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Modeling Spontaneous Volunteers in Cross-Border Crisis Scenarios

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Abstract: The rise of social media has led to a new degree of spontaneous volunteering in the aftermath of disasters, even in border areas. However, spontaneous volunteering across national borders creates further obstacles that need to be addressed and prepared for. This paper introduces an agent-based simulation to examine coordination procedures of spontaneous volunteers in crisis scenarios, particularly the specifics of travel restrictions imposed after the COVID-19 pandemic. Moreover, research is conducted on the effects of insufficient or delayed coordination of the population's offer of voluntary help, which reduces the motivation of volunteers and leads to missed request for help.8. The results show that coordination of spontaneous volunteers is a key factor for helping the affected population, especially in a pandemic, where the possibilities to help are limited. These results are discussed with regard to costs that need to be considered in order to establish coordination, as well as health issues and motivation of spontaneous volunteers in different coordination scenarios.

Keywords: cross-border; crisis management; agent-based modeling; spontaneous volunteers

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1 Introduction

The role of spontaneous volunteers (SV) has been discussed in scientific literature for many years and practical concepts for the involvement and coordination of volunteers who travel to disaster sites with the desire to help and support can also be found in practice. In the context of cross-border crisis scenarios – i.e. scenarios that cross political and functional borders (Ansell, Boin, and Keller 2010) and have a direct impact on border regions – , SV play a special role. Since planning in civil protection is already predominantly related to individual countries (Ondarza and Parkes 2010), no cross-border coordination of SV has been preplanned thus far. This is remarkable since, for example, 30 % of EU citizens live in border regions, occupying 40 % of the area, and there are more than two million people crossing borders for work. Natural river courses, mountains, or coasts often form national borders and, consequently, border regions share risks and hazards (Tokarski 2021). Additionally, the (critical) infrastructure in Europe, such as the energy infrastructure or transport infrastructure, are interconnected. In the event of a failure or malfunction, the population of various countries may suffer significant consequences. It is therefore to be expected that, when crises and disasters develop in border regions, the affected bordering population will become active as spontaneous volunteers (Table 1).

This study addresses the role of SV in cross-border crisis scenarios, focusing on the socio-economic cross-border networks of countries which affect citizens' lives, on the one hand, and the fact that individual countries have their own planning for disaster prevention and crisis management, on the other. In the event of a disaster, these two aspects seem to be relevant to the emergence of SV, and it is also plausible to assume that SV also become active and provide support for other countries. To cite one example, this phenomenon was seen in the flood disaster in Central Europe in 2021: "The license plates reveal: many travel here, some even from Belgium and the Netherlands" (translated from an Article by Unger (2021) in Berliner Morgenpost).

The following sections examine these circumstances in depth. First, the basics of SV in a cross-border context are described, followed by briefly examining the significance of the COVID-19 pandemic as an SV cross-border scenario. As the scientific literature on the utilization of SV in border regions is still limited, this article extends an agent-based coordination framework to analyze the specifics of travel restrictions introduced due to a pandemic scenario. Moreover, it investigates the effects of missed requests for help from the population due to misleading assignment and decreasing motivation of volunteers when the tasks cannot be assigned timely.

2 Background

2.1 Spontaneous Volunteers' Fundamentals

SV have received considerable attention in research and practice in recent years, although the phenomenon of people gathering and working together to help in the aftermath of disasters is not a new one. As early as 1957, Fritz and Mathewson (1957) described how volunteers without affiliation to relief organizations travel to disaster sites to help. Included in their description were also first aid activities after accidents and local neighborhood help as activities of volunteers. The focus here is on groups that emerge after disasters, as described by Dynes (1970) as informal groups with non-regular tasks. Stallings and Quarantelli (1985) further identified five basic factors that favor the emergence and functioning of such communities: (1) the existence of an acute or imminent danger; (2) the perception of this danger by supra-regional organizations and the press, and the consequent attention to those helping; (3) a set of social norms and values shared by the group, which enables a consensus on the goal to achieve; (4) the establishment of new social relationships, including relationships with other organizations, which gives the group a certain legitimacy; and (5) the existence of sufficient resources to face the danger, such as information and skills but also material things (Stallings and Quarantelli 1985). Independent of group motivation, an individual's willingness to help often results from a personal relationship or identification with the victims (Fritz and Mathewson 1957, 47), in addition to a lack of authority in the initial phase. Another reason for this supporting behavior is the generally urgent need to help and to make a positive contribution in such a hopeless situation (Lowe and Fothergill 2003).

