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Resource deployment under consideration of conflicting needs in times of river floods

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Abstract

Purpose – The purpose of this paper is to present a system dynamics (SD) model that allows one to simulate resource deployment to fulfill increasing needs for commodities such as food and other consumables during disaster situations. The focus is on managing a suddenly increased demand (hoarding behavior) of an affected population under restricted transport conditions. The model aims to support decision makers by fostering comprehension of the systemic behavior and interdependencies of those complex settings.

Design/methodology/approach – Through literature review and case study analyses the SD model was established and implemented with STELLA 10.1.1.

Findings – The needs of relief units for response operations and supply of evacuees in the affected region result in conflicting needs under limited transport conditions during disaster situations. Therefore, uncertainties and dynamic parameters as, e.g., occurring delays, limited information, or delivery constraints and their influence on resource deployment under a sudden demand, have been identified and incorporated in this work. The authors found that an oscillating behavior within the system is possible to occur and is more intensified in case of regarding the additional needs of evacuees and relief units.

Research limitations/implications – Due to the high level of abstraction, it is not possible to incorporate all influencing variables in the SD model. Therefore, the authors focused on the most important ones with regard to the model objective.

Practical implications – To focus on awareness raising is of importance for decision makers in the context of disaster management. Furthermore, the authors found that the oscillating behavior is more irregular in case of assuming a higher increase rate of the water gauge than if a low increase rate is assumed.

Originality/value – To the best of the authors' knowledge, none of the work already done refers to providing a flood-prone area with commodities under consideration of a sudden demand, by applying the SD approach. The presented model contributes on the generation of systemic insights of resource deployment under consideration of conflicting needs in times of a river flood to support decision makers in those situations.

Keywords Decision making, Flood response, System dynamics model, Conflicting needs

Paper type Research paper

1. Introduction

Disasters are characterized by severe consequences to society, causing fatalities, loss of property or damage to environment and are exceeding the population's capability to cope with it (Kiss *et al.*, 2014). According to Doll *et al.* (2014), future changes in precipitation and flood patterns highly influence weather-related delays in transportation. In disaster response, the key logistical issues result from limitations in transport resources and damages to infrastructure (Balcik *et al.*, 2008). Hence, during disasters, the transport sector is critical (Bíl *et al.*, 2015). Therefore, it is crucial to better understand the influences of transport disruption on supplying affected areas with

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commodities, especially as an increasing number of disasters and higher impacts occur in Europe (EEA, 2011). In contrast to commercial supply chains, humanitarian relief is coping with victims suffering from delivery delays and shortages (Chakravarty, 2014). To avoid panic reactions, supplying the affected population is crucial, however, suddenly increasing and unpredictable demand due to uncertainties in post-disaster environments challenges decision makers (Balcik and Beamon, 2008; Safeer *et al.*, 2014). According to Terpstra and Gutteling (2008), the households' perceived responsibility concerning flood risk is low. Hence, sudden shifts toward extreme demands for certain goods or to certain areas may occur due to limited household preparedness. These are main reasons for the uncertainties of decision making (Kumar and Havey, 2013). Baker (2011) show that a hazard threatened population reacts by stockpiling food and water. An increasing demand as a panic reaction is linked to the people's observation of decreasing commodity availability at stores due to supply disruptions and limited reaction time for retailers (Cavallo *et al.*, 2014). During Hurricane Katrina in 2005, people mainly stocked non-perishable food, bottled water, cleaning supplies, flashlights, candles, first-aid supplies, generators, batteries and ice (Katrandjian, 2011). Even though an appropriate forecast was made in the case of Hurricane Katrina, decision-makers reacted ineffectively, which resulted in unsatisfied needs (US House of Representatives, 2006). Holguín-Veras *et al.* (2012) state that in case of a disaster, supplies have to be delivered for victims, and additionally, for the response process. In the case of the Tohoku disaster in 2011 in Japan, an unexpected demand of supplies occurred because of the combined needs of the affected victims and the needs for conducting relief operations (Holguín-Veras *et al.*, 2014). This challenges decision makers and inadequate ordering patterns may occur due to the complexity of demand and underestimations concerning inventory management (Barlas and Özevin, 2004). In times of disasters, many retailers order emergency supplies reactively to a sudden increase in demand (Lodree *et al.*, 2012). Regarding inventory control, this wait-and-see approach is currently applied primarily in practice as opposed to pre-positioning inventory before being hit by a disaster (Lodree *et al.*, 2012).

