Leveraging place-based social capital to decentralize emergency resource allocation in communities

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Abstract

This study focuses on the 'last mile' distribution of emergency supplies during disasters, emphasizing the potential of social capital within communities for effective distribution. Based on the survey data of two Seattle communities, we proposed a quantitative analysis of social capital networks and developed a decentralized resource allocation scheme based on peer-to-peer sharing. The findings indicate that decentralized resource allocation can achieve higher average satisfaction and resource coverage rates compared to traditional centralized methods. Moreover, the applicability of decentralized resource allocation varies, influenced by factors such as residents' sharing preferences and the number of social ties. One key factor in implementing the decentralized resource allocation scheme is having a subset of residents willing to share with the majority.

Keywords: Decentralized emergency resource allocation, Peer-to-peer sharing, Social capital, Sharing preference, Disaster response

1. Introduction

Emergency disaster response has garnered significant attention from scholars, primarily segmented into four phases: mitigation, preparedness, response, and recovery (Neal, 1997, Bullock et al., 2017, Seba et al., 2019). Our work centers on the disaster emergency response phase, wherein the judicious allocation of emergency resources is pivotal for protecting affected residents and facilitating post-disaster recovery (Hu et al., 2016, Guo et al., 2019). Current disaster relief distribution practices in disaster areas or communities primarily rely on past experiences of relief agencies and instructions. National county logistics planning (DEM, 2016) offers guidance for the operation, location, and evaluation of distribution points. The Federal Emergency Management Agency (FEMA, 2015) has provided guidelines for distributing relief supplies. A common method of emergency supply distribution is fixed-point distribution, where relief materials are delivered to one or multiple fixed locations for victims to collect. This method is suitable for large-scale, efficient distribution and is widely used in most post-disaster reliefs. Following Hurricane Katrina's strike on New Orleans in 2005 (Pipa, 2006), FEMA and the Red Cross established several fixed distribution points in the affected areas, supplying food, drinking water, medical equipment, and other essential relief materials. After the 2010 earthquake in Haiti (Margesson and Taft-Morales, 2010), NGOs and the United Nations set up regular distribution points in Port-au-Prince and other severely affected cities, providing food, water, and medical supplies to the affected population.

These studies and implementation schemes are based on top-down, governmental, and centralized resource allocation methods, overlooking the potential of mutual aid within communities. In centralized distributions, a minority of vulnerable residents might struggle to access resources (Dynes, 2006). For instance, the elderly might be unable to obtain resources due to mobility issues, travel barriers, or lack of timely relief information (Fernandez et al., 2002). Klinenberg

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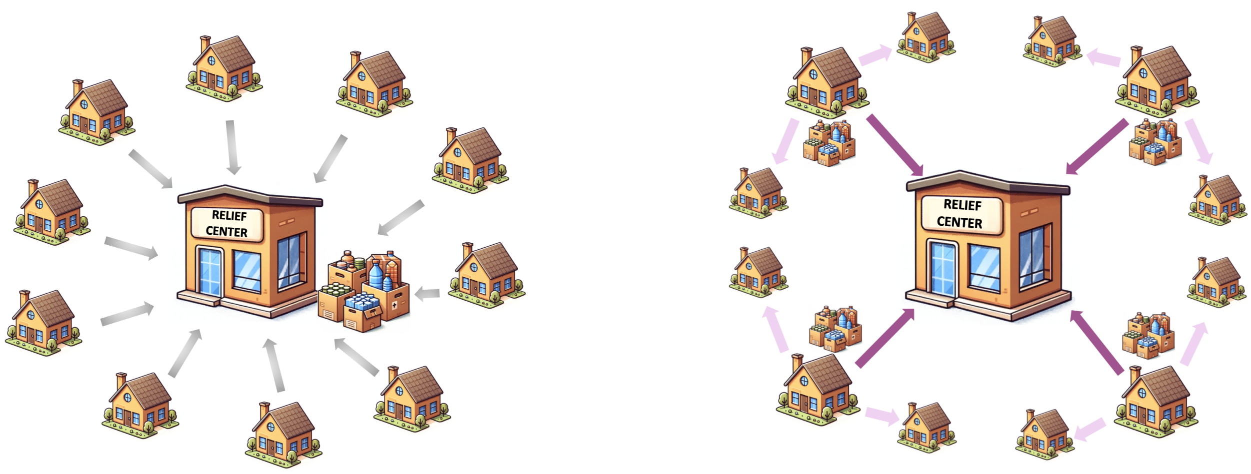
(2015), studying the 1995 Chicago heat event, also found that isolated groups of older people were most likely to die, even undetected. It is usually a challenge for community managers to clearly understand the disaster and resource status of all families in the community (Gunessee et al., 2018), while informal contacts, especially neighbors, often act as the actual first responders (Scanlon et al., 2014). Neighbors check on the well-being of others nearby and provide immediate life-saving assistance (Wasserman and Faust, 1994, Aldrich and Meyer, 2015). Empirical evidence suggests that during the 1995 Kobe earthquake, most of those rescued were saved by neighbors rather than firefighters (Aldrich, 2011). Post-Hurricane Katrina, residents, and grassroots social institutions participated extensively in disaster relief and assistance (Pipa, 2006). In the 2010 earthquake in Chile, the inhabitants of a fishing community, El Morro, in the Talcahuano region survived without any external assistance, attributing their resilience to a strong sense of community and tight-knit networks, where individuals spontaneously rescued pregnant women, cared for the elderly and kept track of evacuees and their well-being (Moreno et al., 2019). During the 9.0 magnitude earthquake that struck Japan's northeastern coast in 2011, many elderly and frail individuals were rescued by neighbors, friends, and family from the impending tsunami (Aldrich and Sawada, 2015). In the floods caused by Hurricane Matthew in 2016, neighbors assisted each other in escaping using rafts temporarily made from inflatable mattresses (Prociv, 2016). During the freezing period in Texas in February 2021, community residents helped each other through the devastating winter storm (Martinez, 2021).

The essence of peer-to-peer sharing and mutual assistance stems from the social capital inherent within communities (Meyer, 2018). Hanifan (1916) introduced the concept of social capital, defining it as the goodwill, friendships, mutual sympathy, and social interactions between a group of individuals and families constituting a social unit. Morsut et al. (2022) consolidated views from various scholars, defining social capital as norms, values, trust, and networks embedded within society, which can provide resources for mutual support and promote coordination and collaboration in the face of risks and crises. Under the impetus of social capital, commendable performances of decentralized implementation without centralized authority during disasters have been evidenced: during the 2000 Walkerton crisis, when trucks carrying relief supplies arrived in Walkerton prior to coordination with the emergency operations center and municipal authorities, community members, including municipal employees, forklift operators, and business owners, effectively coordinated in the distribution of resources (Murphy, 2007). Some residents even volunteered to deliver water to those who were unable to reach the distribution centers. Gunessee et al. (2018) also found that decentralization of decision-making can stimulate spontaneous volunteerism and positively impact disaster relief operations. Clearly, this social capital didn't develop overnight but was based on pre-existing social networks within the community (Dynes, 2002). While the role of social capital in disasters is recognized, most studies remain qualitative, and the potential of social capital in community responses to emergency disasters remains under-researched (Meyer, 2018). Meanwhile, research involving emergency resource allocation in disasters has primarily focused on supplier selection, inventory optimization, warehouse location problems, and routing and scheduling (Caunhye et al., 2012). However, there is limited research on how to effectively distribute relief supplies to individuals within communities once they reach the disaster area.

In our research, we focus on the effective distribution of relief supplies after they reach the community. Specifically, our objective is to explore the potential of peer-to-peer sharing driven by social capital in the distribution of emergency supplies at the community level. We propose a decentralized resource distribution method that incorporates social capital, an intangible asset, into the distribution process, as shown in Fig. 1. Different from traditional centralized resource distribution methods, where individuals queue at relief centers, our decentralized distribution approach includes identifying several 'sharing hubs' within the community, sharing hubs obtain resources from the relief center and subsequently share them with other residents. We primarily investigate the following questions:



(a) Centralized resource allocation

(b) Decentralized resource allocation

Figure 1: Satisfaction rate of decentralized and centralized resource allocation

1. Is a decentralized distribution scheme, inspired by peer-to-peer sharing stemming from social capital, effective?
2. Does the potential of social capital in emergency resource distribution vary across different communities?
3. If considering social capital and encouraging peer-to-peer sharing proves effective, what recommendations can we offer for emergency supply distribution in community disaster scenarios?

The remainder of this paper is organized as follows. Section 2 introduces the theoretical framework of the paper. Section 3 elaborates on the construction of the community social capital model. Section 4 details the implementation of decentralized resource allocation. Section 5 presents the results, sensitivity analysis, and discussions. Section 6 discusses the conclusions, and Section 7 offers suggestions for community disaster response and prepareness.

