = Crisis\ Start\ Time, Capability\ to\ Resist\ Crisis \\ & \qquad * Crisis\ Progression\ Rate, 0) \end{aligned} \tag{3}$$

The physical state variable of the *People Exposed to Crisis* is used, in part, to keep track of the key outcomes of this model: the dispositions of people in this system and exposed to the crisis. As conceptualized here, people can either stay in the system or leave. There is no emigration during the crisis period, as this model focuses on the efficient or inefficient removal of people from a crisis.

$$\begin{aligned} & \frac{d}{dt}(People\ Exposed\ to\ Crisis) \\ & \qquad = -Successful\ Evacuation - Unsuccessful\ Evacuation \\ & \qquad - Death\ from\ Crisis \end{aligned} \tag{4}$$

Of interest in a model like this is the relative fraction of each of the different dispositions of people over time, including overall survival rate. This becomes a matter of accounting, keeping track of those of the initial endowed population who exit the system under each of the different disposition routes defined above.

$$Died\ from\ Unsuccessful\ Evacuation\ (t) = \int_0^t Unsuccessful\ Evacuation \tag{5}$$

$$Died\ from\ Crisis\ (t) = \int_0^t Death\ from\ Crisis \tag{6}$$

$$Survial\ Rate(t) = 1 - \frac{Died\ from\ Unsuccessful\ Evacuation\ (t) + Died\ from\ Crisis\ (t)}{People\ Exposed\ to\ Crisis_{t=0}} \tag{7}$$

These core mechanisms define both the state space of the model, and the essential output metrics by which the behavior of the model can be judged. The subsequent subsections elaborate on how the inputs into this differential equation model were developed.

2.1. Capturing Effect of Activities on Stress (Concern for Safety)

The key state variable *Concern for Safety* is conceptualized here as being normalized to a value of 1, and when larger than 1 drives a desire in the population to act to reduce this level of concern, either through directly mitigating the source of the concern, or by removing people from the crisis. Stated differently, *Concern for Safety* is a motivating stressor that can be mitigated by either reducing the source of that stress (mitigating the crisis), or by removing oneself from the stressor outright (evacuating from the crisis).

First, consider the relationship between how the level of concern affects the fraction of effort devoted towards evacuation (versus mitigation). For this model we assume that evacuation is one-way (there is not return to the system after exit), and that at most 100% of available resources or activities can be dedicated towards either evacuating, mitigating the degradation of system capability, or sit idle. A number of different functional choices could work here, including a logistic model. For simplicity, this work assumes a ‘blocky’ logistic model, bounded between 0 and 1 with a linear progression between controlled by a sensitivity factor.

$$Effort\ Fraction\ Devoted\ towards\ Evacuation$$
$$= max(0, min(1, Concern\ Response\ Sensitivity * Concern\ for\ Safety - Concern\ Response\ Sensitivity)) \quad (8)$$

This function is visualized for various values of the sensitivity factor in Figure 1.

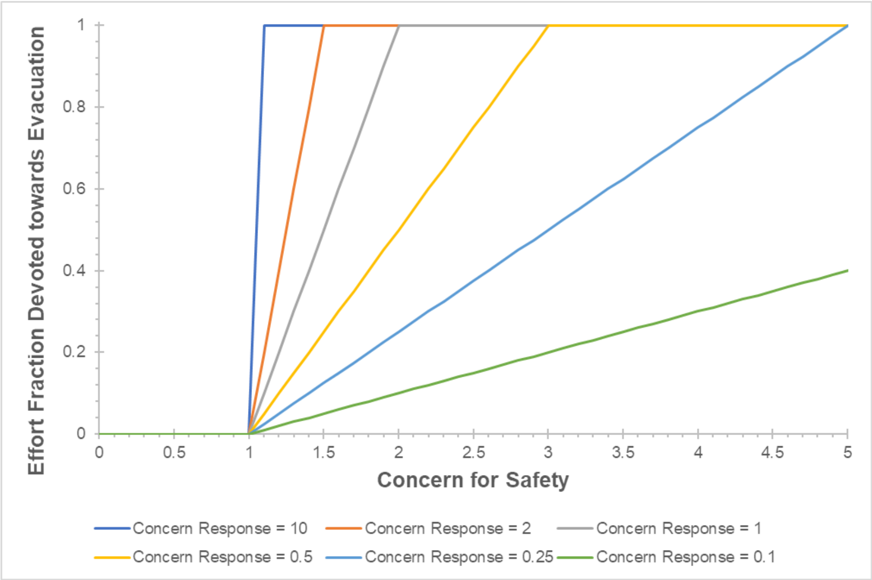

Figure 1. Functional Form Examples with Different values for 'Concern Response Sensitivity'

Next, consider the effect on stress from the perception of crisis mitigation activities going around the individuals currently under stress. We can now ask ourselves what is the *valence* of this stressor (positive or negative). Evacuation, e.g. fleeing the modelled environment, can be assumed generally to always drive-up concern as this supposes that others have made the assertation that staying in the system is not worth it anymore.

Mitigation is an active attempt to reduce the degradation of system capability. However, the witnessing mitigation efforts can have either a positive valance (calming) or a negative valance (stressing). A visualization of the structure is seen in Figure 2 below.