In recent years, special attention has been paid to SV in connection with social media, which has made the phenomenon even more visible after major disasters. In Europe, for example, volunteers used social media to organize themselves and support emergency services during the 2013 floods in the Elbe. The tasks that SV can perform range from the provision and supply of professional emergency forces (e.g. food) to goods and blood donations, and simple tasks, such as filling sandbags or even providing special machinery of local construction companies (Twigg and Mosel 2017). Research on the assignment of SV tasks after an event and SV coordination was undertaken by the research project INKA of the German Red Cross. GIS-supported coordination was addressed by the KUBAS research project (Sackmann et al. 2018; Schorr et al. 2014).

Other recent studies on SV discuss the improvement of the operational involvement and integration of SV in the structures of civil protection and preparation, as well as the response phase. For example, in a particular research project,

SV activities were specified and individual tasks with corresponding work requirement profiles were formulated in the form of an activity catalog (Drews et al. 2019). In consequence, civil protection units were able to recognize the potential of the helpers with the idea of using this knowledge in upcoming situations (Drews et al. 2019). The research project Wukas, which dealt with the topic of occupational health and safety for SV, was also built on this framework. In said project, easy-to-understand pocket cards were developed for instructing SV in occupational health and safety measures. Moreover, requirements for personal protective equipment were defined, and these could be carried by emergency response units to equip potential SV (Bier et al. 2022; BUW and Malteser 2021).

During the flood disaster in Central Europe in 2021, studies on SV recorded how the abovementioned concepts were used (Drews et al. 2021) while surveys of SV recorded their motivation to help, the duration of their commitment and the distance between their place of residence and the place of volunteering (Bier et al. 2023).

Further research can be found on technology-supported SV integration. The focus of the research project "KatHelfer" is on volunteers' cultural backgrounds, and the idea is to integrate volunteers via local community structures by using a smartphone application (Posselt 2023). A special topic in the field of SV with regard to technology is the unique forms of engagement, such as digital volunteers – i.e. people who take on coordinating activities in social media to manage SV, or other tasks such as mapping a disaster area. Institutionalized forms of volunteering in this area are Virtual Operations Support Teams (VOST), which draw on a pool of volunteers. VOSTs are affiliated with disaster relief organizations to contribute by analyzing social media content and they can, therefore, engage with SV (Fathi et al. 2020).

A broader overview on the different forms of civic engagement is provided by the ATLAS Engage research project, which records and categorizes the various forms of engagement. This is future-oriented research aiming to determine how social transformation will alter civic engagement in coming years. The question here is how voluntary engagement in society can be promoted in the future and how different forms of volunteering can be integrated in civil protection (Katastrophenforschungsstelle 2021). Despite the wide range of studies in the area of spontaneous volunteering, the specific context of spontaneous helpers in border regions is not sufficiently addressed in research.

2.2 SV in a Cross-Border Context

As stated in the introduction, special problems arise in the assignment of SV to border regions. These include that different countries feature different systems of volunteer assistance. However, a common understanding of the meaning of SV in different

countries is fundamental to the analysis. Thus, we follow a definition of SV that can be used across borders and includes the characteristics outlined in Section 2.1, such as being unaffiliated and arising spontaneously. A suitable framework covering these aspects can be found in International Organization for Standardization (2017), which defines SV as an "individual who is not affiliated with an existing incident response organization or voluntary organization but who, without extensive preplanning, offers support to the response to, and recovery from, an incident" (ISO 22319:2017-04, p. 1). This definition provides a framework for a mutual understanding.

To outline the relevance as well as to understand the specifics of SV in border regions, a brief look at some studies is presented here.

The study by Bier et al. (2023) takes the flood in the Ahr valley in Germany as an example to highlight the challenges of volunteers in a non cross-border context and outlines their relevance and expected application to borderland scenarios. First, the motivation to help is analyzed, but also the travel behavior of the helpers, as well as the integration into the structures of disaster management and the use of communication infrastructures by the volunteers.

In particular, the article of Bier et al. (2023) refers to the 2021 flood in Europe and focuses on the Ahr valley in Germany. Here, according to the German Federal Ministry of the Interior and Community (BMI 2022), up to 100,000 volunteers were on site. The article picks up on some exciting aspects that may also apply to volunteers in border regions: SV will travel to disaster areas in large numbers during large-scale disasters. It can be assumed that this is not only the case for regionally limited disasters, but also for cross-border disasters. They are motivated to do something good and identify themselves with those affected. To do so, they are also willing to travel great distances, i.e. it is not only the local/regional affected population that offers its help. This is supported by an empirical study of Klein, Wiens, and Schultmann (2022) investigating the social cohesion and the willingness to help each other especially in border regions. The findings of a representative study show that 63.6 % of respondents in the French-German border region are willing to help also in their neighboring country. The motivation of volunteers to cross national borders in order to provide on-site help is also addressed as well as a question on perceived problems. Here, the majority of respondents states the unfamiliarity with crisis response procedures of the neighboring country as main hindering factor. This is also pointed out by Bier et al. (2023) highlighting that the status quo in the involvement of volunteers in disaster management structures remains low, despite years of research and knowledge of the situation among practitioners (in Germany). In the Ahr Valley there has been (almost) no involvement of disaster management professionals and volunteers and the SV have been left to their own efforts and organize themselves

