Geosimulating Hazard Warning Triggers:

Geometry, Dynamics, and Timing

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Abstract

Warning triggers are a means to answer the question: who should be warned to take a protective action in a disaster and when? A warning trigger is comprised of a target population, a recommended protective action, and an environmental condition – where the target population is warned to take the action if the condition occurs. While triggers have been studied across different hazards for specific study areas, they have not been explored from a general geometric perspective. The goal of this study is to apply geosimulation to compare the efficacy of two geometric approaches to defining warning triggers using assumptions regarding threat dynamics, decision making, and public response. The results reveal strengths and weaknesses of each approach that may help inform decision makers on which trigger type would be most effective in a given threat scenario.

Keywords: hazards, public warnings, triggers, geosimulation.

1. Introduction

Warning triggers are a means to answer the question: who should be warned to take what action and when (Cova et al. 2017)? A warning trigger has three components: 1) a threatened target population, 2) a recommended protective action, and 3) an environmental condition, such that the target population will be warned to take the protective action if the condition occurs. A common environmental condition is the threat crossing a geographic threshold. Examples include warning a community to seek shelter if a tornado comes within 5 miles of a town, or ordering wildland fire fighters to retreat if a wildfire crosses a fire break. Setting warning triggers in real-world disaster events is challenging and common errors include warning a community too late to complete the protective action, and warning a community that is not at risk which leads to unnecessary disruption.

Applied studies on warning triggers are a current research topic (Li et al. 2015; Beloglazov et al. 2016; Steer et al. 2017) but triggers have not been explored from abstract geometric perspective. Studies tend to be hazard and place-specific where the findings apply to the particular threat scenario and study area. Adopting a more generalized approach to testing trigger efficacy may lead to general findings that hold across environmental hazards and study areas. An example general question might be: in what hazard scenarios is one warning trigger method more effective than another?

The objective of this research is to develop an initial geosimulation framework to compare methods for setting warning triggers using simulated threats, decision making, and human response. The goal is to improve understanding of triggers independent of any particular threat or place.

2. Methods

The geosimulation framework developed allows a user to define the threat scenario and select a trigger method. The simplest geometric case is to represent both a threat and vulnerable target (populated place) as point objects. The speed and direction of the threat can be constant or variable. For example, one threat might appear at a given location and move at a constant speed and direction for a fixed duration, but another threat might be able to accelerate, decelerate or change direction, which represents a greater challenge in setting an effective trigger.

Figure 1 depicts cases where a threat appears at a random location and moves in a constant direction and speed for a given duration. A community is shown in green with a fixed-radius trigger, such that the community is warned if a threat crosses the buffer boundary. Three cases are shown: a 'miss' where a warning was not triggered, a 'near miss' where the community was warned but the threat missed, and a 'hit' where the community was warned and impacted.

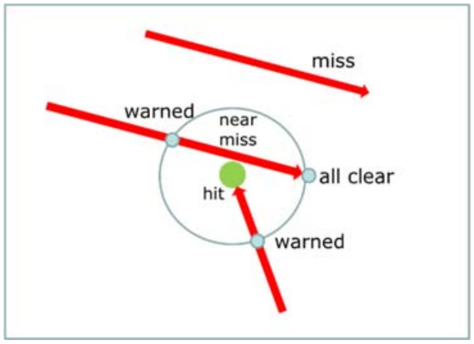

Figure 1: Threat cases (red arrows) near a community (green circle) with a warning trigger buffer.

The framework was implemented in Python and includes parameters that can be used to define the threat dynamics, trigger type, and community response. Two types of threat movement are considered: constant and variable. In the constant case, a threat moves at a constant direction and speed for a random duration, and in the variable case the threat randomly changes direction and speed according to parameters that define how often and dramatically. The constant case represents relatively predictable threats, and the variable case simulates threats with less predictable movement dynamics. Figure 2 depicts an example threat where its speed and direction are randomly perturbed as it progresses.