2. Methodological framework

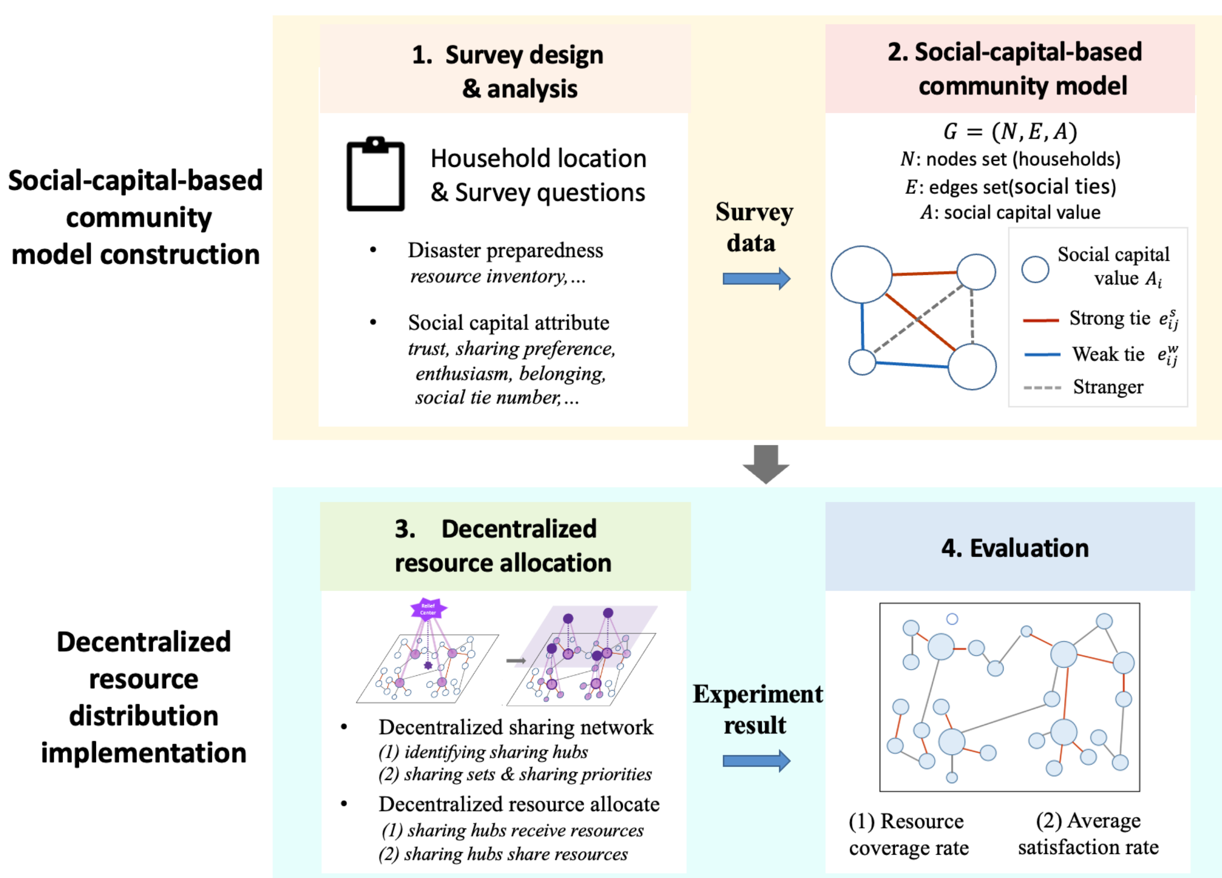


Figure 2: Methodological framework of the decentralized resources allocation model considering social capital

In this Section, we focus on the specific methods employed to address the research objectives of this article. Our study is divided into two main parts: social-capital-based community model construction and decentralized resource allocation implementation, as illustrated in Fig. 2.

First, we propose a method for quantifying the community's social capital. We designed and distributed the survey questionnaire to collect responses from a community sample to understand their preparedness for disasters and the inherent social capital. Based on the data gathered from the survey, we establish a social capital network model for the community grounded in social network theory, including the social tie network of the community and the social capital value of each household, laying the foundation for implementing a decentralized resource allocation scheme.

Subsequently, we introduce the methodology for implementing decentralized resource distribution. The community first identifies sharing hubs based on the social capital network. Then, the sharing hubs acquire and distribute resources, and a decentralized sharing model is designed to determine the sharing process. Additionally, we establish two evaluation metrics to assess the performance of this implementation.

3. Social-capital-based community model construction

3.1. Survey design

When disaster strikes, community capital can be divided into material capital and social capital. Material capital is mainly reflected in resource inventory (Li et al., 2023), with different residents having varying levels of disaster preparedness (Zamboni and Martin, 2020, Wang et al., 2023). The social capital of the entire community is a potential force we can utilize (Putnam, 1993), described as the intangible resource in relationships between people (Coleman, 1988). Many sociological literatures demonstrate how to assess a community's social capital, including the existence and participation of community groups (Putnam, 1993, 2015), groups' negative/positive perceptions of the community (Wasserman and Faust, 1994), the level of trust among citizens (Nakagawa and Shaw, 2004, Putnam, 2000), and the depth of social relationships (e.g., how many friends do you discuss your problems with?) (Center, 2000, Forbes and Zampelli, 2013). Therefore, our designed survey is divided into two modules: one focuses on people's disaster preparedness, including resource reserves and preparedness; the other on people's lives within the community, including sharing preferences, social ties, participation in public affairs, trust, and sense of belonging. Given that resources most directly related to survival (DEM, 2016), such as water, food, warm clothing, medicine, and first aid, are often distributed first in disasters, we emphasize the distribution and sharing of these items. The designed survey questions are shown in Table 1.

3.2. Survey analysis

We chose two Seattle neighborhoods: Laurelhurst Community and Southpark Community, whose geographic locations are shown in Fig. 3. Seattle is one of the cities with the highest number of natural disasters in the United States, including winter storms, landslides, floods, and earthquakes (Joffe et al., 2013). Tapping into the social capital to improve emergency relief coverage and response efficiency, helping people through the crisis, is our desideratum.

These two communities have certain representativeness and differences to capture heterogeneous community characteristics and disaster preparedness. Specifically, Laurelhurst has one of the highest median household incomes and life expectancy for Seattle residents and is made up mostly of white residents. In contrast, South Park is a racially diverse neighborhood, where 45% of residents are Hispanic or Latino, 50% of families speak English as a non-native language and 25% of families live below the poverty line. Questionnaires were randomly distributed to some households in Laurelhurst and South Park [1], and Fig. 2 and Fig. 3 show the survey responses of Laurelhurst and SouthPark, respectively.

[1] The number of responses in Laurelhurst and Southpark are 263 and 203, respectively.

Attribution	Question
Resource inventory	How long your household is prepared to be on its own in the case of a disaster? (Regarding water, food, warm clothing, medicine, and first aid)
Disaster preparedness	How many neighbors have you talked to about disaster preparedness?
Sharing preferences	Assuming you had a one-week resource (water, food, medications, first aid supplies and warmth), with whom (nobody; family and close friends only; family, close friends, and acquaintances only; anyone in need) you be willing to share?
Trust	Do you agree or disagree with: “In general, you can trust people” ? (strongly agree; agree; no opinion; disagree; strongly disagree)
Belonging	Do you agree or disagree with: “I feel the community is a part of me” ? (strongly agree; agree; no opinion; disagree; strongly disagree)
Participation	How many hours did you spend participating in community activities with other people?
Social ties	How many close friends/family members and how many acquaintances (people you know on a first-name basis) do you have in each area?