Olcina *et al.* (2016) show that beside flood control and post-disaster assistance, flood policy concentrates on measures as warning and emergency actions. Based on the definition of Schanze *et al.* (2006), flood event management consists of flood control, flood defense and emergency response. Flood control focuses on managing the water level, flood defense refers to flood protection structures, and emergency response encompasses ways of mitigating damages and harm of the affected population by evacuation and rescue. In this context, decision making can be divided into three levels: long-term strategic, medium-term tactical and short-term operational decisions (Leiras *et al.*, 2013). According to Simonovic (2011), the response phase deals with the implementation of measures that have been developed during the phase of mitigation and preparedness. We present a system dynamics (SD) model that refers to flood event management and focuses on emergency response on an operational level. The SD approach is used by several authors in the field of disaster management, e.g., flood management policies are modeled by Ahmad and Simonovic (2000) and an SD model referring to evacuation is presented in Simonovic and Ahmad (2005). Besiou *et al.* (2011) compare a hybrid, a centralized and a decentralized fleet management system, to show the appropriateness of SD for analyzing transportation and fleet management in humanitarian relief. Voyer *et al.* (2015) present an SD model referring to humanitarian response to a natural hazard, but they do not focus on conflicting needs resulting from the stockpiling behavior of the population and the needs for conducting relief operations. Peng *et al.* (2014) simulate the

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process of providing victims with relief commodities after an earthquake. Ramezankhani and Najafiyazdi (2003) also model disaster management policies for the case of an earthquake, showing the influence of different policies. Furthermore, Gonçalves (2011) model trade-offs between provision of relief assistance (e.g. restoring water, repairing roads and assessing needs) and capacity building (e.g. hiring and training of people, capturing lessons learned and structuring processes) in humanitarian organizations. Similarly, Kunz *et al.* (2014) investigate the issue of investing in disaster management capabilities (e.g. boosting training staff, conducting pre-negotiating of custom agreements and harmonizing import procedure) and pre-positioning of inventory, concluding that a combination is of value. Berariu *et al.* (2015) show the impact of critical infrastructure on response operations. In further work the duration of flood response is analyzed with SD (Berariu *et al.*, 2016).

The presented model focuses on the development of the disaster concerning supplying the population with commodities and considers needs of relief units conducting operations. During flood event, such operations are challenging due to uncertainties and conflicting needs. Decision makers have to be aware of corresponding uncertainties such as a suddenly increased demand of the population and delaying transport conditions due to bad weather or inundated infrastructure. Moreover, a decrease in the availability of commodities on-site due to conflicting needs of the population and relief organizations has to be considered. We show that a hoarding behavior of the population is a possible result from a limited availability of commodities on site. It depends on the delaying transport conditions as well as on the reaction of decision-makers concerning inventory management. The model supports decision makers on the municipal or district level of responsibility in planning of supplying the affected population.

We built the model on a generic level, using data from one province in Austria for the computational experiments. In Austria, educational programs for decision makers for the executive boards of disaster management consist of several modules and are performed on a regular basis. The presented model is developed for application in such training programs. According to Feyen *et al.* (2006), it is expected that the number of people affected by a 100-year flood in the Danube region increases. Austria is a diverse area with regard to hydrological data consisting of lowlands and alpine regions, which influences the development of flood events and results in highly variable precipitation patterns (Merz and Blöschl, 2004). Consequently, we consider environmental data with corresponding delaying conditions and uncertain factors as limited transportation capabilities. Such transport-related limitations strongly influence disaster relief operations (Berariu *et al.*, 2015). Hence, the duration needed for response operations depends on the affected region and on the number of victims and their behavior. Due to disrupted transport infrastructure, the mobility of the population is limited, which leads to increasing need for support by the relief units for vulnerable individuals of the affected communities (Christie *et al.*, 2016). Hence, a fraction of the population will be evacuated to shelters, causing additional demand for supplies (Davis *et al.*, 2013). According to the flood risk zones, which determine the extent of flood risk exposure in Austria, 12 percent of the Austrian property is exposed (Url and Sinabell, 2008). Furthermore, it is estimated that 5 to 10 percent of the affected population do not cooperate during an evacuation, which delays the response process (Berariu *et al.*, 2016). The model allows users to easily modify the input data of different parameters to adjust it to specific location-dependent characteristics. Hence, it enables one to analyze different scenarios by changing uncertainty parameters such as transport disruptions, the availability of vehicles and

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commodities on site as well as the level of cooperation of the evacuees and relief units. Hence, the presented model contributes on the generation of systemic insights of resource deployment and considers conflicting needs in times of a river flood to support decision makers. To the best of our knowledge, no prior work refers to supplying a flood-prone area with commodities and incorporates a sudden demand, depending on a decreasing availability of commodities, by applying the SD approach.

2. Method

SD, first applied in Forrester (1961), aims to reveal the system's behavior, which is characterized by complexity (Morecroft, 2007). For the SD model, which consists of a qualitative (causal loop diagrams (CLDs)) and a quantitative (stock flow (SF) model) part, various elements have been determined. Table I provides an overview of the most relevant elements, which are used in the model.