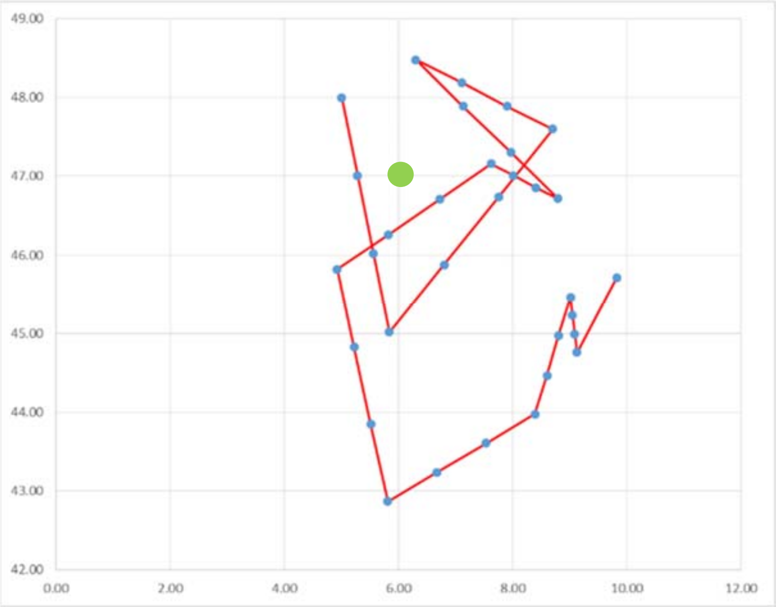

Figure 2. A point-based threat with semi-random movement (speed and direction).

The two trigger types applied: fixed-radius and variable radius. The fixed-radius trigger relies on a distance parameter that creates a circular buffer (e.g. 10 miles). In this case, decision makers are confident in the speed of the threat, such that a given distance will offer suitable time. The variable trigger adapts according to the threat's speed toward the community in an attempt to offer a minimum amount of time for the community to respond.

Figure 3 depicts an example variable trigger for two threats. The trigger is designed to offer 10 hours of warning, so it would moving further from the community if the closing speed of the threat increased or closer if it decreased. The left side shows a threat moving at 1 mph which requires that the warning trigger-point be set 10 miles from the community such that 10 hours is available to respond. The right side shows a threat moving at a speed of 0.5 mph, so the trigger point is 5 miles from the community (i.e. 5 miles offers 10 hours of time). The threat speed towards a community is calculated at each time step based on the Euclidean distance difference between the threat and the community in the last time step and current time step. This rate can range from 0 in the case where the threat is moving away from the community to the threat's forward speed if it is on a direct path towards the community.

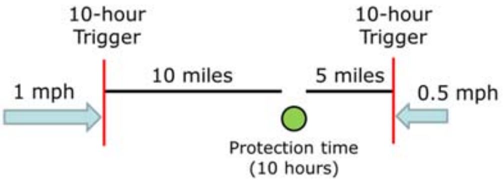

Figure 3. Variable-distance warning trigger (red lines) with two threat speed cases (blue arrows).

The key parameter for community response is the percent of the community that adopts the protective action in each time step. If this parameter is set to 10% for 'evacuate', then ten percent of the population would evacuate in each time step (i.e. 10 time steps to evacuate the community).

In each experiment, a series of outcome metrics are computed to assess the trigger method efficacy. Table 1 shows the metrics that are computed at the end of N simulation runs. The most important metric in assessing trigger efficacy is “cleared (hit)”which is a count of the number of times the trigger led to a successful clearing (evacuation) of a community which was then hit. The most important metrics in assessing the failure of a trigger are “not cleared (hit)” and “not cleared mean (hit)” which refer to the number of times the community was impacted when it was not cleared (evacuated), as well as the mean percent of the population that was able (or not able) to clear the area in time. To a lesser extent, similar metrics are important for assessing trigger efficacy when a community was missed, but in this case the problem is unnecessary disruption when the threat missed. This is a lesser problem than not evacuating everyone given a direct hit, but a perfectly effective trigger would warn a community in time to successfully evacuate in cases that led to a direct hit but never in cases when the community was missed.

Outcome metric	Type	Description
Missed	Count	No warning triggered
Warned and missed	Count	Warning triggered; threat missed community
Warned and hit	Count	Warning triggered; threat hit community
Cleared (miss)	Count	Warning triggered; community successfully cleared
Not cleared (miss)	Count	Warning triggered; community not cleared
Not cleared mean (miss)	Percent	Mean percent cleared when community not cleared
Cleared (hit)	Count	Warning triggered; community successfully cleared
Not cleared (hit)	Count	Warning triggered; community not cleared
Not cleared mean (hit)	Percent	Mean percent cleared when community not cleared
Inside (missed)	Count	Threat originated inside trigger buffer but missed
Inside (hit)	Count	Threat originated inside trigger buffer and hit

Table 1: Outcome metrics recorded at termination of N runs.

3. Results

Figure 4 shows the results for a fixed-radius trigger and a threat with constant movement. The community has a 1 mile radius, and a hit was defined as the threat crossing the community edge. The percent of the community that evacuates was set to 10% per time step (1 hour), so 10 hours would be necessarily to evacuate everyone successfully. Under the 2 mile trigger radius, there was no case where the entire community was successfully evacuated. However, as the trigger buffer was expanded to offer more warning time, an increasing percent of cases occurred where the entire community was able to evacuate. Note that this percent never reaches 100 because a larger trigger buffer leads to more cases where the threat originates inside the buffer. A community is still warned when this occurs (in the current system), but it will have less time to act than if the threat had originated outside the buffer. This also explains why the percent successfully evacuated does not increase monotonically with the trigger radius – it depends on the percentage of threat events that occur within the trigger buffer.