accordingly. The desire for integration or contact with the disaster control organizations is definitely present. There is also a potential recognized and demanded by the volunteers themselves to make their help more effective. The involvement of SV not only has advantages in terms of resource allocation, but can also avert hazards for the volunteers. This point is particularly relevant for cross-border scenarios as the SV may not know the emergency numbers in the other country or their insurance may not apply. Disaster areas pose risks that require instruction and equipment. However, as the equipment can be different in other countries, the correct use might not be known to volunteers. In addition, volunteers (as well as) professional forces are affected by psychological stress. Much of the coordination and communication among SV takes place via the Internet and social media, e.g. via Facebook and instant messaging services. Bier et al. (2023) conclude that in addition to individual aspects, these two things are essential to meaningfully integrate the help of SV: Coordination and communication. It must be ensured in advance that the authorities have the competencies and structures to actively involve helpers (across borders). In particular, it is to note that authorities need to be able to deal with different languages to address helpers also from other countries.

These aspects are also of particular importance for border regions. Ansell, Boin and Keller (2010) describe three difficulties in cross-border events. The disaster has an unknown origin (in another country), the course of the disaster is difficult to assess, and the measures taken to deal with it may initially be unknown to the partner organizations on the other side of the border. These problems can make coordination and communication difficult, even though border regions in Europe have already grown very close together. For example, Dahles and van Hees (2007) describe everyday problems in cooperation in civil protection, such as the lack of interoperability of material or in data exchange. Civil protection responsibilities and planning often relate only to individual countries, and cross-border risks are not considered, nor is the planning of SV operations. In the worst case, national borders become visible again, as happened during the pandemic (see next section). The close relationships in civil protection suffered from the border closures and the exchange of relief goods/material was suddenly strictly controlled again. Citizens were also no longer able to cross borders easily everywhere; negative COVID-19 test certificates had to be provided. On the other hand, the pandemic raised a huge wave on local actions of mutual support and brought up innovative solutions to overcome the difficulties.

At this point it can be concluded that SV will also appear in border regions and offer their help. Due to different or non-existing concepts for the integration of volunteers in this areas, special difficulties may arise when volunteers seek a connection to the civil protection organizations. In border regions, due to the

involvement of two or more countries, a larger number of actors are active in civil protection and need to coordinate in their response.

Communication with volunteers is key for their integration into disaster response. However, the demand in border regions is even higher. Joint coordinated communication with volunteers regarding points of contact and tasks need to be pre-planned, taking into account linguistic difficulties. Residents close to the border may be able communicate in the border region, but not necessarily SV coming from further away. Disaster response organizations need to think about in advance how to engage with volunteers via online social media groups. This is backed up by Klein, Wiens, and Schultmann (2022). The article deals with the special needs and reservations of SV in border regions. Potential volunteers were asked about obstacles to their cross-border engagement, and the interviewees primarily cite language and the unfamiliarity of disaster management organizations in border regions as reasons for not becoming active as SV.

For disaster management authorities there is a need to think about in advance how to organizationally involve SV across borders. In the area of information dissemination, online groups in the social media play an important role where authorities should play an active role. There is a need to coordinate these structures across borders.

This article attempts to quantify the different approaches to coordination of SV in border regions (from none to a fully integrated cross-border coordination approach) via an agent-based model, as empirical data is lacking. The importance of coordination in cross-border settings is examined, taking into account particular aspects such as infrastructural conditions and external influences such as border closures in the event of a pandemic.

Summarizing, both studies support the argument that volunteers will be crossing borders to offer their help. However, the authors of this paper did not find sufficient articles on the cross-border utilization of SV in Europe, which is why the approach of modeling their engagement with an agent-based simulation was chosen for this article (see Section 3). Therefore, an existing coordination framework for SV is extended to the specific questions on the effects of missed help requests from citizens as well as decreasing volunteers' The following Section 2.3 examines the COVID-19 pandemic as relevant cross-border scenario.