The model includes decision-making rules and forecasting structures suggested in Morecroft (2007). We further incorporated structures of inventory management and order fulfillment of Sterman (2000). Moreover, it is based on the archetype of a balancing loop with delay, which aims to change a current situation to a desired one (Marais *et al.*, 2006). Consequently, conducting corrective actions closes the existing gap between the current and the desired situation of the system. Therefore, time is required until the corrective action leads to improvements of the actual conditions. We expanded and adapted these structures to analyze resource deployment under increasing demand and delaying transport conditions in the case of a river flood. Furthermore, we added elements and modeling structures from previous work on the deployment of relief units to relief operations (Berariu *et al.*, 2016). CLDs represent the cause and effect relationships of the system (Morecroft, 2007) and can be either balancing (B) or reinforcing (R) (Sterman, 2000). SF models allow calculating dynamic changes via stocks, illustrated as rectangles. These are influenced by inflow and outflow rates, shown as arrows supplemented by a valve. Converters (depicted as circles) define principles or parameters (Morecroft, 2007).

2.1 CLD

The qualitative CLD consists of a balancing loop showing the adjustment of the amount of vehicles according to a changing demand and available commodities on site. Furthermore, two balancing loops focusing on the relief operations are incorporated. These determine the number of people that have to be evacuated and served, which define the desired states. The processes of evacuating and serving represent the corrective actions that have to be conducted by the deployed relief units.

Figure 1 shows the generated CLD, which illustrates the averaged consumption rate that has to be forecasted and the desired stock of available commodities on site. To respond to an increased demand or transport delay, the system adjusts the number of vehicles to achieve an equilibrium state of the system. The factor change in demand determines the requested demand and the average rate of consumption, and depends on the population's reaction and on the required amount by relief units and evacuees. If the available commodities on-site decrease, people may demand higher amounts due to that observation. Depending on the available commodities on site, the required amount for delivery is determined. The number of vehicles depends on the desired amount of vehicles, the time to adjust vehicles and the driving time per driver, which is restricted by the regulatory resting time for drivers. The more vehicles are available, the higher is the supply rate, which increases the available commodities on site.

Elements of the model	
Affected population	Refers to the inhabitants within the area that are affected by the flood
Number of people that have to be evacuated/served	A share of the affected population (12%) will be in need for evacuation. This evacuees have to be served by the relief units
Population	The share of the inhabitants of the affected area that is not evacuated, but may react by hoarding behavior
Relief units	Relief units are deployed for conducting response operations (evacuating and serving victims). We assume that 8.3% of employees are professionals as about 100,000 professionals and 1.2 million volunteers are responsible for disaster relief in Germany (Domres *et al.*, 2000), which is similar to the Austrian system. Volunteers deployed to disaster relief operations are mostly not able to work over a continuing period as they have to perform their regular jobs
Number of available vehicles	Number of vehicles within the system, depending on the required amount for delivery. By the term vehicle, we refer to vehicle and driver. Based on the Transportation Research Board of the National Academies (2012), a driving period of 11 hours and a resting period of 10 hours is modeled
Requested demand	Holguín-Veras *et al.* (2012) state that in case of a disaster, supplies have to be delivered for victims and, additionally, for the response process
Average rate of consumption	For the volume of transported commodities to satisfy the needs of the population, a share of 8.9% is determined to be food and other consumables, which are about 2.9 t per habitant and year (Austrian Ministry for Transport, Innovation and Technology, 2011). According to Holguín-Veras *et al.* (2012), the demand of commodities for response operations ranges from 15 to 80 kg per person/day
Changing demand	The demand changes, depending on the available commodities on site, as the population starts to demand higher amounts with decreasing availability. Additionally, the evacuees need commodities for being supplied and the relief units that are deployed also increase the demand. Increase in demand is approximated based on the published demand dataset of Xu *et al.* (2010), which resulted in an average increase in demand of approximately 28% for the following 20 days
Available commodities on site	The amount of commodities that is available within the affected area. This refers, e.g., to food and water, but also to equipment for response operations
Required amount for delivery	The required amount for delivery is a result of the average rate of consumption, the adaption time of decision makers, the available commodities on site and the transport duration. This amount influences the desired amount of vehicles
Desired amount of vehicles	Amount of vehicles needed to meet the demand in accordance to a changing demand and to the available commodities on site
Driving time	The number of vehicles depends on the desired amount of vehicles, the time to adjust vehicles and the driving time per driver, which is restricted by the regulatory resting time for drivers
Supply rate	The supply rate depends on the vehicle capacity and the number of available vehicles
Evacuating/serving	The processes of evacuating and serving represent the corrective actions that have to be conducted by the deployed relief units
Deployed relief units	The number of relief units is based on the flood of 2013 within a selected Austrian region