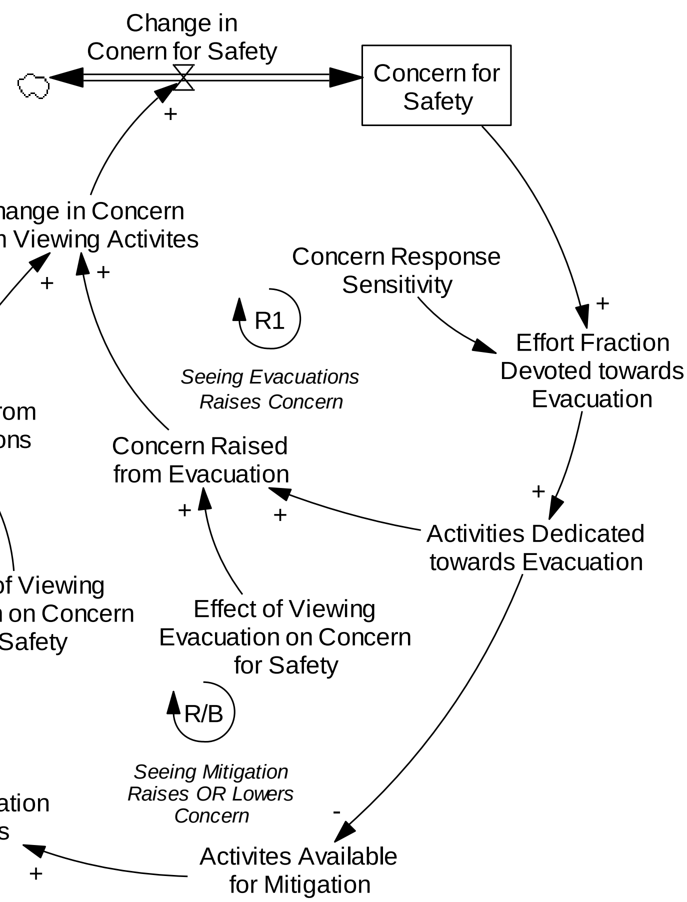

Figure 2. Concern for Safety and Seeing Mitigation or Evacuations

Note that the polarity of loop through *Crisis Mitigation Efforts* can be reinforcing or balancing. It is reinforcing if sign if the valance on *Effect of Viewing Mitigation on Concern for Safety* is positive (e.g. viewing crisis mitigation activities is stressing), or balancing if the valance is negative (e.g. viewing crisis mitigation activities is calming).

2.2. Capturing Effect of Stress on Performance

As discussed in the introduction to this paper, the effect of stress on performance has been a central feature of many prior pieces of literature, and the topic of focused research efforts (Rudolph & Repenning, 2006; Teigen, 1994; Yerkes & Dodson, 1908)

This work adopts a similar approach to this prior literature by considering both the positive and negative effects of stress on the net output efficiency of individual effort. Specifically, this work adopts a functional form very similar to that employed by Rudolph & Repenning 2006, with two different logistic functions combining together to generate the characteristic Yerkes-Dodson curve, and visualized in Figure 3 below.

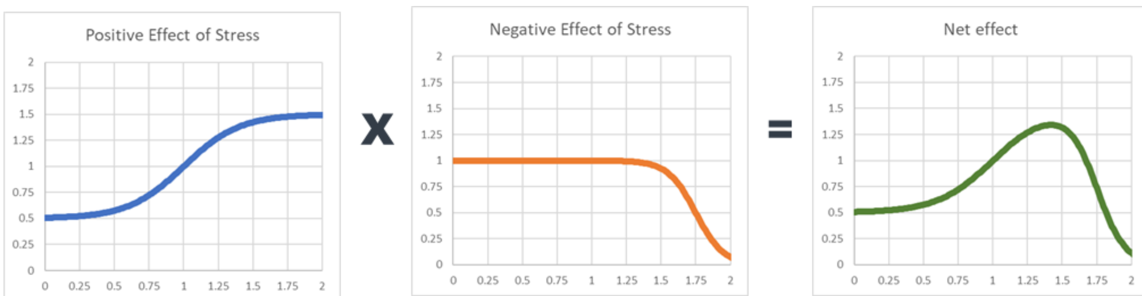

Figure 3. Example of the Decomposition of Positive and Negative Effects of Stress

The structure shown in Figure 2 can now be expanded as shown in Figure 4.

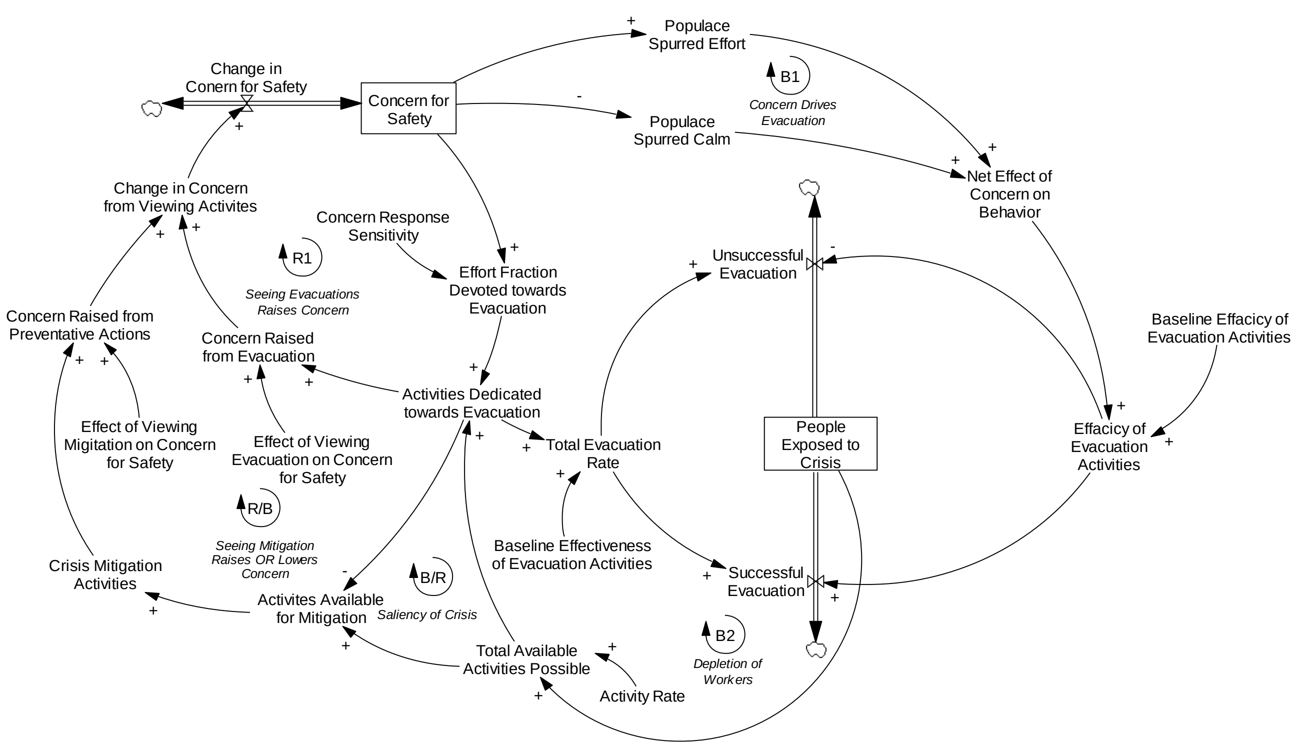

Figure 4. Stress Response Feeds into Efficacy of Evacuation

Note that evacuation is *not* assumed to be successful. *Efficacy of Evacuation Activities* shown in Figure 4 is affected by the level of *Concern for Safety* (i.e. stress). At moderate levels of concern, efficacy of evacuation efforts may increase, but at high levels of concern, efficacy may be undermined.