2.3 Relevance of the COVID-19 Pandemic to Spontaneous Volunteering

The COVID-19 pandemic is an example of a cross-border crisis. Weber and Wille (2020) outline a chronology of events related to border regions in Europe. On March

15, 2020, the first border in the EU (Poland-Germany) with a neighboring country was closed, the movement of people was restricted, and border controls were introduced. The following day, Germany decided to establish temporary border controls for Austria, Switzerland, France, Luxembourg, and Denmark. In the following days, these decisions were implemented, and restrictions on land and air travel, as well as border crossing points, were specified. These measures were aimed at reducing the movement of people, thus preventing the spread of the virus. With these measures, national borders regained significance in the EU, which, up until then, were hardly or not at all visible or noticeable in many places because of the Schengen Agreement. Weber and Wille (2020) state that these were spatial measures on the national borders of each country and, therefore, special conditions in border regions were not considered. The needs of citizens in border regions remained unconsidered in crisis management measures, since decisions were made by political bodies located far away from such border regions and were utterly focused on the own territory.

The closure of borders also had an impact on day-to-day emergency responses. For example, it led to the suspension of cross-border rescue services between Denmark and Germany (Peyrony, Rubio, and Viaggi 2021, 8–9). The EU reacted quickly (in mid-March 2020) and issued recommendations for measures that border crossing should be possible for border commuters as well as for the establishment of so-called green lanes, which would ensure the necessary movement of goods and enable the crossing of emergency management personnel. Similarly, it was communicated that health service personnel and protective material should be allowed to cross the border (European Commission 2020a, 2020b, 2020c). Over the following weeks, the challenges of border regions also reached the political decision-makers, e.g. the "Cross-Border Task Force Corona," an association of political decision-makers from North Rhine-Westphalia and the Netherlands, which met on a regular basis, was established. Furthermore, an Interreg project called *Pandemric* was launched in this border region, which is specifically dedicated to crisis management in the border region. One of the measures of the project was the compilation of the currently valid rules in the border triangle of Belgium, Germany, and the Netherlands for citizens and responsible authorities (2021).

Spontaneous volunteering has evolved at the individual level during the pandemic. Volunteers sewed masks for relatives or even complete strangers, or performed weekly grocery shopping for elderly people who no longer left the house because of the risk of infection. In many cases, these offers were coordinated via social media in the context of other SV activities. A particular research project has developed special SV guidelines for the pandemic, which outlined measures to protect volunteers against infection. Special activities such as shopping or walking dogs were examined from the point of view of occupational safety and health. Hazards were identified, and appropriate measures for protection were specified.

Despite having been presented in a way that was understandable to individuals, these guidelines were issued to organizations that coordinated volunteer assistance (BUW and Malteser 2021).

3 Simulation Framework

In the previous sections, it was outlined that SV are expected to appear in crises and disaster situations of any kind. Even though much is known about the potentials and challenges of dealing with SV, there are still problems in integrating them into the local crisis management structures to cope with an event (see Section 2.1). Furthermore, it was shown that SV can also be expected in border regions, triggering special challenges (see Section 2.2). The COVID-19 pandemic is a notable example (see Section 2.3). Despite an intensive search, the authors of this article have not found any empirical work that takes into account the special context of border regions when it comes to cross-border crisis management and spontaneous volunteering. Therefore, in the following sections, a simulation framework that takes into account specificities of a border area is examined on the basis of the work of Schulte et al. (2020), and it is enhanced by the pandemic scenario.

Agent-based modeling is a widely used approach to study the global dynamics of locally taken decisions. Particularly, disaster situations are changing very fast, requiring adequate reaction, whether locally or by the coordination of different actors – e.g. during the COVID-19 pandemic, regulations of different countries on the dynamic situation of incident numbers were changing, and, in some cases, they were issued locally as in the federal states of Germany. In this regard, Wu et al. (2022) designed an agent-based model to assess the impact of human behavior on disaster management. As regards cross-border collaboration, the dissertation of Klein (2022) presents an agent-based model to study effective information flows among the actors involved focusing on the collaboration between different authorities and considers SV inclusion. However, this article addresses the coordination of SV in the pandemic scenario.

In Schulte et al. (2020) we offer a basic model design which studies coordination across borders. The model considers a two-dimensional coordinate system of patches representing the border region of two countries (countries A and B) that are separated by a river that can be crossed through a bridge. Each patch has a variable recording whether it is hit by a disaster or not. Thereby, the model allows to vary the extent of the disaster to picture different scenarios.

In this setting, a number of persons is placed, distinguishing between citizens that are affected by the disaster, spontaneous unaffiliated volunteers, and professionals in disaster response. Each of these agents has variables indicating its home

patch as well as the corresponding country. In addition, citizens have a variable showing their needs, distinguishing needs that can be fulfilled by SV and those that require professional help. Moreover, a set of different social media groups is simulated so that citizens also have a list of social media groups that they follow. Professionals in disaster response are assigned a variable showing their availability, and SV are assigned to the simulated social media groups. Furthermore, the region is divided into different areas that can be chosen by helpers to perform their search and rescue procedures. Thereby, the decomposition of the areas for professionals resembles a chess board, while the decomposition for SV is scattered (i.e. areas can overlap, as shown in Figure 1).