Table I. Overview of the most important elements

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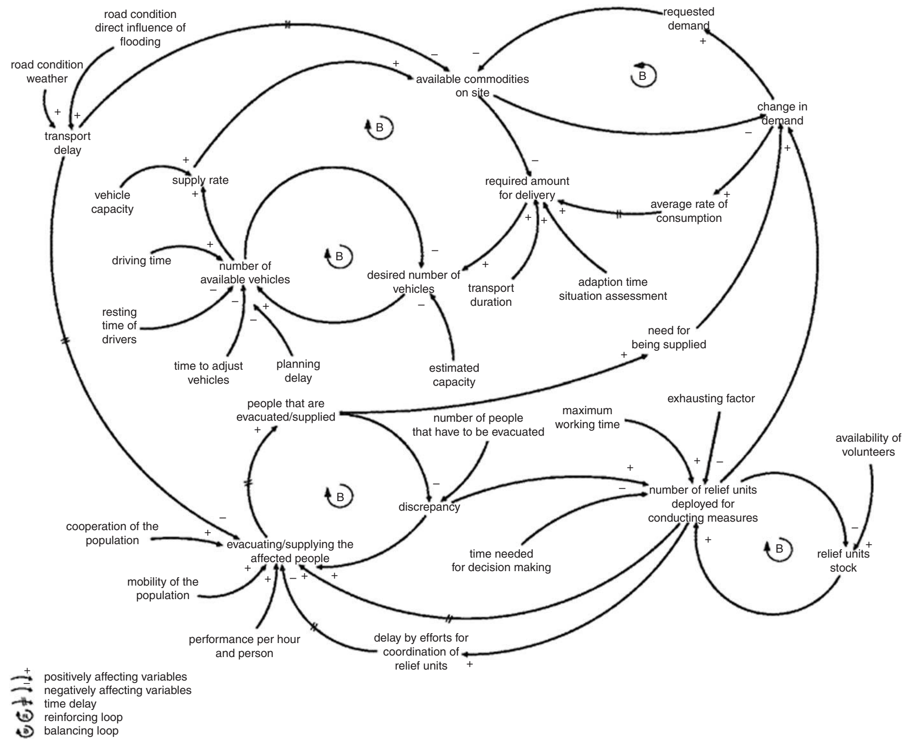

Figure 1.
Causality and feedback of the system

To incorporate external conditions as heavy precipitation or inundated areas, the factor transport delay is determined. This modeled structure results in an oscillating behavior regarding the available commodities on site, due to adjustment patterns.

2.2 SF diagram

This CLD was transferred into an SF model. The following inputs, modeled as parameters, can be easily adapted. Based on the Danube River, a lead-time of 48 hours before a region is hit by a flood is assumed (Blöschl *et al.*, 2013). The increase of the water gauge is determined for four days. As flood response measures, evacuations as well as the supply of evacuees and relief units with commodities are considered. We assume that the majority of relief units are volunteers (Domres *et al.*, 2000). An increasing demand is the reaction of a decreasing availability of commodities at stores during times of disasters (Cavallo *et al.*, 2014). This relationship is implemented by a graphical function, which defines the height of the increasing demand depending on the decreasing availability of commodities on site. Decision makers are able to react to changing conditions by forecasting the average rate of consumption that determines the delivery amount. Based on Cuervo *et al.* (2010), we assume 24 hours for the replenishment time of commodities available on site and the reaction time, needed by the decision maker to respond to changes of the population's demand. Depending on the number of commodities that are available on site and the desired amount of commodities, the needed number of vehicles to satisfy these requirements is adjusted by the model's structure. Based on simulation experiments for Tulln, Austria, an

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increase of transportation time due to the flood of up to 1,000 percent is further assumed (Fikar *et al.*, 2016). Figure 2 visualizes the SF model in its entirety. The corresponding equation set can be found under: www.wiso.boku.ac.at/en/production-and-logistics/research/instances/

3. Model behavior and numerical investigations

For the computational experiments, we differentiate between excluding (variation 1) and including (variation 2) the additional demand of relief units and evacuees and vary the beginning of the hoarding behavior (scenario A) as well as the initial inventory (scenario B). Moreover, the impact of a low- and high-increase rate of the water gauge is analyzed for each scenario. An overview of the calculated scenarios is given in Table II.