As the capability becomes lower, the system is less able to respond support life. Below a critical threshold, it is assumed that people begin exiting the system not through successful or unsuccessful evacuation but rather though the action of the crisis itself.

$$Death\ from\ Crisis = max(0, if\ then\ else(Capability\ to\ Resist\ Crisis < Minimum\ Viable\ Capability, People\ Exposed\ to\ Crisis / Avg\ Time\ for\ Death\ Under\ Crisis, 0)) \quad (9)$$

Note that the above formulation assumes a first-order decay that kicks in only after a critical threshold has been reached. This is a structural assumption of this model, but one not central to the dynamics explored below.

2.3. Capability to Manage (Resist) a Crisis

As discussed above, the resources or activities available in this system can be spent on either evacuating, or mitigating the degradation of capability onset by the crisis (or left idle). The exogenous crisis erodes capability, but mitigation can rebuild it.

The capability rebuilding is, for simplicity, modeled as a first-order goal-seeking mechanism, limited only by the number of resources available in the system. This is visualized in Figure 5, noting loop *B3* captures this rebuilding mechanism.

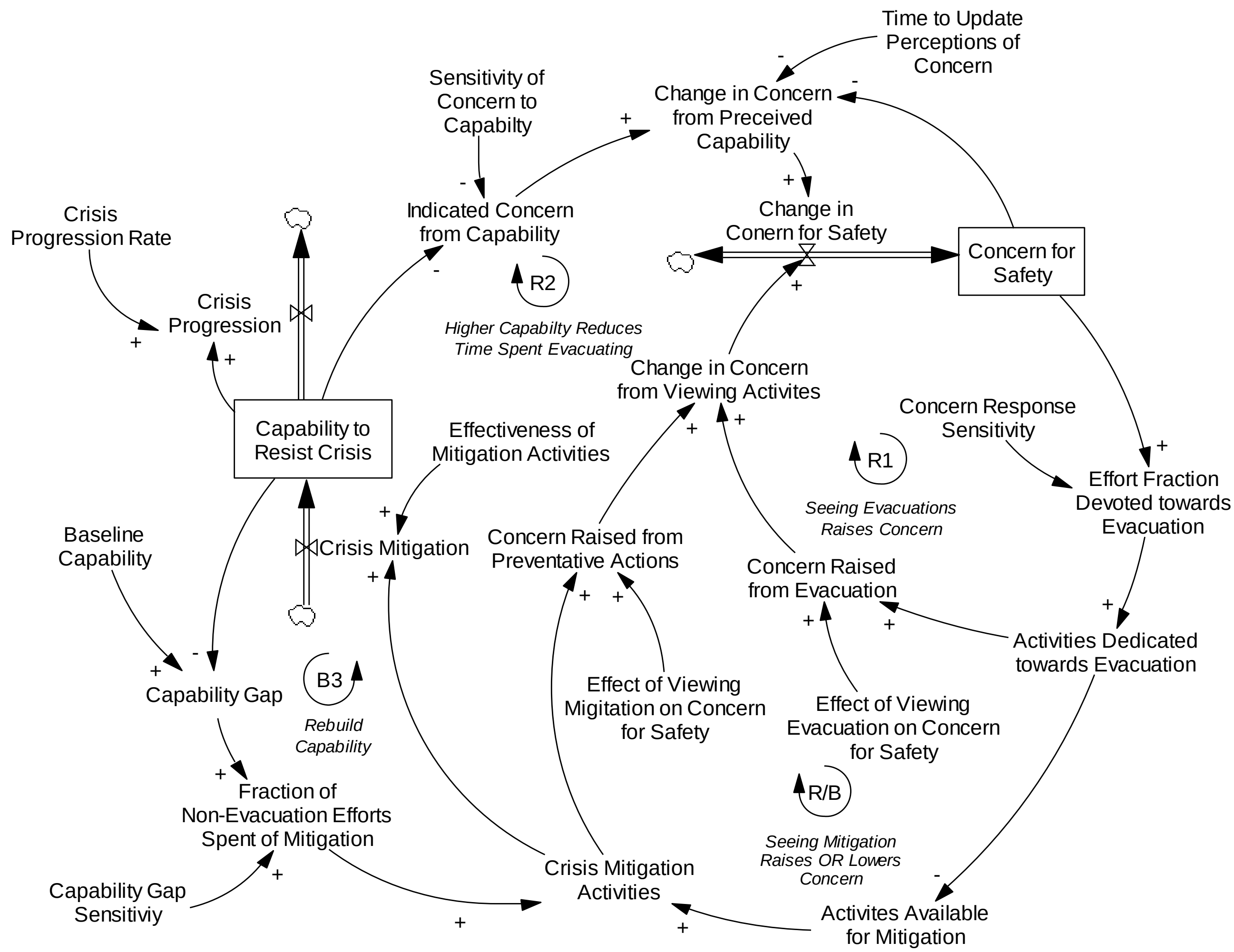

Figure 5. Concern for Safety affects Efficiency of Evacuation Efforts

Note that the structures in Figure 4 (describing evacuation efforts) and Figure 5 (describing mitigation efforts) are actively competing for activities. The available activities themselves are dependent on the number of people in the system available to do this work.

$$\begin{aligned} &\mathit{Total\ Available\ Activities\ Possible} \\ &\qquad = \mathit{Activity\ Rate} * \mathit{People\ Exposed\ to\ Crisis} \end{aligned} \tag{10}$$

$$\begin{aligned} &Activities\ Dedicated\ towards\ Evacuation \\ &\quad = max(0, Total\ Available\ Activities\ Possible \\ &\quad * Effort\ Fraction\ Devoted\ towards\ Evacuation) \end{aligned} \tag{11}$$

$$\begin{aligned} &Activities\ Available\ for\ Mitigation \\ &\quad = Total\ Available\ Activities\ Possible \\ &\quad - Activities\ Dedicated\ towards\ Evacuation \end{aligned} \tag{12}$$

Observing the system capability to resist crisis is assumed to also be a source of stress for those in this system. As the system becomes less capable, the risk of death (or stated more broadly being forced to the exit the system due to the crisis) increases. This is shown as the loop *R2* in Figure 5.