If the variable of citizens' needs falls below a critical threshold, they can decide to request the aid of professionals in disaster response by calling a coordination center or to post about it in an established social media group. Note that coordination centers dispose of a common set of information according to which they prioritize all incoming requests and send out the available forces. Furthermore, coordination centers organize the resources for meeting citizens' needs, which are then distributed by volunteers. In a next step, the operating forces move to the areas where the citizens request help and fulfill their needs before they move back and become available for the next task. Social media groups only have their individual set of information on which they decide on the area with the most incoming requests, to which they move and provide their help. It is assumed that all volunteers belonging to the same social media group help in the same area to picture the feeling of togetherness that is always reported by helpers.

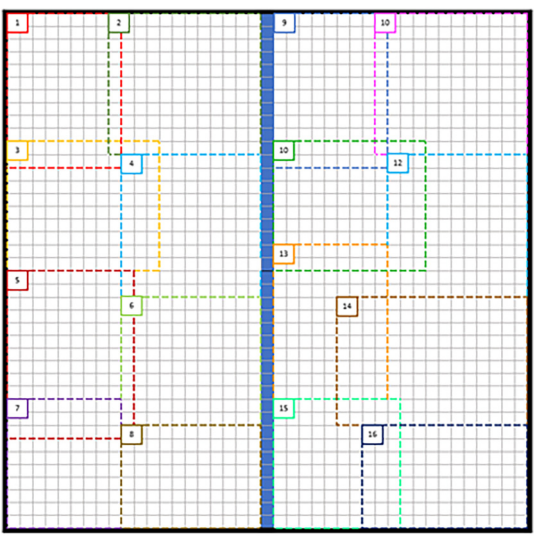

Figure 1: Simulation environment.

Table 1: Overview of our coordination scenarios considered (Schulte et al. 2020).

	Separated coordination per country	**Cross-border coordination**
Decentralized coordination	1. Volunteers in both countries acting on their own (no coordination at all)	2. Spontaneous volunteers of both countries coordinate themselves without involvement in professional crisis response (rather hypothetical considered for sake of completeness)
Centralized coordination	3. Both countries include spontaneous volunteers separately in their professional crisis response	4. Common coordination of both countries including spontaneous volunteers to their professional crisis responses (perfect coordination)

Studying a border region, our coordination framework (see Schulte et al. 2020) covers the following four scenarios of cross-border spontaneous volunteering (see Table 1). It further analyzes coordination along two dimensions: The integration of SV into existing disaster response structures and coordination across national borders.

This simulation framework is taken as the basis for the present study. The peculiarity of this work is the consideration of a pandemic scenario.

3.1 Model Design

The pandemic is outlined in Section 2.3 as a borderland-relevant scenario in which SV may appear to provide their help. However, during the COVID-19 pandemic, borders were closed to prevent the virus from spreading. This intervention measure affected border regions in particular, as family members living in other countries were not able to support their vulnerable relatives, who became dependent on external helpers. This situation did not diminish the willingness to help, and SV were seen locally buying groceries for the elderly or vulnerable people. This study expands the framework by analyzing the pandemic as described in Section 2.3, with border closures in which volunteers can only provide *local help* due to measures such as travel restrictions and contact reduction. Therefore, this paper introduces an additional scenario – Scenario 0 – , in which volunteers are only allowed to help *within the area in which they are located.*

Moreover, two different types of well-known problems occurring with spontaneous help have been analyzed for border regions. On the one hand, requests from the population may be missed if coordination structures are not well established,

and, on the other hand, SV may leave the disaster area if they are not assigned a task that proves that they are needed.

The simulation runs in discrete time steps, called “ticks”, in which time-dependent variables are updated. It is modeled along the structure of the *Gaia* methodology (Wooldridge, Jennings, and Kinny 2000) and implemented using the *Repast Simphony* toolkit (North et al. 2013).

3.2 Simulation Experiment

To run the simulation, we initialized 2000 citizens randomly in the border region so that 1000 citizens were located in each country. Their needs varied from 0 to 14. It reduces by 1 every 24 ticks, and the critical threshold for starting a request procedure is a value of 10. Initially, population needs were normally distributed, with a mean of 2 and standard deviation of 4. Per country, there are 5 groups on social media that can cover one area each. Additionally, the number of professionals is chosen for each country, so that they can deal with the five areas simultaneously.