3.1 Scenario A – influences of the population's reaction

The results of varying the triggering value for the commodities available on site, which cause a hoarding reaction, are shown in Figure 3. Therefore, the variation without the demand of relief units and the evacuated people (A1) is compared to the scenario including the additional demand (A2). The results indicate that the later the population reacts, the longer a possible stock-out lasts. This is due to the fact that if the population reacts later, the availability of commodities on site is already low. Hence, the system takes longer to adjust to this increased demand, leading to stock-outs. An equilibrium state is reached for the scenarios A1 [1, 2] and A2 [1, 2], but not for A1 [3] and A2 [3]. The oscillating behavior continues over the entire simulation period, due to inadequate adjustment patterns in these settings. The system permanently overshoots, reverses, and then undershoots the equilibrium state. This is due to the time delays, causing corrective actions that after reaching equilibrium state, cause corrective actions in the contrary direction (Morecroft, 2007). If the hoarding behavior starts earlier, the population does not react by hoarding high amounts. This is due to the assumption that fewer available commodities result in a higher hoarding amount. Furthermore, the results indicate that the oscillating behavior is more irregular considering a higher increase rate of the water gauge. For scenario A1, the number of vehicles for satisfying the needs is lower than in A2 as the stocked commodities on site may satisfy the demand. The fluctuation of the scenarios A1 [3] and A2 [3] is higher than for A1 [1, 2] and A2 [1, 2]. Additionally, in A1 [1, 2] and A2 [1, 2], a possible stock-out will not last as long as compared to the scenarios A1 [3] and A2 [3]. This is because the system adjusts the number of needed vehicles much earlier. For A1 [3] and A2 [3], no equilibrium state is reached and the fluctuation of the commodities on site and the number of vehicles is continuing over the entire simulation period. This is a result of the wait-and-see mentality of decision-makers combined with the delaying conditions and as the population starts the hoarding behavior at a point in time where availability of commodities on site is low.

3.2 Scenario B – influence of the initial value of available commodities on site

As the population reacts according to the availability of commodities on site, we investigate the influence of varying initial values for the commodities on site. Figure 4 shows an oscillating behavior, for assuming the low and the high increase rate of the water gauge. The magnitude is higher for B1 than for B2. The results indicate that in all cases, short stock-outs occur (Figure 4). With a relatively high amount of available commodities on site, the needed number of necessary vehicles at the beginning of the

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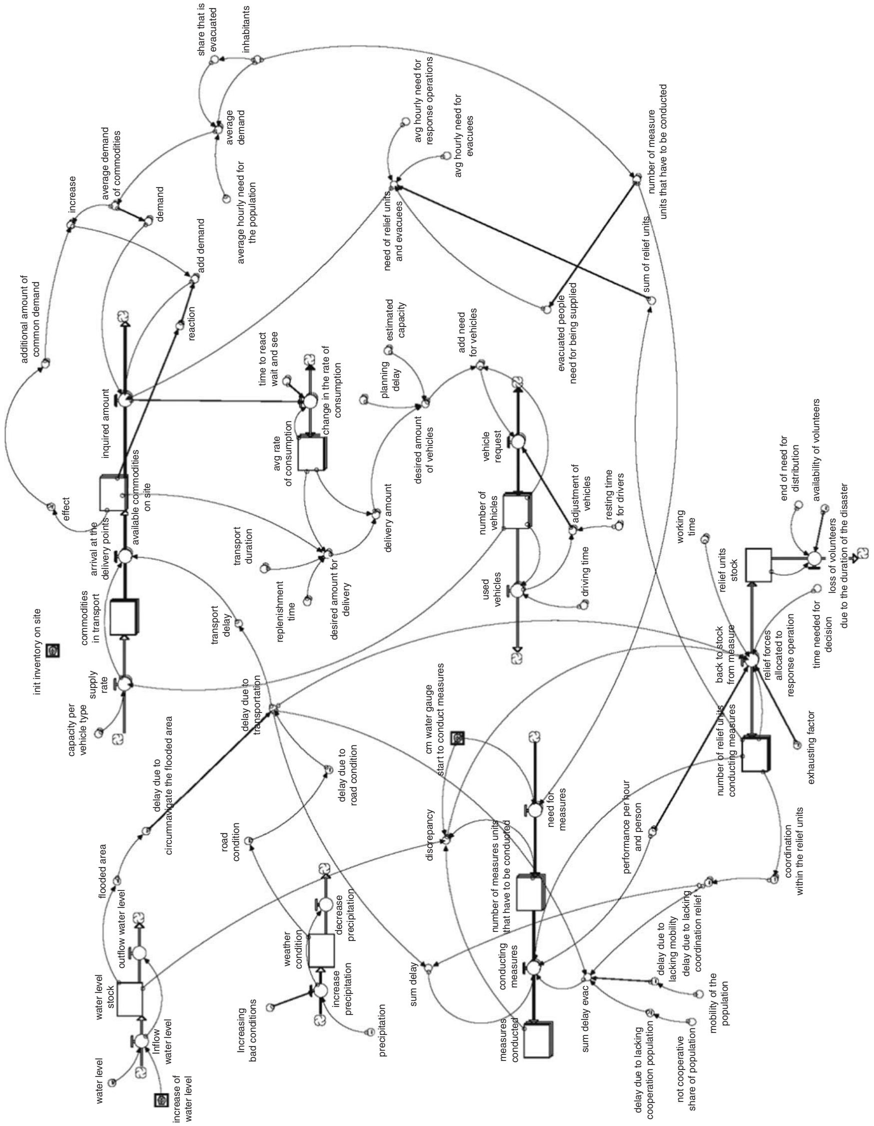