The degree of response to this stressor was model using a decreasing function described below and visualized with different sensitivity parameters in Figure 6.

$$\begin{aligned} &Indicated\ Concern\ from\ Capability \\ &\quad = Sensitivity\ of\ Concern\ to\ Capability \\ &\quad * (Sensitivity\ of\ Concern\ to\ Capability\hat{}(-1 \\ &\quad * Capability\ to\ Resist\ Crisis)) \end{aligned} \tag{13}$$

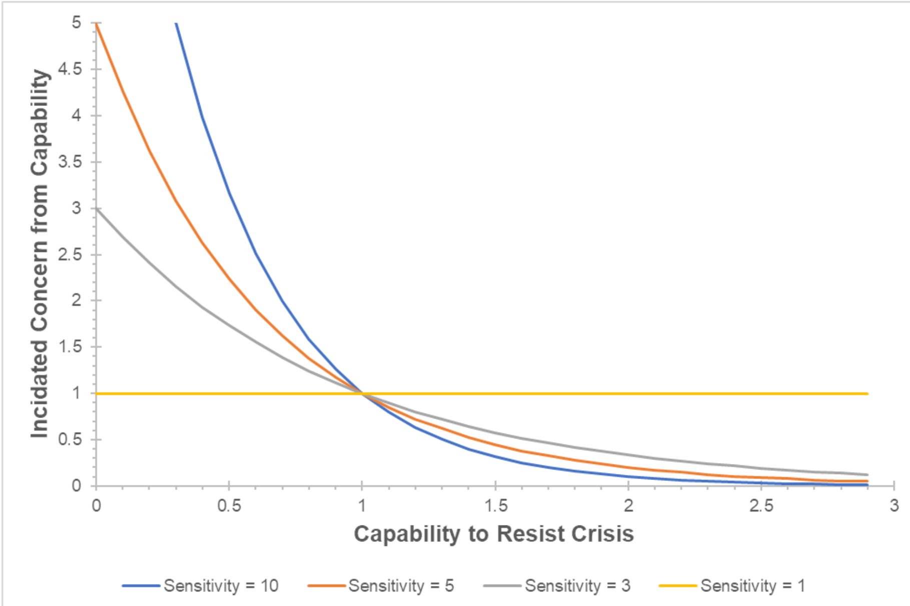

Figure 6. Functional Form Examples with Different values for 'Sensitivity of Concern to Capability'

2.4. Fully Combined Dynamic Hypothesis

A fully combined visualization of the model, combining Figure 2, Figure 4, Figure 5 along with annotations is shown in Figure 7 on the next page.