Table 1: Survey questions

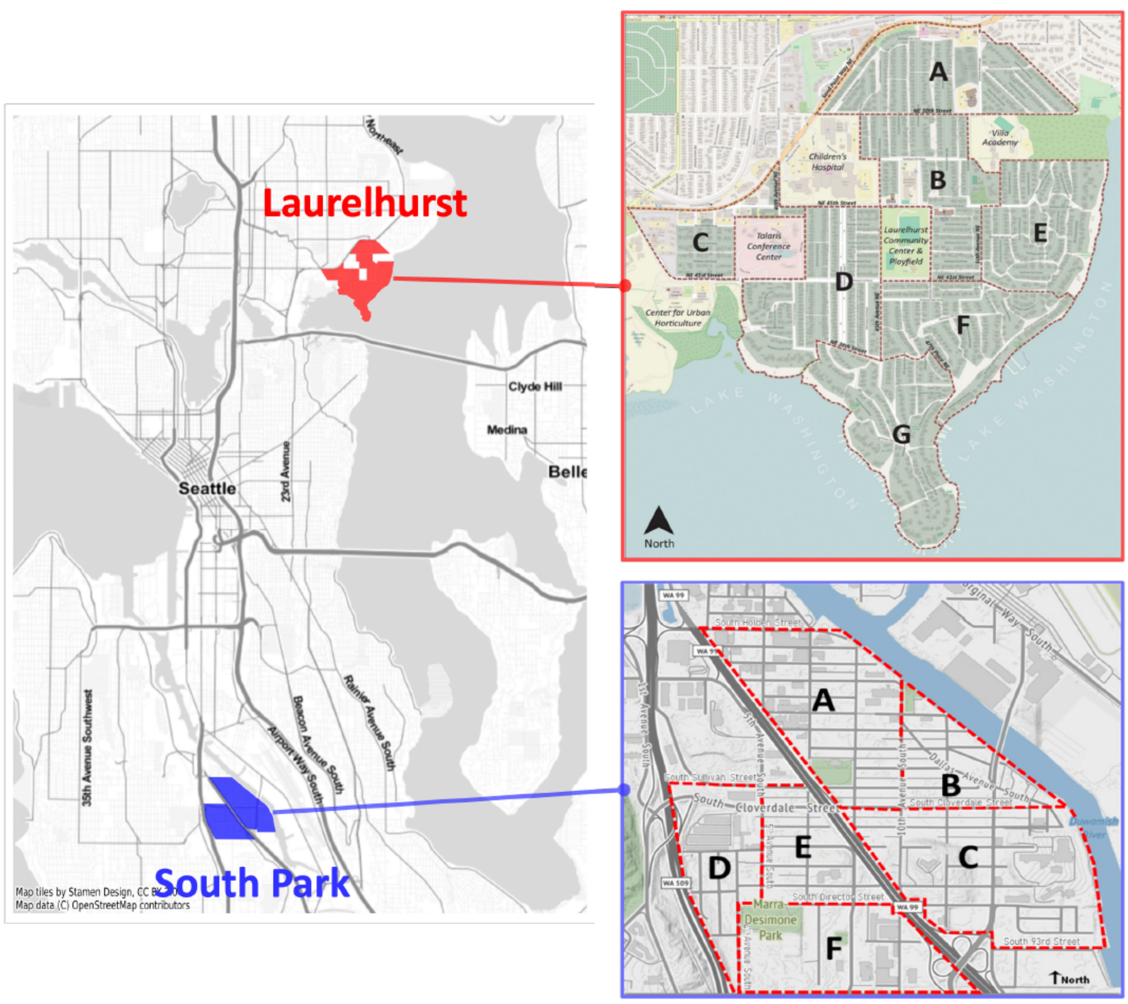


Figure 3: The geographic location of Laurelhurst and Southpark communities

We can see that households in the community have different inventories. For Laurelhurst, almost more than 40 % of households have less than three days of stock for water, food, and medication and less than six days for first aid supplies and warmth. The situation is similar but worse in South Park. For social capital, in Laurelhurst and South Park, about 80 % of people are willing to trust others, and more than half feel their community is part of them. About 30 % of residents living in Laurelhurst devote more than 10 hours a week to community activities. In comparison, only about 20 % of residents in South Park devote more than three hours a week. Regarding social ties, about 40% of residents have more than 10 weak social ties in Laurelhurst, and 20% have more than 30 weak social ties and more than 20 strong social ties. By contrast, only

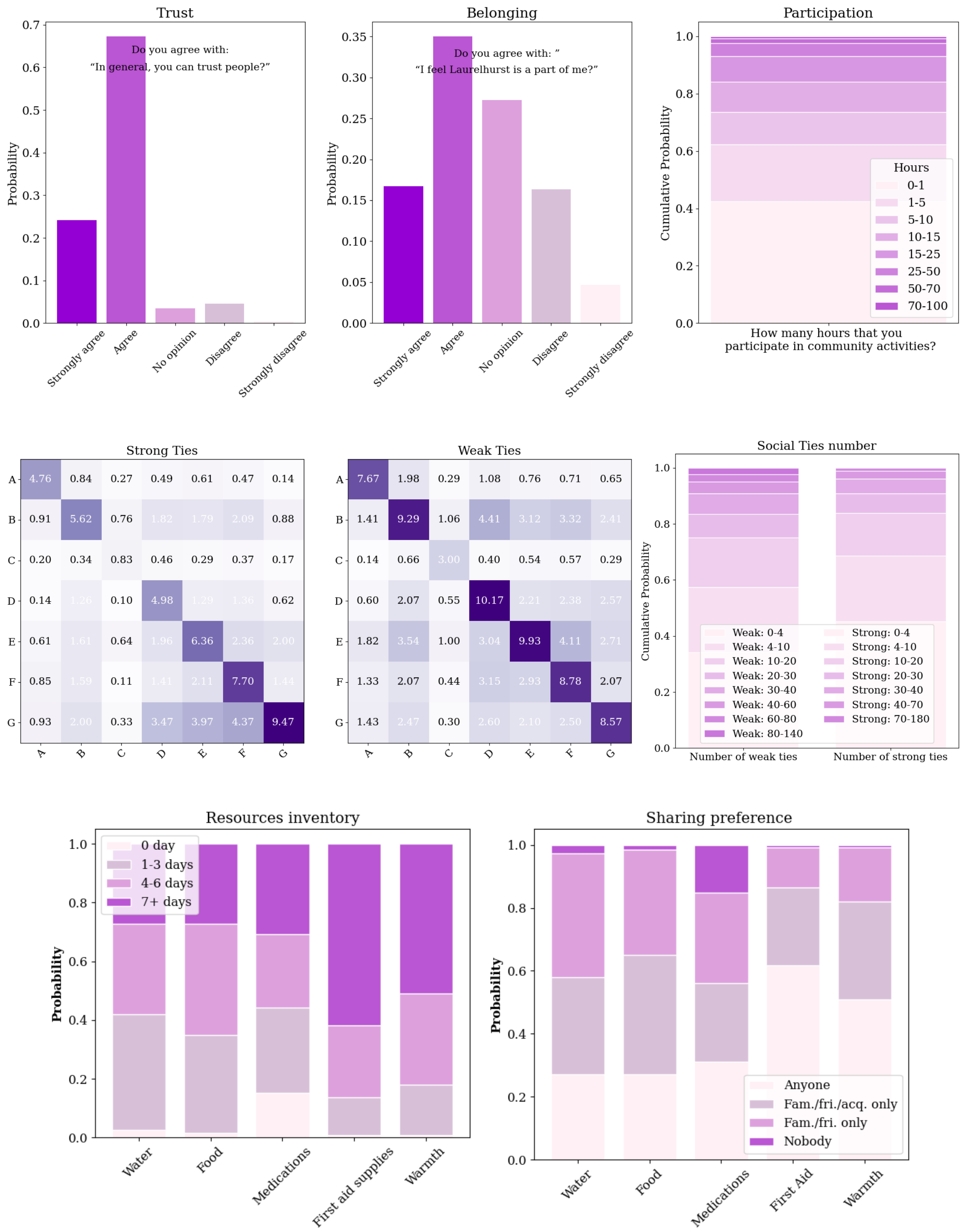


Figure 4: The survey responses of Laurelhurst neighborhood

20% of residents have more than 12 weak social ties and more than 8 strong social ties in South Park. This means the Laurelhurst community has more social connections and a stronger social network.

3.3. Social-capital-based community model

It is hard to know every individual's information in a community, but responses to survey questionnaires through sampling allow us to glimpse the disaster preparedness and important social capital attributes of community residents, providing a basis for quantifying the community's social capital. Since the social capital of a given area often follows some repeatable patterns (Newman et al., 2002, Liben-Nowell et al., 2005), we constructed a community social network $G = (N, E, A)$ based on known survey data, where N is a set of nodes, and each node represents a household; E is the set of social ties, if there is a social tie between node i and node j, then there is an edge e_{ij},

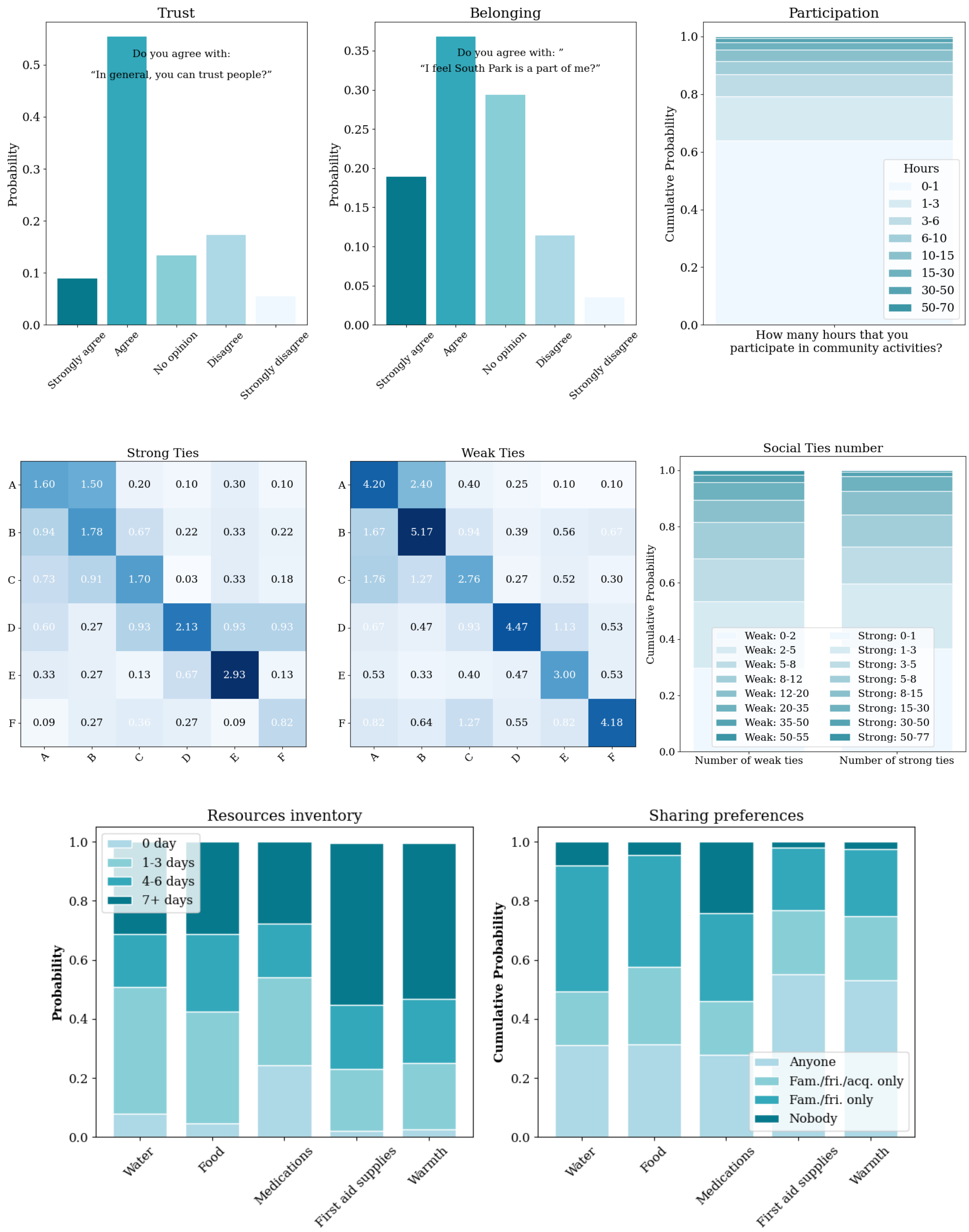


Figure 5: The survey responses of SouthPark neighborhood

of which e^S_{ij} represent strong ties and e^W_{ij} represent weak ties; A_i stands for the social capital value of node i.