Figure 2.
Stock and flow diagram

Scenario	A Varying the triggering value of hoarding behavior		B Varying the initial inventory	
Variations including (2) vs excluding (1) additional needs caused by evacuees and relief units	A1 Excluding the demand of relief units and evacuees	A2 Including the demand of relief units and evacuees	B1 Excluding the demand of relief units and evacuees	B2 Including the demand of relief units and evacuees
Triggering value of commodities available on-site causing a hoarding reaction of the population	10,000 [1] 5,000 [2] 2,500 [3]	10,000 [1] 5,000 [2] 2,500 [3]	5,000 [1, 2, 3]	5,000 [1, 2, 3]
Initial stock of available commodities on site	6,480 [1, 2, 3]	6,480 [1, 2, 3]	0 [1] 6,480 [2] 12,960 [3]	0 [1] 6,480 [2] 12,960 [3]
Increase of the water gauge	Low High	Low High	Low High	Low High

Note: [ ] describe the varying initial values 1, 2 and 3 within the different scenarios

Table II.
Scenarios

simulation decreases and increases later, according to the increased demand. This means that at the beginning of an event, the number of vehicles does not increase due to the stocked amount of available commodities on site as shown in the scenarios B1 [2, 3] and B2 [2, 3]. Without stock at the beginning, as simulated in the scenarios B1 [1] and B2 [1], the system starts to adjust the needed amount of vehicles promptly. This is resulting according to the need of available commodities on site and the population's reaction, the demand of relief units and the demand of evacuees. The high rate of increase of the water gauge leads to higher fluctuations in the needed number of vehicles compared to the low one.

The simulation experiments show that stock-outs due to conflicting needs for commodities last longer the later the population reacts to a decreasing availability of commodities on site. This is a result of the relatively low amount of available commodities on site. Hence, a longer adjustment time of the system can be observed. If the additional needs of evacuees and relief units are included in the planning structure of the system, a higher amount of commodities is required. In this case, the system reacts by adjusting a higher number of vehicles. The experiment shows that if the simulation starts with a higher amount of available commodities on site, there is no need for a higher number of vehicles up to a certain point in time. When demand increases due to decreases in the availability of commodities on site, the system reacts by deploying a higher number of vehicles. As the system starts to adjust the number of vehicles at a later point in time, it takes longer to reach a new equilibrium state, if the initial amount is very high. The oscillating behavior is more irregular in settings where the population starts to hoard when the amount of available commodities on site is already low. No equilibrium is reached due to the wait-and-see strategy of decision makers. Particularly, it is of importance to increase the availability of the commodities for supplying the victims and for serving the deployed relief units.

3.3 Discussion

The generated model illustrates the system's behavior in case of conflicting needs, resulting due to an increasing demand of the population and additional needs by relief