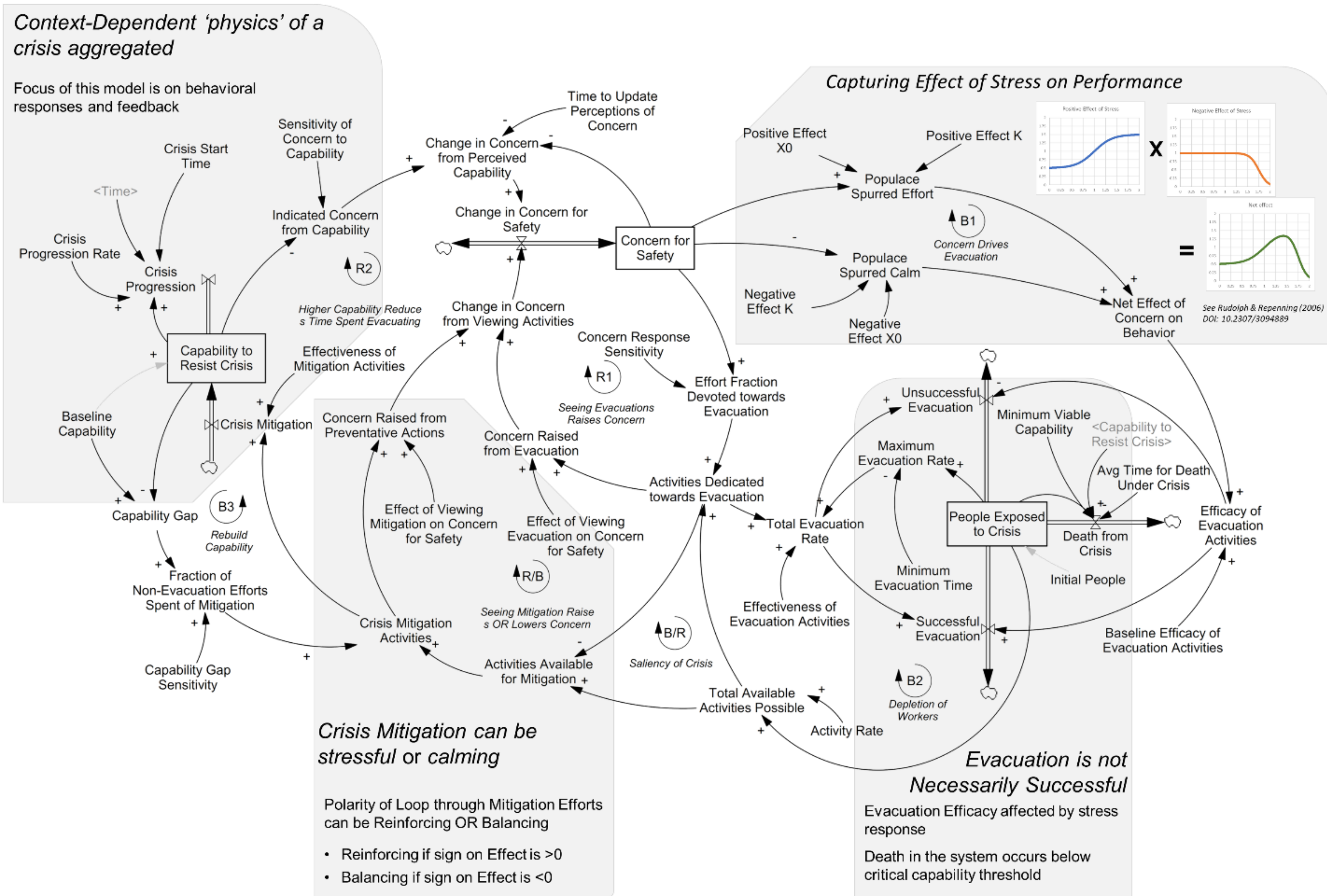

Figure 7. Full Model with Annotations on Key Structures

3. Exploring the Dynamic Behavior

The model was first parametrized using the baseline values in Table 2.

Table 2. Baseline Parameterization of the Model

Parameter	Baseline Value	Units
Activity Rate	1	Activities/Person/Hour
Avg Time for Death Under Crisis	1	Hour
Baseline Capability	1	Dmnl
Baseline Efficacy of Evacuation Activities	0.5	Dmnl
Capability Gap Sensitivity	1	Dmnl
Concern Response Sensitivity	0.05	Dmnl
Crisis Progression Rate	0.5	Dmnl/Hour
Crisis Start Time	10	Hour
Effect of Viewing Evacuation on Concern for Safety	0.25	Dmnl/Activity
Effect of Viewing Mitigation on Concern for Safety	0.01	Dmnl/Activity
Effectiveness of Evacuation Activities	1	People/Activity
Effectiveness of Mitigation Activities	0.05	Dmnl/Activity
Initial	100	People
Minimum Evacuation Time	5	Minutes
Minimum Viable Capability	0.01	Dmnl
Negative Effect K	-10	Dmnl
Negative Effect X0	1.75	Dmnl
Positive Effect K	5	Dmnl
Positive Effect X0	1	Dmnl
Sensitivity of Concern to Capability	5	Dmnl

As an exploratory analysis, this section first varies intensity of how fast the crisis erodes the system's capability to support life (*Crisis Progression Rate* in the above table) to verify the model behaves as expected and provide some degree of validation of the structural assumptions.

This baseline behavior and dynamics is as expected, as seen in Figure 8 and in Figure 9. The rate at which crisis erodes capability largest driver of survival rate. Faster erosion of capability leads to a quicker response, but also more stress. People evacuate quicker, but eventually at decreasing efficacy.

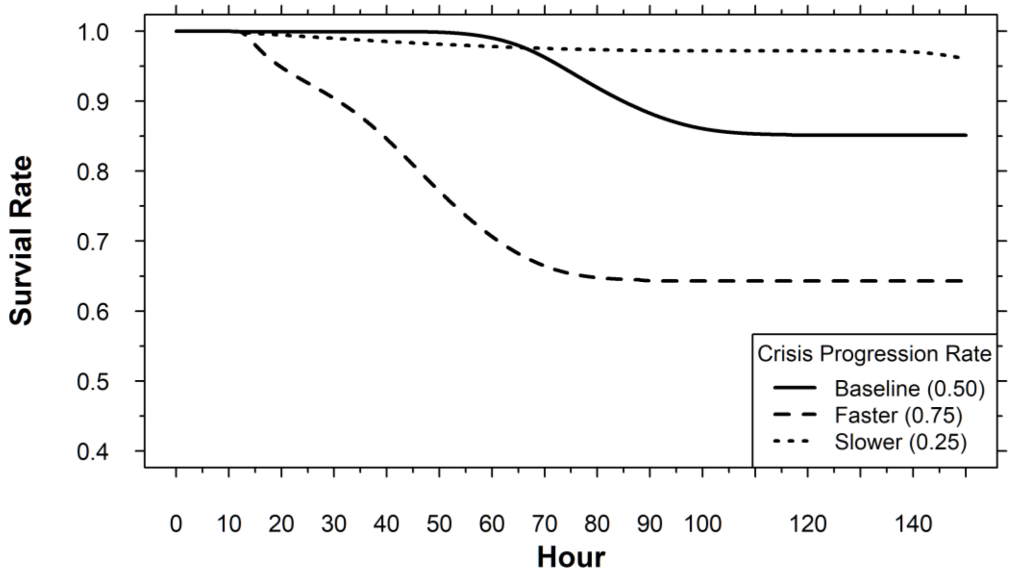

Figure 8. Model Behavior Using Baseline Parameters Across Different Crisis Progression Rates