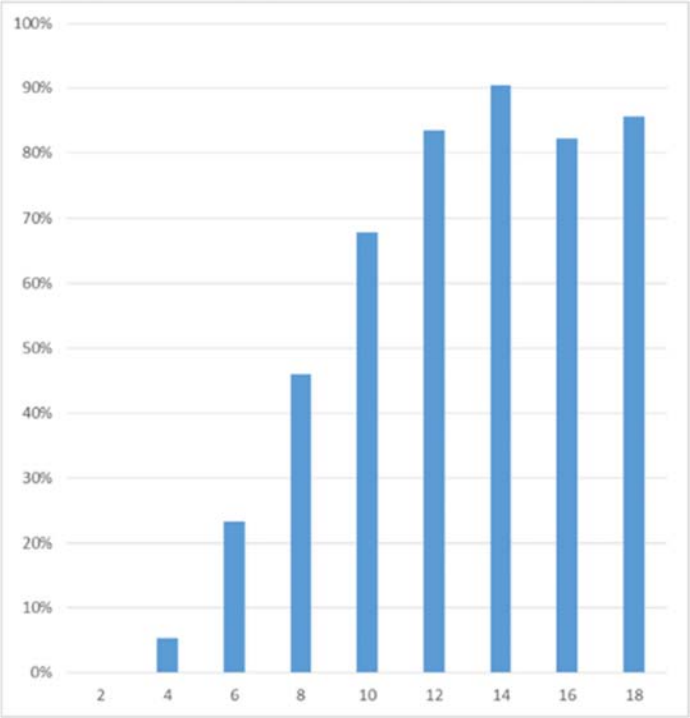

Figure 4. Fixed-radius trigger success (% community cleared) by trigger radius (miles).

Figure 5 shows a more complex case where a threat has variable speed and direction, and a variable trigger buffer was applied. In this case the trigger buffer can expand or contract according to how fast the threat is closing in on the community. This can be viewed as a scenario with very adaptive decision makers who are monitoring threat movement and attempting to offer the community 10 hours to evacuate given a threat with variable speed and direction. The x-axis represents the time that officials wish to offer the community to be able to respond. However, because the threat has variable speed, it can accelerate and reduce this time or decelerate and increase it. The histogram shows that attempting to offer 2 hours of warning time led to a success rate of 13% (i.e. all community residents evacuated prior to impact). This was As warning time is increased, a greater success rate is achieved, but a 100% success rate is not possible because of the increasingly common case where the threat originated inside the buffer.

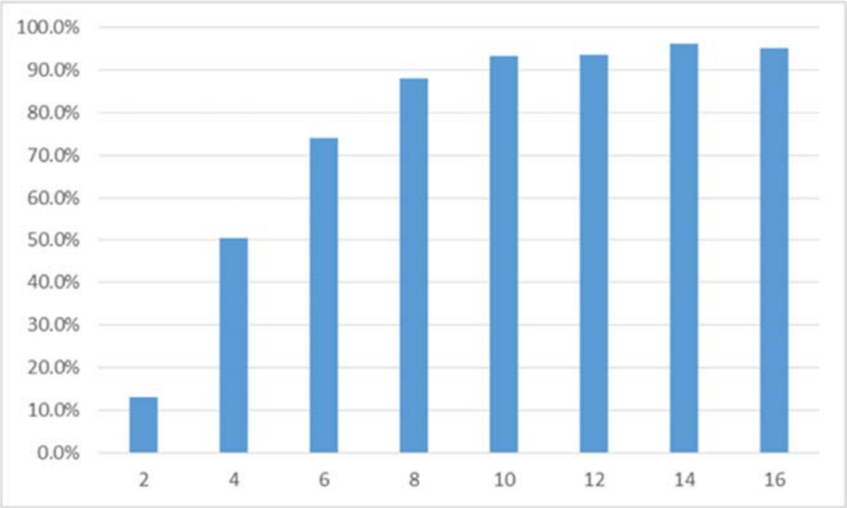

Figure 5. Trigger warning time (hours) against percent cleared (0-100)

4. Conclusion

Warning triggers vary in their efficacy according to the threat and scenario context, but their assessment is an exercise in assumptions. The geocomputational experiments in this study are very simplistic, but there is a tradeoff as adding detail for a specific hazard and place yields findings that are hazard and place-specific. There is much more that can be done towards comparing and assessing trigger efficacy in terms of developing this framework.

5. References

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