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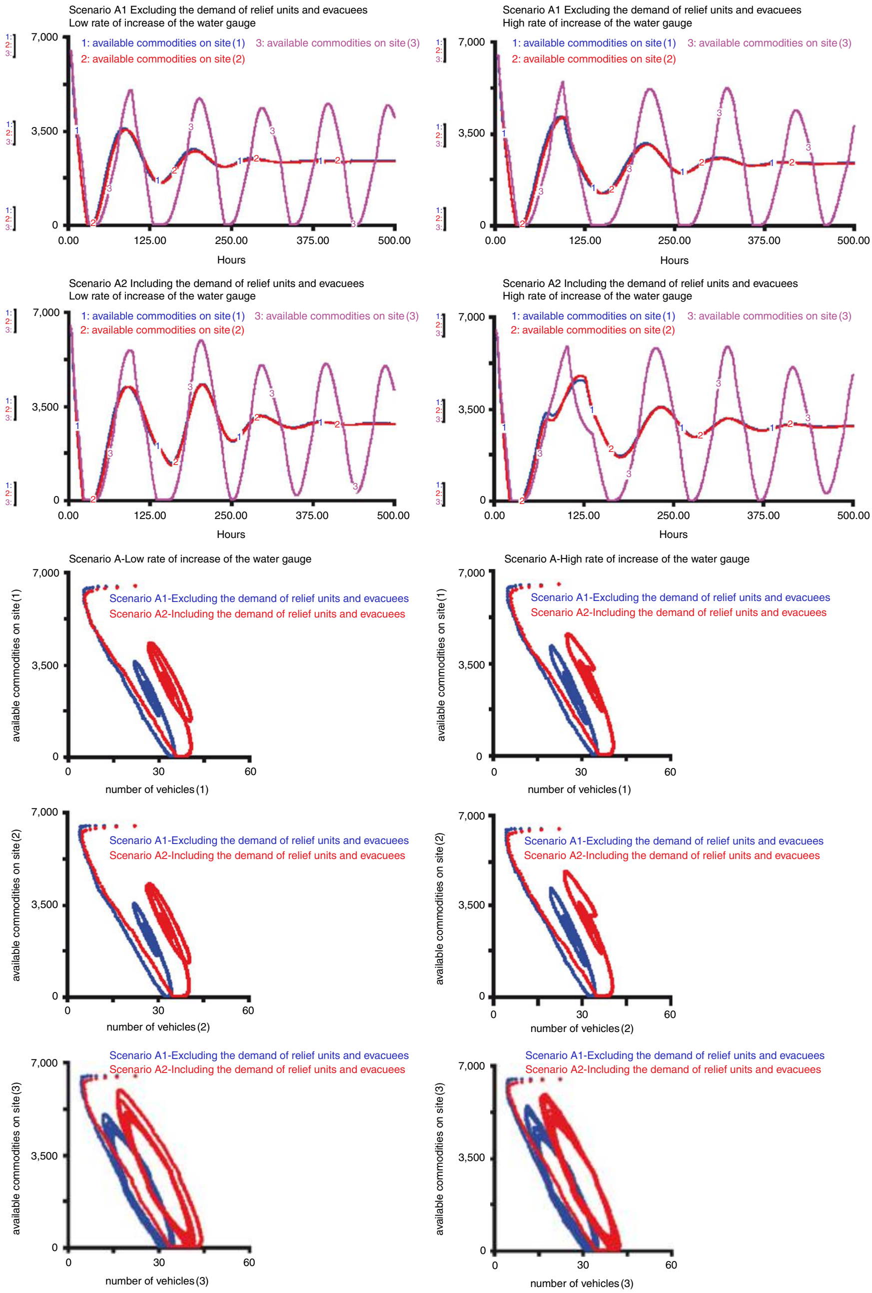

Figure 3.
Results for Scenario A

units and evacuees. Furthermore, transport limitations as consequences of a flood are considered. The objective of the model is to capture the most important interdependencies to simulate resource deployment in times of a disaster under a suddenly increased demand. The model is based on the archetype of a balancing loop