Step 1: Generate connection number o_i between nodes in the community network

We employed node degree distribution (Erdős et al., 1960, Barabási and Albert, 1999), commonly used in generating social networks (Liben-Nowell et al., 2005, Xu et al., 2022), to depict the probability of connection counts in the network, thereby generating the number of social links for each household. Assuming v is the number of social relations a family has, and V represents the set of social ties derived from the survey results, the probability mass function of the negative binomial distribution and its log-likelihood function for v is:

$$P(v) = \frac{\Gamma(v+n)}{v!\Gamma(n)} p^n (1-p)^v \tag{1}$$

$$l(v; n, p) = \sum_{v \in V} [log \frac{\Gamma(v+n)}{v!\Gamma(n)} + nlogp + vlog(1-p)] \tag{2}$$

where $\Gamma(\cdot)$ refers to the gamma function, while n and p are the parameters that need to be determined. For each community, the values of n and p can be obtained from the values of the maximum likelihood estimation parameter of the survey data.

Based on the node degree distribution obtained for the community, we generate the node degrees o_i ($0 \le o_i \le |N| - 1$) for all nodes within the community network, representing the number of their social ties with other nodes.

Step 2: Calculate the connection probabilities between all nodes.

Considering the distance decay effect (Stutz, 1973, Bourgeois and Friedkin, 2001), where closer households have stronger social ties (Goldenberg and Levy, 2009), the social strength follows a power-law decay with geographic distance (Liben-Nowell et al., 2005, Xu et al., 2022), which can be described by:

$$p(d_{ij}; \gamma) \propto d_{ij}^{\gamma} \tag{3}$$

where $p(d_{ij}; \gamma)$ represents the likelihood that a social connection exists between two nodes households i and j, based on the geographical distance d_{ij} between them, and γ is a parameter that needs to be determined.

Since it is difficult to estimate every resident's social connections within the community, we generate the probability of households having social ties in each sub-area of the community based on Equation (3):

$$p_k^i(\gamma) = \frac{\sum_{j \in N_k \setminus \{i\}} p(d_{ij}; \gamma)}{\sum_{j \in N \setminus \{i\}} p(d_{ij}; \gamma)}, \quad \forall i \in N_{\text{sample}}, \ k \in K \tag{4}$$

where k denotes the regions within the community, as illustrated in Fig. 1; N represents all the households within the community; N_k is the set of households within region k; N_{sample} refers to the households that were surveyed; $p_k^i(\gamma)$ signifies the anticipated proportion of social ties of household i in region k.

Further, based on survey results, we calculate the value of $\hat{\gamma}$ using the least squares method:

$$\hat{\gamma} = \underset{\gamma \in \mathbb{R}}{\text{argmin}} ||\mathbf{P}(\gamma) - \mathbf{P}_{\text{survey}}||^2 \tag{5}$$

where $\mathbf{P}(\gamma)$ and $\mathbf{P}_{\text{survey}}$, respectively, represent the observed and predicted proportions of social relationships among sampled families in different subareas of the community. Based on the probabilities of connections between nodes, for household i, other nodes are selected to connect with it until the node degree of i is satisfied. Subsequently, based on survey data, each household is allocated a proportion of weak and strong social ties, as shown in Fig. 2. Unconnected nodes in the network are considered strangers.

Step 3: Calculate residents' social capital values

We set a series of indicators a^z to represent each household's social capital attribute, including sharing preferences, trust, sense of belonging, participation, and number of social tie numbers. From Step 1, we obtain each household's number of social contacts with other households. For other attributes, based on survey data, we can obtain their probability distribution in the community, $P(a^z)$ (see Fig. 4-5). Following the methods used in past research to measure the level of community social capital based on individual-level survey data (Graddy and Wang, 2009, Jordan et al., 2010), we randomly generate the values of a_i^z for each household i based on the corresponding probability distribution $P(a^z)$. Additionally, we assign a weight to each attribute and calculate the social capital value of each resident based on the following steps.

(1): Normalize each indicator including a^z;

(2): Assign a weight w^z to each indicator and add them up to get the social capital value of each household: $A_i = \sum_{z \in \{Z_1, Z_2\}} w^z * a_i^z$.

Based on that, we obtain the social-capital-based community network $G = (N, E, A)$.

4. Decentralized resource allocation

4.1. Decentralized sharing network

After quantifying the community's social capital, we introduce the preliminary of the decentralized resource allocation approach, the decentralized sharing network.

4.1.1. Sharing hubs and sharing sets

We select households from high to low according to the social capital value obtained in Chapter 3.3 to form a sharing hub set $\mathcal{K}$. On the one hand, households with higher social capital value have connections with more people and can help more people in times of disaster; on the other hand, those who are more willing to participate in public affairs, share resources with others, and trust others are more willing to contribute to the sharing and distributing of resources.

Households selected as sharing hubs travel to the relief center to collect resources and share relief supplies with other families in the community. We define $\mathcal{D}_i$ as the sharing set of families that Hub i is willing to share resources with, for example, if the sharing preference of Hub i is "family and friends", the set $\mathcal{D}_i$ includes all families with whom hub i has strong social ties. It is worth noting that there may be overlap in willing sharing sets of different sharing hubs in reality because most people have more than one social tie in the community, as revealed in Fig. 6.

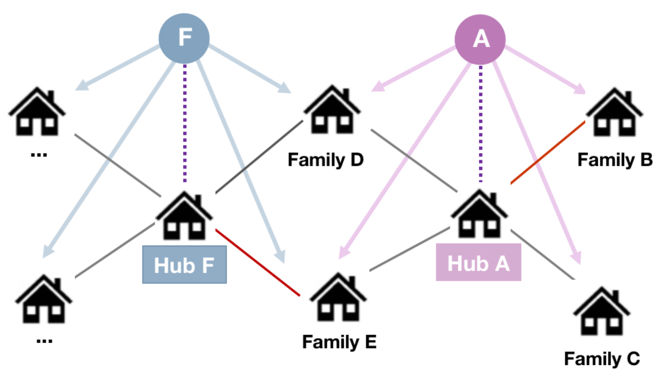


Figure 6: Decentralize sharing network

4.1.2. Sharing hubs' sharing priority

Considering it is unrealistic for sharing hubs to allocate and share resources to different families at the same time, we define the concept of resource sharing priority $\theta_{ij}(\forall j \in \mathcal{D}_i)$, indicating the priority of sharing hub i to share resources with family j. After people obtains resources, on the emotional side, they tend to share resources with the family with strong social connection (Schreiner et al., 2018), that is, their family or friends; on the rational side, their sense of responsibility prompts them to help the family that lacks resources and faces survival difficulties in the disaster as the humanitarian assistance (Rennemo et al., 2014, Huang et al., 2015). Therefore, sharing priority is jointly determined by the number of resources that family j lacks and the social ties between family i and family j, that is $\theta_{ij} = \xi_1 * \hat{r}_j + \xi_2 * \hat{\epsilon}_{ij}$ $(\xi_1 + \xi_2 = 1)$, where $\hat{r}_j$ represents the number of resources the household j lacks and $\hat{\epsilon}_{ij}$ is used to quantify the strength of social ties, they are both normalized.

The number of resources that household j needs (r_j):

People's resource situation is dynamically changing every day, but the survey responses reveal people's resource inventory distribution, shown in Fig. 2-3, based on which we can generate the average resource inventory q_i of each household in the community at the initial stage of the disaster (we consider the necessities of life: water, food, medications, first aid supplies and warmth). We assume that the estimated lockdown time of the community is τ, usually given by the emergency response department, after which people can normally obtain daily necessities, then the number of resources that each family needs is: $r_i = max(\tau - q_i, 0)$.

The strength of social ties between families i and j (ϵ_{ij}):

Different values were assigned to quantify the weight of different types of social ties in the sharing priority:

$$\epsilon_{ij} = \begin{cases} 3, & \text{if families i and j have a strong tie} \\ 2, & \text{if families i and j have a weak tie} \\ 1, & \text{if families i and j are strangers.} \end{cases} \tag{6}$$

4.2. Decentralized resource allocation model

Based on the social-capital-based community network, we develop a resource allocation and sharing scheme based on social capital, shown in Fig. 7. The relief center allocates resources to the sharing hubs, and the sharing hubs will share with other households in the community according to their sharing willingness and sharing priority.