To study the two additional coordination failures, we include the probability of failure $p \in [0, 100\,\%]$ in the second analysis. If p is below a critical threshold, the requests from the population are missed. The probability of requests being missed grows when fewer coordination structures are established. In addition, we include a probability $q \in [0, 100\,\%]$, which represents SV motivation. Motivation is high for all volunteers at the beginning but decreases over time when there is no task assigned to them. If this value too small (i.e. below a critical threshold), SV leave the disaster region and their work power is no longer available.

The *Repast Simphony* framework allows integrated parameter tracking over time. For the analysis of coordination effects compared between the different scenarios, we track the number of undersupplied citizens during the simulation duration (i.e. at tick 240).

3.3 Results

As presented in previous work (*see* Schulte et al. 2020), for each simulation run 1000 citizens were located in the region (500 citizens per country). The performance of volunteers’ coordination is measured by their effectiveness in the distribution of resources, i.e. by counting the resulting number of undersupplied citizens after the duration of the simulation. The following results show the mean number and variance of undersupplied citizens over three simulation runs. Figure 2 displays the four scenarios and shows that Scenario 1 without coordination has the worst performance

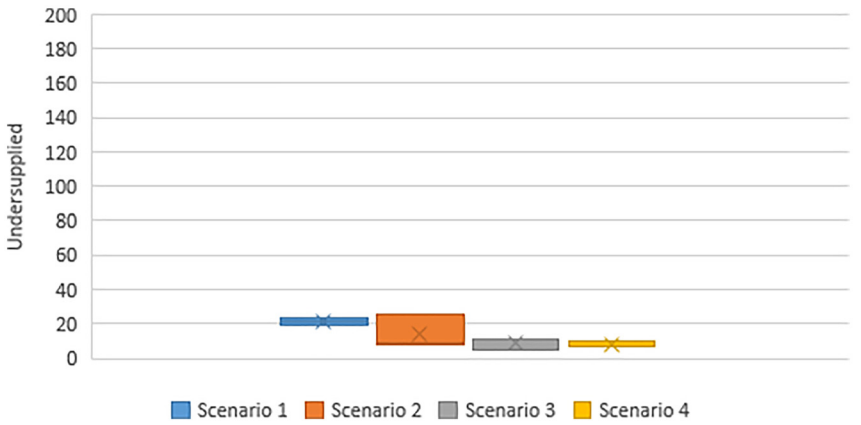

Figure 2: Mean undersupplied citizens scenarios 1–4.

(i.e. highest mean of undersupplied citizens) while Scenario 4 with common coordination in both dimensions features the best performance (i.e. lowest mean of undersupplied citizens).

We now compare these results with further specifications made in this study. We simulated 2000 citizens in the region (1000 per country). Furthermore, we take the mean number of undersupplied citizens over a number of 10 runs to obtain further insights into the mechanisms of the simulations.

Figure 3 features Scenario 0, the new scenario picturing a pandemic in which volunteers can only help in their local area. We see that this yields the highest number of undersupplied persons due to the least flexibility in the movement of helpers.

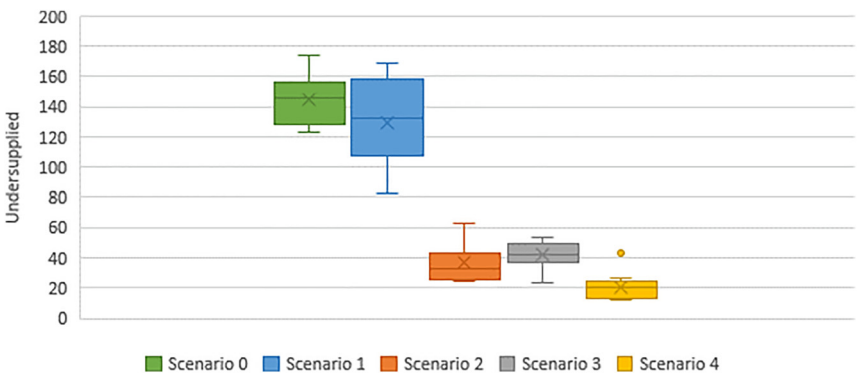

Figure 3: Mean undersupplied citizens comparing scenario 0 to scenarios 1–4.

After comparing the results with the simulations with 1000 citizens, we observe that the number of undersupplied people increases by doubling the number of affected citizens while keeping the number of potential helpers constant. The highest increase can be observed in Scenario 1, where the complete lack of coordination outlines the importance of coordination, especially for scenarios with high numbers of disaster-affected citizens. This scenario also resulted in the highest variance among the different simulation runs.