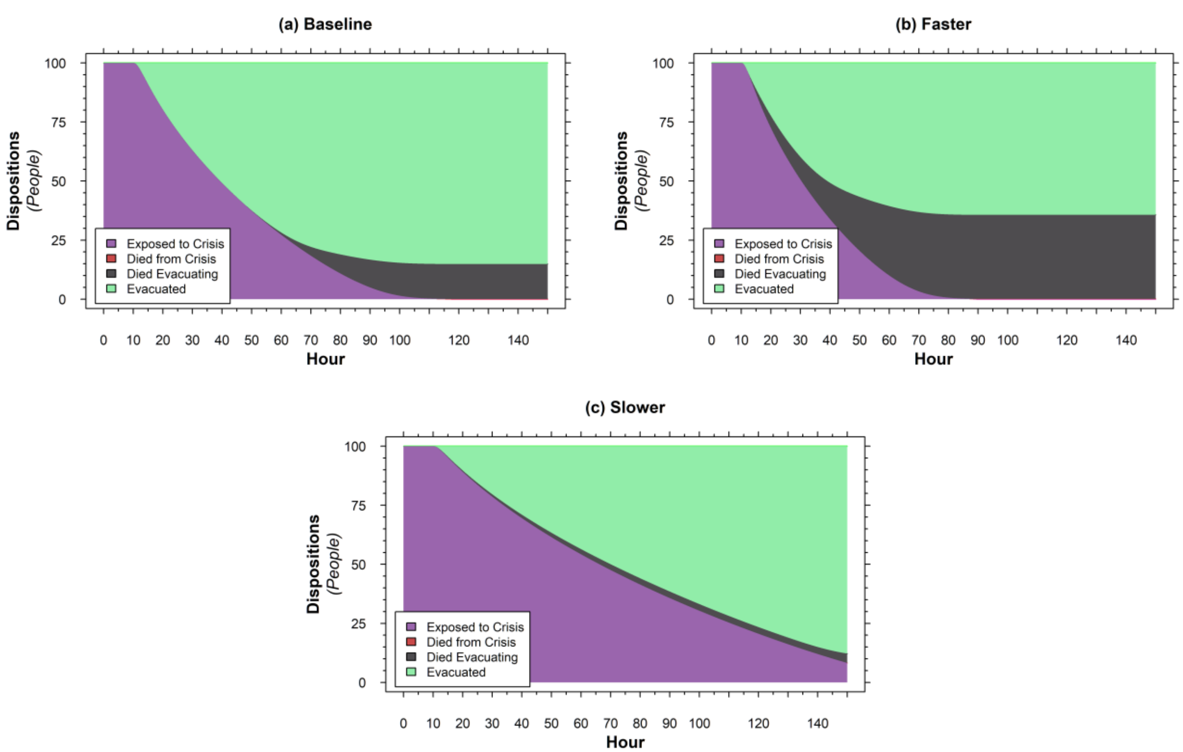

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Figure 9. Outcomes Using Baseline Parameters and Varying Crisis Progression Rates

3.1. Varying Effectiveness of Mitigation Activities

Next, this section varies the *Effectiveness of mitigation activities.* From strictly positive, but small, versus a value of zero (e.g. mitigation that has no effect on capability building). The results of this analysis on the key output metric of traces of population dispositions and survivability are seen in Figure 10.

As expected, less effective mitigation leads to quicker evacuation (as the system capability degrades faster) but also more deaths. Totally ineffective mitigation leads to significant deaths from the crisis itself .

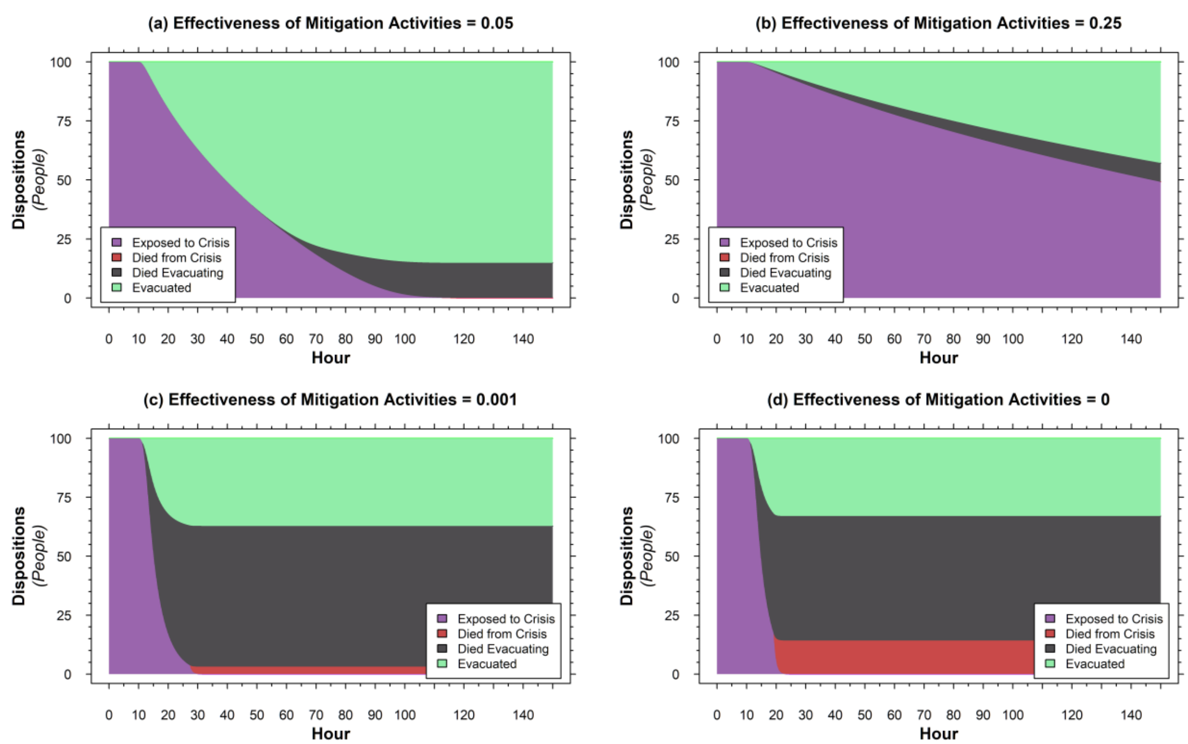

Figure 10. Outcomes Using Baseline Parameters and Varying Effectiveness of Mitigation Activities

3.2. Varying the Effect from Viewing Mitigation

Next, in order to derive more insights from this model, this section varies *Effect of Viewing Mitigation on Concern for Safety* from strictly positive (stressing) to strictly negative (calming).

More stressful mitigation means faster evacuation, but an evacuation effort that is in net less efficacious. Calming, but still effective, mitigation can increase evacuation efficaciousness, or even outright allow the population to prevent crisis from progressing as seen in Figure 11 (d) specifically. Here, people don't panic and flee, and instead spend effort maintaining system capability.