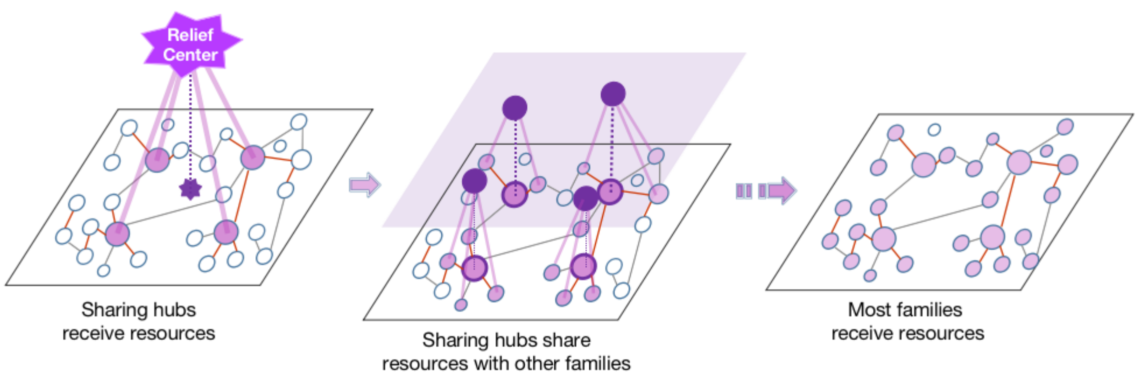


Figure 7: Decentralized allocation scheme

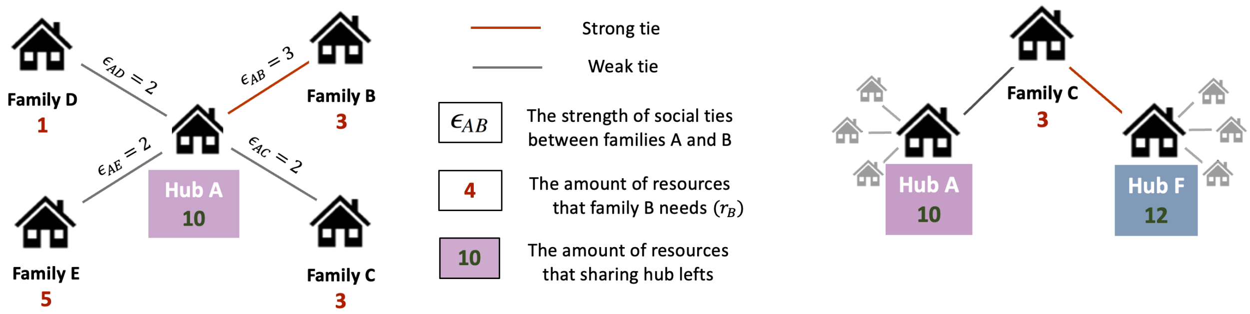
4.2.1. Sharing hubs receive resources

Commonly used traditional resource allocation methods are Fixed Site Distributions (FEMA, 2015), which can be modeled by the queuing network (Ozen and Krishnamurthy, 2018, 2022). Even though we focus on decentralized allocation, which is driven by the social capital existing within the community, the behavior of sharing hubs traveling to relief centers to collect resources can still be simulated using the queuing network model. We assume that there is one service node in the relief center, and we use the Poisson distribution (Consul and Jain, 1973) to simulate the time for the sharing hubs to reach the rescue center, with the arrival rate λ and the service rate of the relief center set as s, following the Exponential distribution. Based on the queuing network model, we can obtain the time t_i for each sharing hub i when receiving the resources.

4.2.2. Sharing hubs share resources

Before going into details of sharing hubs' sharing process, we make some necessary assumptions underlying the social-capital-based resource-sharing behavior in community: (1) After receiving resources from the relief center, the sharing hubs will share resources, except those they need, with other families in the community, and the rest will be returned to the relief center; (2) Each family receives no more resources than they need.

We utilize a simplified example to elucidate the sharing behavior of sharing hubs, as depicted in Fig. 8 (a). Assume that family A is designated as sharing hub, with a sharing preference encompassing "family, close friends, and acquaintances". Consequently, its sharing set incorporates all families with whom it shares strong and weak social ties. For simplicity, we posit that this set comprises only families B, C, D, and E. Further, we compute the sharing priority of hub A towards each family within its sharing set. For hub A, we assume the rational and resource-related factors to be 0.5, which mirrors a realistic scenario where hub A would contemplate both the resource



(a) Sharing behavior of each sharing hub (b) Receiving behavior of each family

Figure 8: Social-capital-based resource sharing-receiving behavior in the community

Family	B	C	D	E
Hub A	3	1	1	5
Hub F	-	2	-	-
Resource coverage situation	✓	✓	✓	✓

Table 2: The number of resources that sharing hubs share with each family

reserves of families B, C, D, and E and the intensity of their social ties to determine the sequence of resource sharing. In this instance, the priority ranking of hub A's sharing with each family is: $\theta_{AE} > \theta_{AB} > \theta_{AC} > \theta_{AD}$. However, it is pivotal to note that the total resources available for distribution by hub A might not suffice to meet the demands of all families in its sharing set. Given the typical resource scarcity during disasters, the relief center's allocation to each sharing hub is finite (Su et al., 2016). As illustrated in Fig. 6, overlaps exist among the sharing sets of different sharing hubs due to the intertwined nature of social ties within the community. Suppose family C is also part of another sharing hub's set, as shown in Fig. 8 (b). In that case, hub F could also allocate a portion of its resources to family C, and one simulated resource allocation situation based on this scenario is shown in Table 1.

In the real world, peer-to-peer sharing by sharing hubs is more intricate than our illustrative example, given their extensive social ties. To simulate the resource-sharing of sharing hubs, we present the following model formulation:

The model formulation of resources sharing of sharing hubs is as follows:

$$max \sum_{i \in \mathcal{K}} \sum_{j \in \{N|\mathcal{K}\}} \theta_{ij} x_{ij} \tag{7}$$

$$\sum_{j \in \mathcal{D}_i} x_{ij} \leq Q_i - r_i, \quad \forall i \in \mathcal{K} \tag{8}$$

$$\sum_{i \in \mathcal{K}} x_{ij} \leq r_j, \quad \forall j \in \{N|\mathcal{K}\} \tag{9}$$

$$x_{ij} \geq 0, \quad \forall i \in \mathcal{K}, \forall j \in \{N|\mathcal{K}\} \tag{10}$$

where x_{ij} represents the amount of resources that sharing hub i gives to family j, and Q_i represents the amount of resources that hub i receives at the relief center.

In the model, the objective function (7) is designed to maximize the total amount of resources that each sharing hub shares with the families in the community, taking into account their sharing priorities. Equation (8) ensures that the amount of each resource shared by the sharing hubs do not exceed the amount of the corresponding resources they obtain from the relief center minus the amount of their own resources required. Equation (9) requires that the amount of each resource received by each household does not exceed what they need. Equation (10) is a non-negative constraint on the variables. We use $\mathcal{F}_i$ to represent families that receive resources from sharing hub i ($\mathcal{F}_i = \{j|x_{ij} > 0\}$), the order of which can be obtained according to the sharing priority of Hub i. Assuming the sharing hub's resource sharing rate is u, following the exponential distribution, we can obtain the time t_j for each family j when receiving resources.

4.3. Evaluation of resource allocation scheme

To measure the performance of the decentralized resource allocation model, we define the two metrics:

(1): T time resource allocation coverage rate:

We calculate the resource distribution coverage for different time periods T as:

$$C_t = \frac{\sum_{i \in N} I_i(T)}{|N|} \tag{11}$$

where $I_i(T)$ is an indicator function, indicating whether family i received the resource before T time:

$$I_i(T) = \begin{cases} 1, & t_i \leq T \\ 0, & t_i > T \end{cases} \tag{12}$$

(2) Time perception satisfaction:

Perception is the result of people's subjective feeling and cognition, which is based on the limited rationality (Kahneman and Tversky, 1984), and victims with limited rationality are sensitive to rescue time in the process of emergency relief (Huang et al., 2012). According to the prospect theory (Kahneman and Tversky, 2013, Chen, 2020), we define each household's time perception satisfaction as:

$$f(t_i) = \begin{cases} 1, & 0 < t_i \leq \alpha_i \\ e^{-0.5[(t_i - \alpha_i)/\alpha_i]^2}, & t_i > \alpha_i \end{cases} \tag{13}$$

where α_i is the expected time for household i to obtain resources, also known as the threshold. It is worth considering that each household has different psychological expectations of rescue time due to their different resource conditions, which can be described as:

$$\alpha_i = \beta e^{-r_i} + \alpha_0 \tag{14}$$

where β describes the sensitivity of the number of resources to the expected rescue time, and α_0 is a lower limit on the expected rescue time. When the time to obtain resources is less than or equal to the threshold, people's time perception satisfaction is 1; when the time exceeds the threshold, the longer the waiting time, the lower the satisfaction. The average satisfaction of all families in the community is:

$$S = \sum_{i \in N} f(t_i) \tag{15}$$

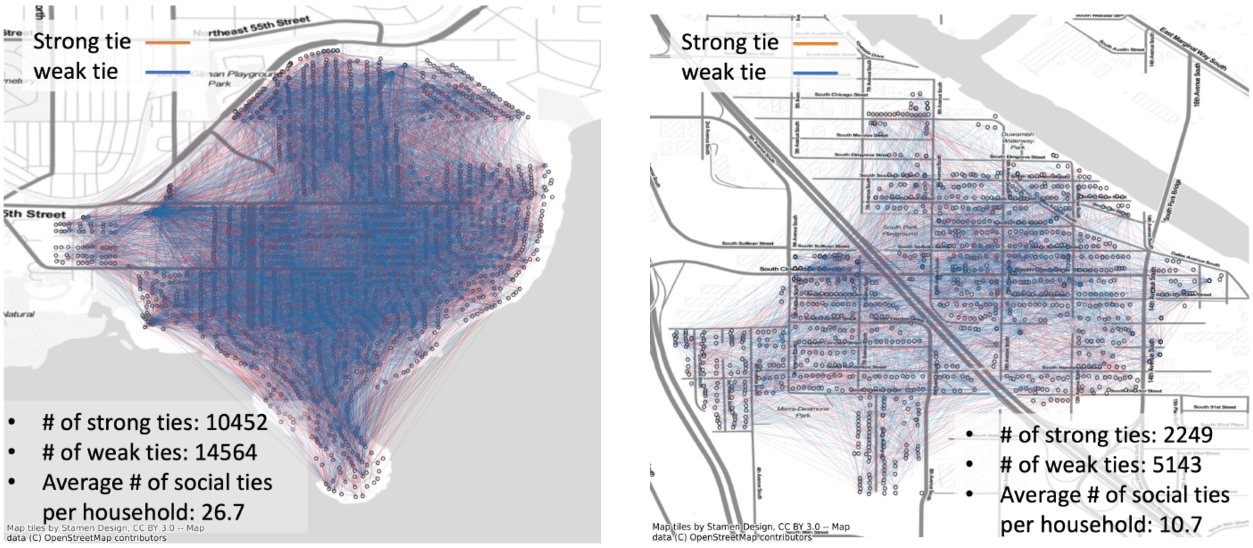
5. Results and discussions

In this section, we present the concrete results of the theoretical framework described in Chapter 2, using the Laurelhurst and Southpark communities as examples. In addition, the decentralized distribution model considering social capital is compared with the traditional centralized distribution scheme to compare the resource coverage and residents' satisfaction under different distribution methods.

5.1. Detailed results of the methodological framework

5.1.1. Social-capital-based community network

Based on the theoretical section in 3.1.1, during the step 1 of constructing the social ties network, we obtain the values of the parameters n and p for the node degree of the negative binomial distribution through the values of the maximum likelihood estimation parameter of the survey data,



(a) Laurelhurst community

(b) Southpark community

Figure 9: Social ties network of two communities

Community	n	p	$\hat{\gamma}$
Laurelhurst	0.7877	0.0256	-1.35
Southpark	0.8266	0.0669	-1.43

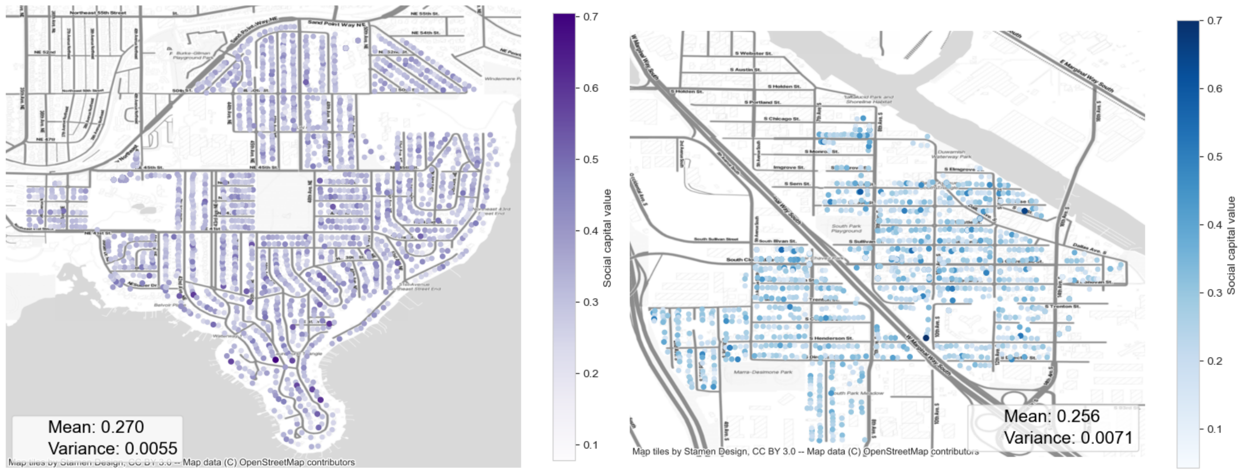
Table 3: The parameters of social network construction in two communities

as shown in Table 2. In Step 2, the social connection probability parameters $\hat{\gamma}$ for the two communities based on survey responses, as derived from Equation 5, are shown in Table 2. Based on this, we obtain the community social network of Laurelhurst and Southpark communities, as illustrated in Fig. 9. It's evident that the number of strong ties and weak ties in the Laurelhurst community is larger, 10,452 and 14,564, compared to 2,249 and 5,143, respectively, in the Southpark community. The number of strong social ties in Laurelhurst is approximately five times that of the Southpark community, and the number of weak social ties is about three times as many.

Further, a social capital value is calculated for each household, representing their potential contribution and capacity to assist the community in the event of a disaster, based on which the community will identify the sharing hubs. The exploration by Choo and Yoon (2022) on how social capital influences residents' ability to respond to disasters effectively demonstrated that civic engagement, informal social networks, and trust are contributing variables to community social capital during disasters. In the research by ZhengYang on community disaster resilience based on peer-to-peer sharing, the significance of social tie number and sharing preference in community disaster response was proven. Therefore, we set $w^z = \{2, 2, 1, 1, 1\}$ as the weight of sharing preference, social tie number, trust, belonging, and participation to calculate the social capital value of residents the two communities, as shown in Fig. 10. It can be seen that the average social capital value of residents in the Laurelhurst community is higher than that of Southpark, and the variance is smaller. At the same time, we calculate the frequency distribution curve of the social capital value of residents in the two communities, as shown in Fig. 11. It is shown that the Laurelhurst community 's distribution skews to the right compared to the Southpark community 's, indicating that residents in the Laurelhurst community have a stronger social ties network and a higher sense of community mutual assistance in the face of disaster.

5.1.2. Sharing hubs

We set the number of sharing hubs $\mathcal{K} = 100$ and make the distribution of sharing hubs and social ties of sharing hubs in the two communities according to Chapter 3.2, as shown in Fig. 12. It can be seen that the strong social ties of sharing hubs in Laurelhurst account for 39.52% of all the strong social ties in the community, and the weak social ties account for 40.39% of all the weak social ties in the community. In comparison, the strong social ties and weak social ties of the Southpark community sharing hubs account for 51.67% and 48.22% of the total, respectively,



(a) Laurelhurst community

(b) Southpark community

Figure 10: Social capital value of two communities

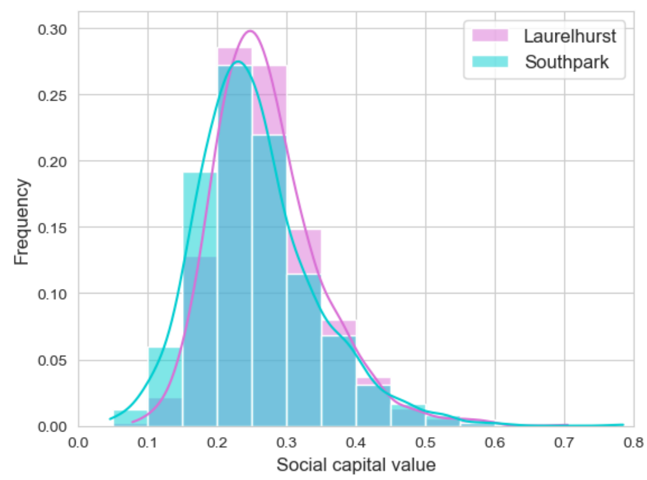
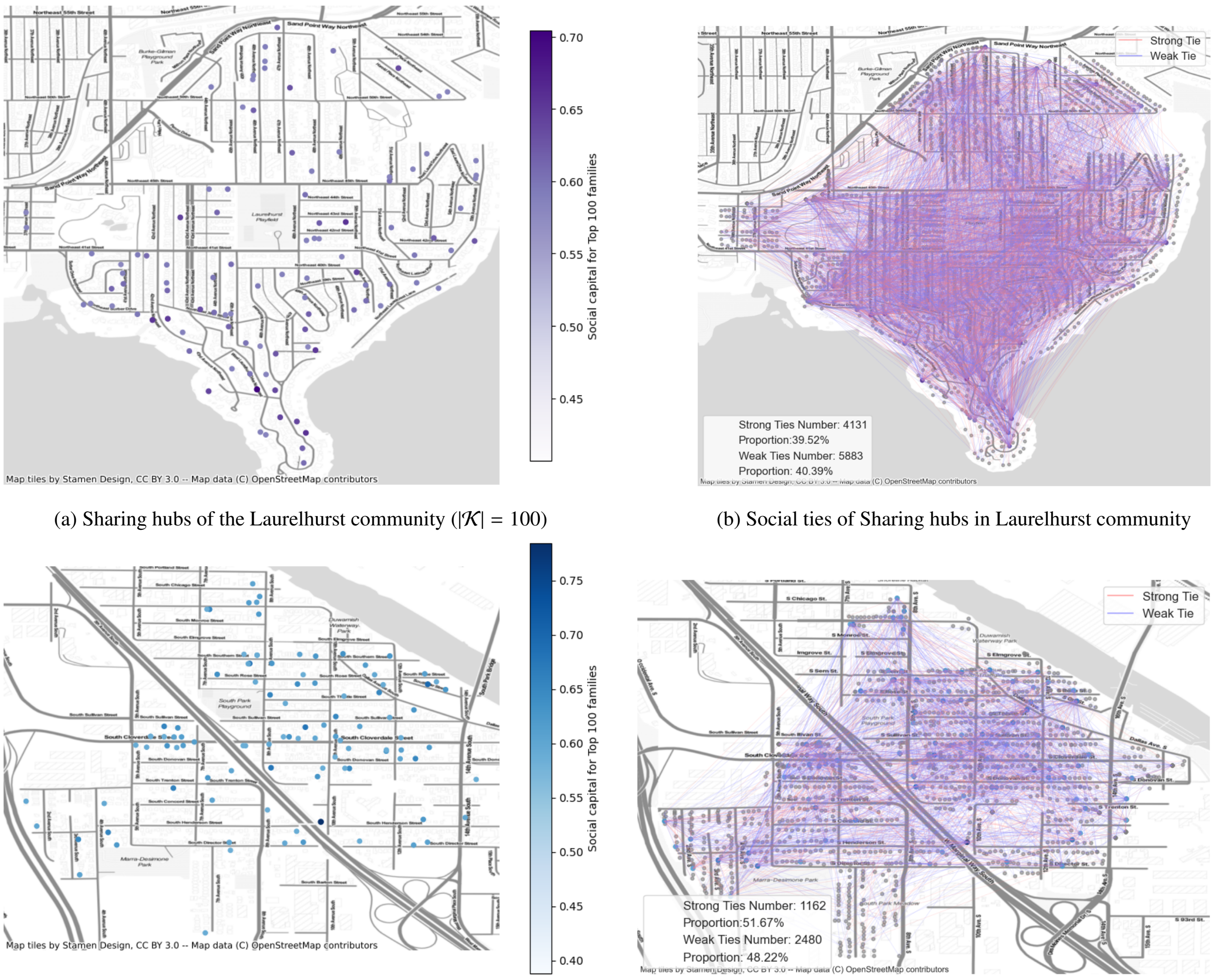