If we compare the number of undersupplied citizens per scenario, we can calculate the performance for 1000 simulated citizens in the order of scenario 1, scenario 2, scenario 3, and scenario 4. For 2000 simulated citizens, the performance of scenario 3 is better than that of scenario 2. A detailed look into the simulation data of Schulte et al. (2020) reveals that the worse outcome of scenario 2 is the consequence of an outlier (high variance). As the means were only taken over three scenarios, the outlier simulation run of 25 undersupplied persons had a strong impact on the result (the other two simulation runs had a number of 8 and 9 undersupplied persons, respectively). However, taking the means over 10 runs uncovers a slightly different order of scenario performances: scenario 1, scenario 3, scenario 2, scenario 4, as outlined in the following figure. In this case, the outlier in scenario 4 does not play a significant role because of the higher number of simulations runs.

Figure 4 shows the slope of undersupply rates with regard to the five scenarios, which reaches its highest point between scenarios 1 and 2. Thus, it highlights that the highest potential for improvement lies between these scenarios. Since the difference between scenarios 1 and 2 lies in the establishment of coordination across the border, that should be the first aspect to be improved.

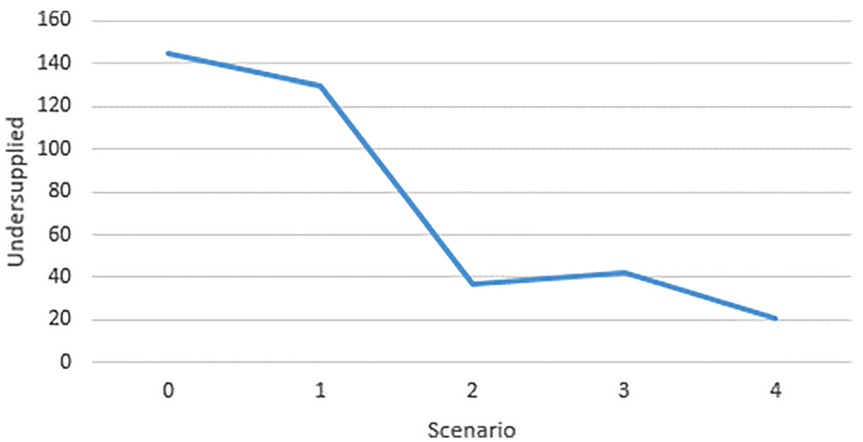

Figure 4: Mean undersupplied citizens per scenario.

To conclude, we can highlight that, especially in large numbers of affected persons with a constant number of volunteers, the greatest potential lies in the optimization of coordination, but SV flexibility (i.e. no travel restrictions between areas) is needed to obtain an optimal overall result. However, the flexibility aspect is small – in a pandemic, it might be a better strategy to encourage people to help in their area to prevent large virus spreading. Coordinating help and allowing for movement to a neighboring area in case volunteers are unequally distributed are key in such a situation.

We will now focus on the analysis of the *two additional coordination* problems in this study. First, *requests for help are missed* in an uncoordinated scenario. Therefore, we analyzed scenario 5 and assumed a probability of $p = 50$ % of failing requests. This leads to roughly twice as many undersupplied requests of citizens as in scenario 5, without failing requests. As the resources are almost equally distributed in the considered setting, there is no substantial difference if requests from Country A or from Country B fail (compare the similar numbers of undersupplied citizens in Figure 5). If only half of the submitted requests come through, the number of undersupplied citizens is doubled, which is an indicator of a well-derived agent-based model.

Finally, we have analyzed the second hindering factor of coordination, i.e. the *decreasing number of SV due to decreased motivation* when they are not assigning tasks in a timely manner. We have analyzed scenario 5 and assumed a probability $q = 50$ % of SV who waited for at least 10 ticks to get a task assigned before leaving the area. We observe that this factor of decreasing workforce clearly has a higher impact, resulting in an even higher number of undersupplied citizens. It should be noted that the decreased motivation of helpers in Country A had a lower impact

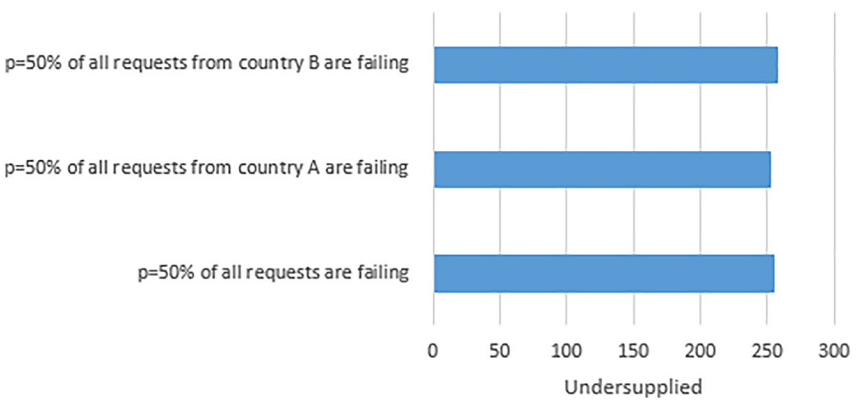

Figure 5: Mean undersupplied citizens with $p = 50$ %.