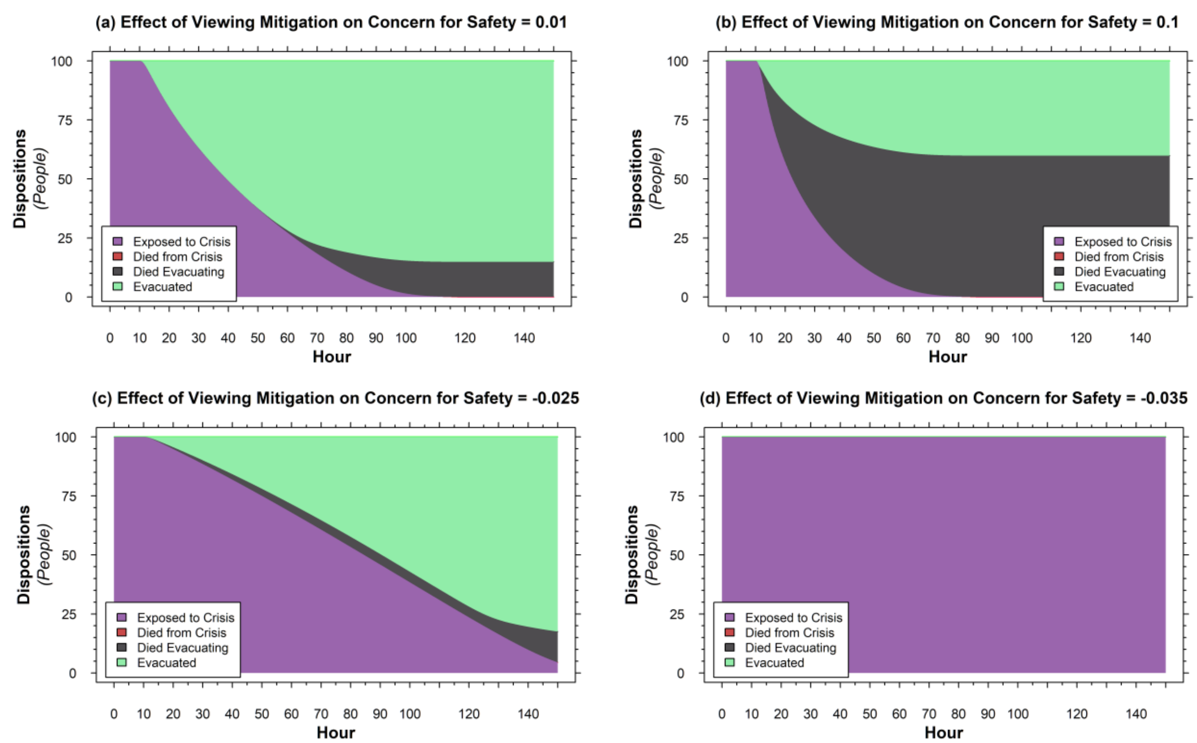

Figure 11. Varying Effect of Viewing Mitigation on Concern for Safety

Figure 12, which shows the trace of the key stocks (versus figure above which shows outcomes), shows another view of the dynamics that lead to this outcome. Mitigation forms reinforcing loop that causes system to avoid collapse (e.g. loop *B3* in Figure 7 remains significantly dominate over loop *R2*).

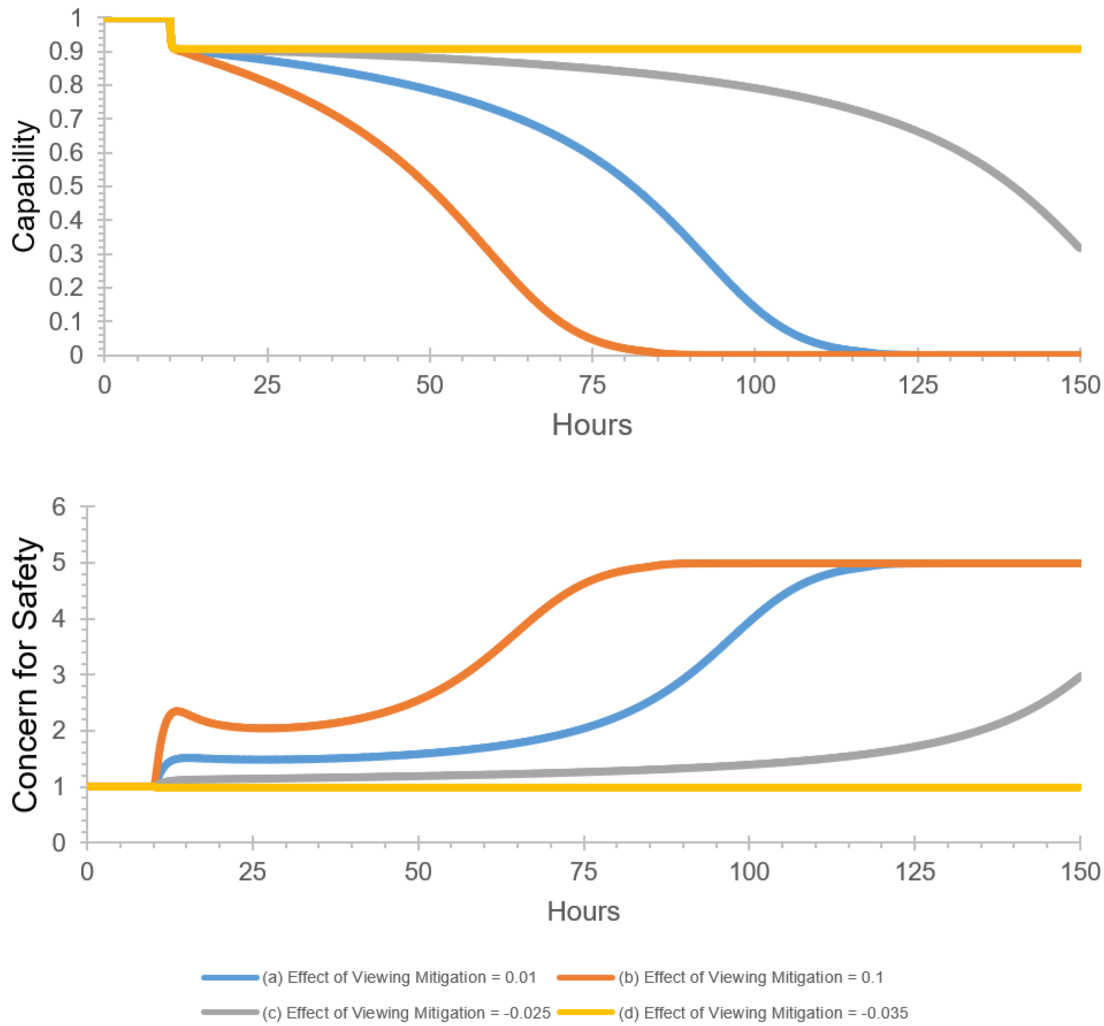

Figure 12. Trace of Key Stocks of at Different Values of Effect of Viewing Mitigation

3.3. Outcomes with Totally Ineffective Mitigation

Note that in the scenario described at the end of the prior subsection in which mitigation activities allow for the crisis to be fully offset, the *effectiveness of these mitigation activities* on offsetting the crisis is positive (specifically with a value of 0.5 here from Table 2).