Figure 11: Social capital value distribution of two communities

because the total number of social ties there is lower.

5.1.3. Evaluation of the decentralized resources allocation model

In Chapter 3.4, we introduced the decentralized resource allocation scheme around the sharing hubs. It is conceivable that the number of sharing hubs will affect the performance of the resource allocation scheme because if the number is too small, other community residents will have to wait too long to receive the resources, but if the number is too big, then most families serving as sharing hubs will have to spend time waiting in line at the relief center, which is not much different from the centralized distribution plan. Therefore, we set the number of sharing hubs $|\mathcal{K}|$ to change within a certain range from 20 to 140, explore the impact of the number of sharing hubs on the average satisfaction of residents, and compare it with the centralized distribution scheme. Other parameters are set as follows: The weights of relational and resource-related factors that comprise sharing priority are $\xi_1 = \xi_2 = 0.5$. In the centralized distribution scheme, referring to the setting of Ozen and Krishnamurthy (2022) about relief distribution in response to the 2015 Nepal earthquake, we set the time for people to go to the rescue center following the Poisson distribution, with arrival rate $\lambda_c = 2$ *families / per minute*; the service speed of the rescue center team following an exponential distribution, with the service rate $s_c = 1$ *family / per minute*. In the decentralized distribution scheme, since only sharing hubs go to the relief center and it takes longer time for them to check information and get more resources to serve other residents, not only themselves, we set the arrival rate and service rate as $\lambda_d = \omega * \lambda_c$, $s_d = \omega * s_c$, where ω is a speed proportional factor, $\omega = 10$. At the same time, after receiving resources, the speed at which sharing hubs share with other families pays an exponential distribution, $s_H = 1$ *family / per 20 minutes*. And the sensitivity of the number of remaining resources to the expected rescue time is set as $\beta = 360$, the lower limit of the expected rescue time is set as $\alpha_0 = 360$ *(minute)*.



(a) Sharing hubs of the Laurelhurst community ($|\mathcal{K}| = 100$)

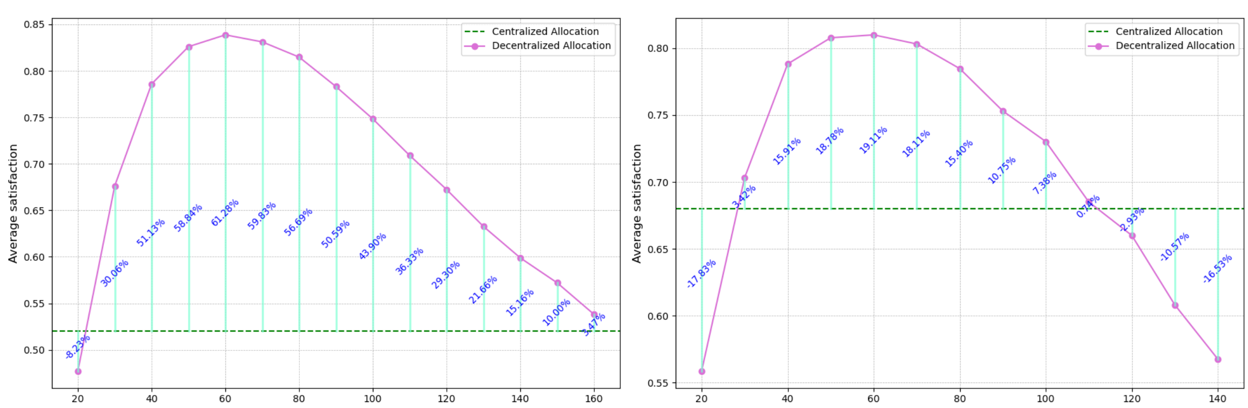
(b) Social ties of Sharing hubs in Laurelhurst community

(c) Sharing hubs of the Southpark community ($|\mathcal{K}| = 100$)

(d) Social ties of Sharing hubs in Southpark community

Figure 12: Comparison of social capital values

We run the implementation 100 times and average the results, as shown in Fig. 13, the average satisfaction of residents increases first and then decreases with the number of sharing hubs, which shows the same trend in both communities. Moreover, when the number of sharing hubs is in the range of 50-80, both communities are close to achieving the highest level of resident satisfaction. By comparing the centralized distribution scheme, we find that the decentralized distribution scheme can achieve a high average satisfaction improvement in the Laurelhurst community, with the highest improvement rate approaching 61.3%. As for the Southpark community, due to the smaller number of people, people in the centralized distribution scheme had a shorter waiting time at the relief center and a relatively optimistic average satisfaction. The improvement rate obtained by the decentralized distribution plan was lower than that of the Laurelhurst community, with the highest improvement rate of nearly 19.1%.

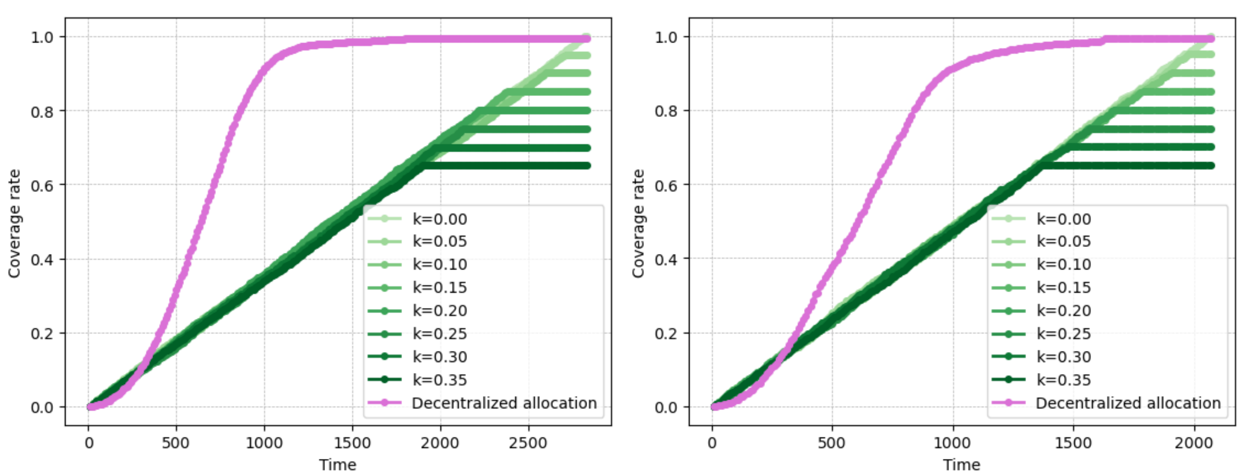


(a) Laurelhurst community

(b) Southpark community

Figure 13: Satisfaction rate of decentralized and centralized resource allocation

Then, we analyze the difference between the centralized and decentralized allocation schemes in t time resource coverage. One of our goals in designing decentralized resource allocation solutions is to explore how to improve resource coverage in communities where there is a portion of people who are injured or unable to access information, such as the elderly and the severely injured, who are unable to go out to rescue centers to access resources. We set the numbers of sharing hubs in Laurelhurst and Southpark 60 (the corresponding number at the highest level of satisfaction, as shown in Fig. 13), respectively, and the proportion of people in the community without access to resources as k, and draw the resource coverage curve under different k under the two schemes. As seen in Fig. 14, the decentralized resource allocation scheme can ensure that all residents in a community have access to resources because most sharing hubs share resources with people who have social ties to them, even strangers in the community. In addition, the decentralized resource allocation scheme can achieve comprehensive coverage of resources in a shorter time. By contrast, the resource coverage of centralized distribution schemes will decrease as the proportion of people without access to resources increases. In parallel, we examined the resource-sharing dynamics in the Laurelhurst and Southpark communities to discern whether sharing predominantly occurred through strong ties, weak ties, or strangers. The findings are presented in Table 3. For Laurelhurst, a significant portion of resource sharing is facilitated through strong ties, which can be attributed to the tight-knit social tie network within the community. In contrast, Southpark, characterized by a more relaxed social tie network, witnesses a majority of its resources being shared through both strong and weak ties, with a minor fraction being shared by strangers.