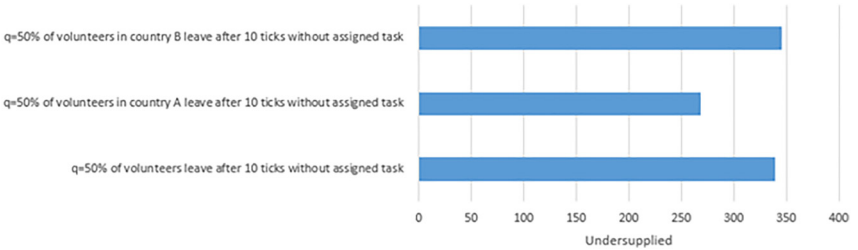

Figure 6: Mean undersupplied citizens with q = 50 %.

than in Country B (see in Figure 6 the lower number of undersupplied citizens when the volunteers in Country A leave compared to leaving volunteers of Country B). This results from the fuzzy distribution of the areas in which SV help. Affected citizens who are located in the overlap of the two areas have the potential to request SV from both areas via social media. Thus, the effect of disappearing helpers was smaller for the country with a higher overlap of areas. A similar effect is seen in the previous analysis, i.e. if requests are missed due to discoordination (e.g. Figure 5).

4 Conclusions

This study contributes to understanding the presence, impact and performance of SV in border regions, by simulating different levels of coordination and taking into account travel restrictions and coordination difficulties due to a pandemic. Despite being an important phenomenon, SV coordination mechanisms across national borders have been insufficiently described in scientific literature so far. This paper aimed at analyzing SV involvement in cross-border scenarios using an agent-based model. Of particular interest for this study are the movement restrictions due to a pandemic as well as two well-known problems, i.e. the missing of citizens' help requests due to miscoordination and the decreasing motivation of the volunteers due to late task assignment. The addressed questions are analyzed as extensions in the coordination framework of Schulte et al. (2020). The results show that a detailed analysis of different scenarios and the changing help behavior regarding various environmental conditions are crucial in the planning phase of disaster response. Therefore, efficient strategies to direct SV help can be developed and communicated to reduce the number of undersupplied citizens.

This study outlines that a high coordination effort is the most important factor to improve supply rates for disaster-affected citizens. The simulation results show a decrease of undersupplied citizens by 71.40 % when there is effective coordination. However, it is worth noting that appropriate coordination mechanisms should be developed and funded so as not to lose SV potentials due to a decrease in motivation. SV preference for individualism over fixed task assignments should also be noted. The model has therefore assigned SV working areas and has not fixed procedures nor tasks within these areas.

The model featured a special focus on the pandemic situation that prevailed in 2021. During the COVID-19 pandemic, border closures were seen by governments as a necessary measure to prevent the virus from spreading. Ordered lockdowns further limited the movement of the population and helpers. In any pandemic, large crowds of SV are dangerous to the health of the helpers. Even though the border closure yielded an increase of undersupplied citizens of 11.03 %, the establishment of coordination showed greater improvements in supply rates. Therefore, future studies should examine the possibilities of helping during a pandemic in which there is a high risk of self-infection, for example, by implementing individual protection measures such as social (physical) distancing and masks to provide insights on the trade-off between real case applications.

The agent-based model addresses the pandemic scenario and particularly considers the effects of border closures. However, the decreasing motivation and missed help requests are constant in various scenarios when it comes to SV help. Thus, the general coordination framework applies to different scenarios, but the environment needs to be changed for studying other scenarios of onsite help. The model is designed in a flexible way that allows adaptations, such as the voluntary provision of help in the aftermath of a flood or an earthquake.

Based on past and current disaster events, it is evident that spontaneous volunteering will be a relevant topic in the future, which means that this must be anticipated. This study shows that preparation and planning for the deployment of SV are also of great importance for border regions. Many people cross national borders within Europe daily, whether for work or shopping. Civil protection planning, as the pandemic has also shown, does not take this into account, but refers only to its own country. Therefore, the needs of the population in cross-border areas as recipients of crisis management measures are not reflected at all. In this article, based on agent-based modeling, we have shown the potential that can be realized through the systematic coordination of SV across national borders. From our point of view, problems such as the lack of protective measures, loss of motivation to help SV, and the negative effects of uncoordinated measures can only be solved through preliminary planning in this area.

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