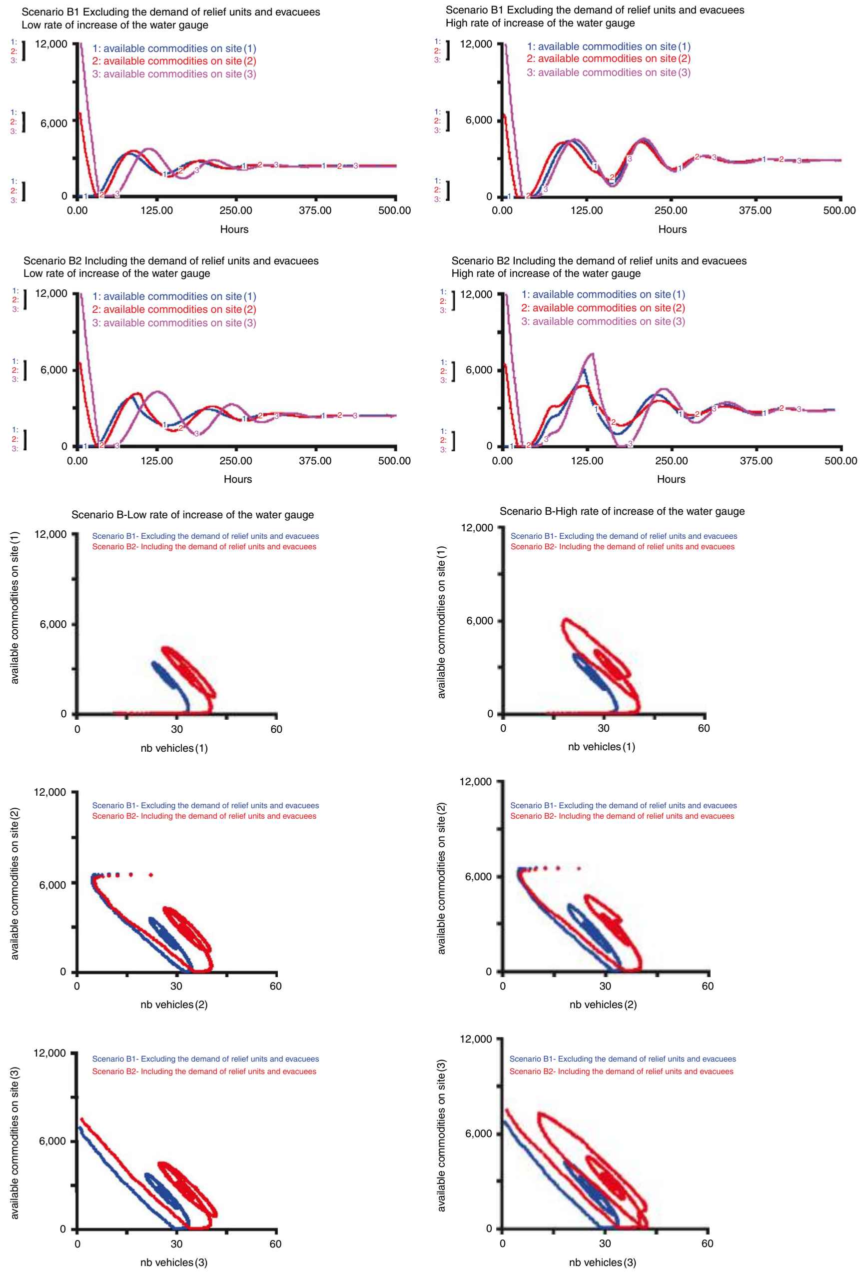

Figure 4.
Results of Scenario B

with delay and well-known structures for inventory management and order fulfillment. Additionally, we incorporated parts of our previous work on modeling the allocation of relief units to flood response operations. The model enables users to analyze the impact of relevant factors in a safe environment from a system's point of view. Although the

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model neglects some factors regarding specific spatial conditions due to the relatively high level of abstraction, it enables one to better understand occurring structures and such complex settings. We found that the archetype of "limits to growth" (Mella, 2012), determining that endless growth is impossible, would also fit to the system's structure. In this case, the available vehicles and the delaying conditions represent limiting factors, while the increased demand of the population determines the growing action. Hence, it is essential for decision makers to anticipate the impact of limiting forces, e.g., by changes in ordering patterns of retailers. Moreover, the influence of the number of vehicles and the change in demand requires further research. Incorporating the population's behavior into the decision-making process and counteracting is crucial. As the hoarding behavior might be a result of insufficient household preparedness by the population, supplying the population with better information will contribute to an avoidance of hoarding behavior. Strengthening the population's feeling of being responsible for their own preparedness measures is essential.

With regard to practical implication of the presented model, the objective is to support decision makers that are responsible on a lower level of responsibility (municipal or district), aiming to secure the supply of the affected area. The model fosters understanding of users for occurring interdependencies such as the available commodities on site and the increased demand. By different scenarios, future decision makers have the opportunity to examine varying initial conditions and the simulation of extreme scenarios. Hence, the users may experience a learning process through the use of the model during educational programs. In previous work (Berariu *et al.*, 2016; Fikar *et al.*, 2016), we generated training tools for decision-makers focusing on the deployment of relief units to different response operations as well as scheduling and routing of relief vehicles, respectively. Extending and combining the presented model with such related problems would be beneficial. The generation of a holistic model for application in educational programs of decision makers in disaster management is the focus of future work.

The presented work shows that a lack of quantitative data with regard to the hoarding behavior of the population in case of floods exists. Further research is of importance to improve the data quality in this field. To allow one to better analyze the behavior of the affected population regarding stockpiling or preparedness efforts, further investigations concerning topics such as the reasons of limited household preparedness are of interest.

4. Conclusion

Our results show that a possible stock-out as a result of conflicting needs for commodities lasts longer the later the population and, consequently, the system reacts to a decreasing availability of commodities on site. If the system starts to adjust the number of vehicles at a later point in time, it takes longer to reach a new equilibrium state that is essential to satisfy the demand. Furthermore, in some cases, no equilibrium state is reached due to inadequate ordering patterns. This is a consequence of underestimations in inventory management by wait-and-see strategies of decision makers. Therefore, preventive measures, as awareness raising within the population are of importance to avoid hoarding behavior resulting from insufficient household preparedness. We found that a lack of quantitative data concerning hoarding behavior of the population in case of floods appears. Future research to analyze the behavior of the affected population regarding stockpiling and preparedness efforts is of high importance. Furthermore, investigating the reasons of limited household preparedness is of interest. Moreover, expanding the model to address additional questions such as the needed number of facility locations to better meet the additional needs in the affected region would be a field for future research. The presented SD model contributes to an extended understanding of the impact of various factors and their interdependencies in the context of resource deployment under a sudden demand. Furthermore, supplying the evacuated population and the deployed relief units in the affected region leads to additional needs under limitations concerning transport conditions at the same time. The presented work shows that applying SD to issues of flood response is of value as the system's approach allows one to analyze different scenarios for strengthening understanding of the system's complexity.

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