However, what if effectiveness of the mitigation activities is *not* positive? In that case, the previous positive effect of calming mitigation lost when mitigation is totally ineffective, as seen in Figure 13.

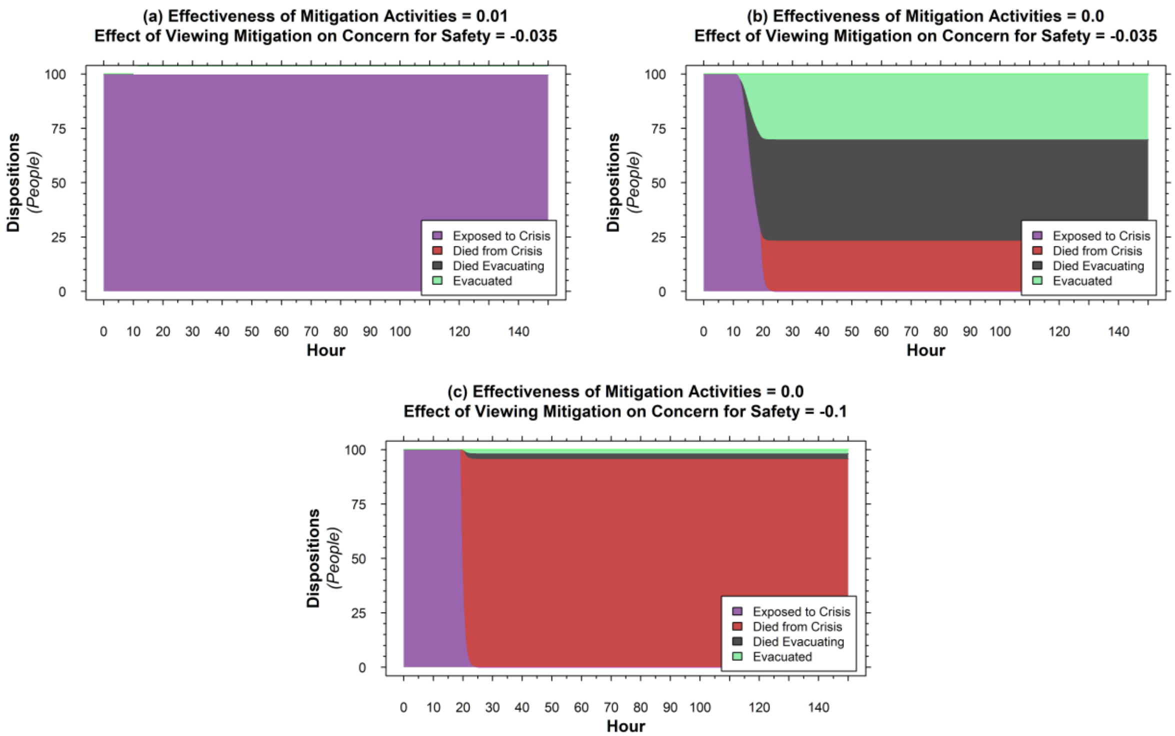

Figure 13. Effect of Viewing Mitigation on Concern for Safety is Calming (negative value) with Varying Effectiveness of Mitigation

For very calming mitigation as seen in Figure 13 (c), can get ‘head in the sand’ outcome. Here, migration activities are both ineffective at actually stopping the crisis from unfolding, but also actively calm the population, meaning that evacuation levels are negligible and the final disposition of the population is almost entirely death from the crisis.

4. Further Discussion and Applications

The behavior shown Figure 13 (c) maps directly to the traditional definition of the expression of “rearranging the deckchairs”. In that scenario, mitigation activities are useless but calming. They provide a means to keep the population distracted and calm but do nothing to either prevent the disaster from unfolding, nor motivate evacuation.

Again mitigation activities can have two purposes: buying time by slowing down the evolution of a crisis, and calming people down to prevent unnecessary deaths from inefficient use of resources. However what this model clearly illustrates is that if too calm, then the population can ignore the problem at hand before it is too late.

This work raises a very practical question: how does one identify effective versus ineffective mitigation? This is not a trivial question to answer. In this model, the difference between these two outcomes is a marginal adjustment in a single parameter. In real life, this is the subject of intense debate during any crisis, both local and global.

Consider the ongoing debate around the use of resources for either mitigation or adaptation to climate change. While much work has been done to show the complementary nature of these approaches, there is still a general perception that expending resources on one of these avenues comes (in the short term) at the expense of the other (Campbell & Krol, 2023; Intergovernmental Panel On Climate Change (Ipcc), 2023; VijayaVenkataRaman et al., 2012; Watkiss et al., 2015). Using the language of this framework developed here, this is an argument on how effective the mitigation efforts are to begin with, and if such mitigation efforts are simultaneously calming enough while being ineffective enough to create a larger crisis down the road. To be clear, this paper does not offer a specific stance on mitigation versus adaptation for climate change response, but rather presents this framework as tool to help in this discussion around comparing different options.

The work presented here was originally conceptualized as a framework to help determine when a mitigation effort is actually meaningful or just “rearranging the deckchairs.” That effort has been successful, but work still needs to be done in applying this framework directly. The climate change example described above is of immediate interest, but provides a risk of clear use of this framework precisely because we are all embedded in that crisis right now. The ability to perceive if a mitigation activity is even marginally effective is difficult when the crisis is unfolding around us all. Other applications of this framework could be in regards to recent humanitarian crises, such as the Syrian Civil War and the COVID-19 pandemic. These are recent and still evolving crises, but with distinct early mitigation efforts that have already shown their effectiveness. These present an opportunity to confirm or refute the general observations developed above.

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