(a) Laurelhurst community

(b) Southpark community

Figure 14: Coverage rate of decentralized and centralized resource allocation

Community	# from strong ties	# from weak ties	# from strangers
Laurelhurst	67.42 %	19.40 %	13.18 %
Southpark	40.95%	42.56 %	16.50 %

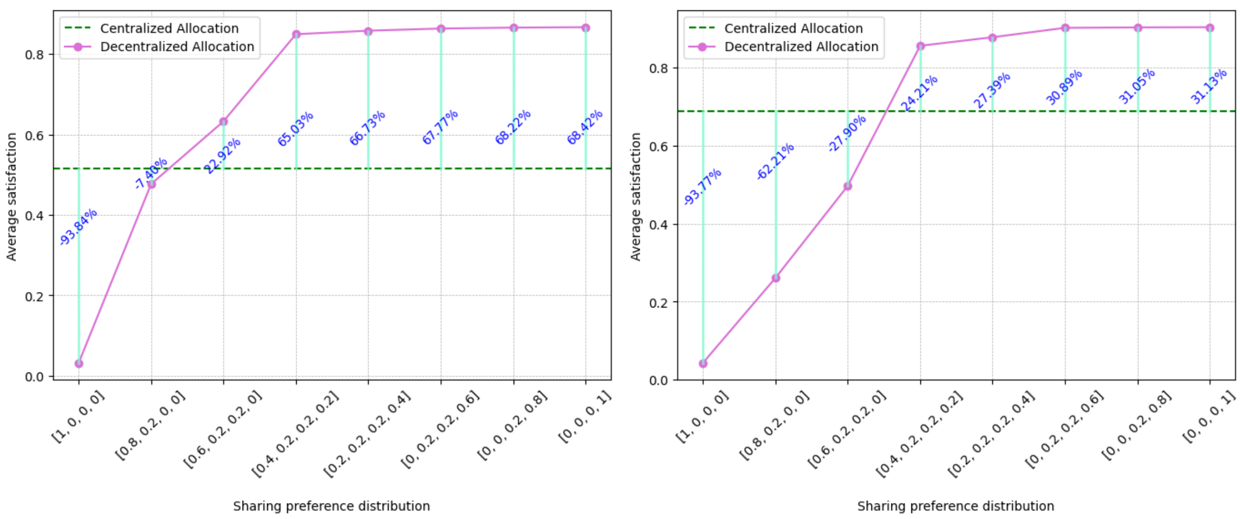
Table 4: The proportion of resources shared through different social ties in two communities

5.2. *Sensitivity analyses*

In this section, we delve into the factors influencing decentralized resource allocation, encompassing residents' sharing preferences, the number of social ties in the community, the sharing priorities of sharing hubs, and the rescue time of emergency resource allocation within the community.

5.2.1. *Sharing preference*

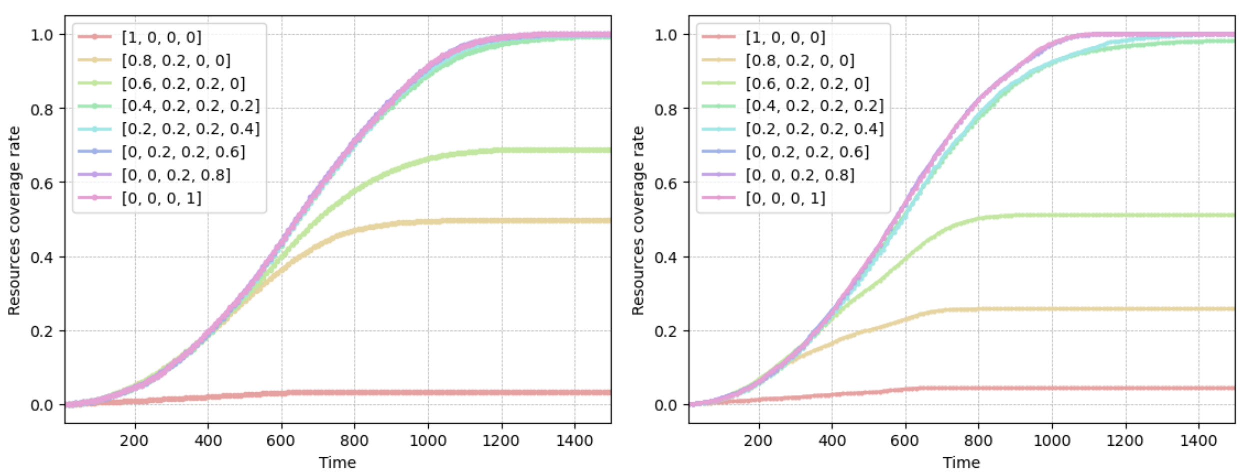
Sharing preference is an important factor affecting the decentralized distribution scheme because the sharing sets of each sharing hub are divided according to their sharing preference, as mentioned in Chapter 3.2. We set the sharing preference of people in the community as [a,b,c,d], where a,b,c, and d correspond to the ratio of people who are not willing to share with anyone, people who are not willing to share with anyone but only those with strong social ties, people who are willing to share with those with weak social ties and strong social ties, people willing to share with everyone. Setting [a,b,c,d] gradually change from [1,0,0,0] to [0,0,0,1], we explore the performance of the decentralized distribution scheme when people in the community have different sharing preference distributions. As shown in Fig. 15, both communities show the same trend, with average satisfaction with decentralized distribution schemes increasing as a larger percentage of people are willing to share with more people.



(a) Laurelhurst community

(b) Southpark community

Figure 15: Satisfaction rate under different sharing preference distribution



(a) Laurelhurst community

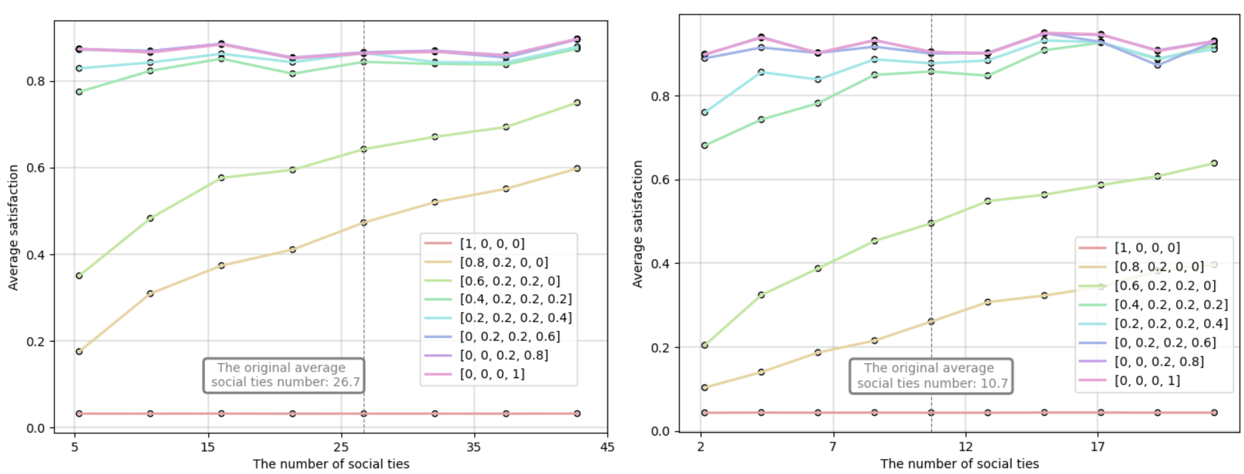
(b) Southpark community

Figure 16: Resource coverage rate under different sharing preference distribution

It is noteworthy that a pivotal point emerges when the distribution of residents' sharing preferences within the community is at [0.4, 0.2, 0.2, 0.2]. Prior to this, as an increasing number of individuals in the community are willing to share, there is a significant enhancement in the community's average satisfaction level. It rises from below 10% (when no one is inclined to share, resulting in most being unable to access resources) to over 80% (when 20%, 20%, 20% of the residents are willing to share with strong ties only, both strong and weak ties, and everyone, respectively). Beyond this inflection point, even as the proportion of those willing to share with more people increases, the growth in average community satisfaction becomes gradual and less pronounced. Comparing the Laurelhurst and Southpark communities, while the overall trend is similar, the increase in average satisfaction is more pronounced in Laurelhurst. Even when the sharing preference is at [0.8, 0.2, 0, 0], Laurelhurst's average satisfaction (around 49%) is significantly higher than Southpark's (around 24%). This can be attributed to Laurelhurst having a greater number of strong social ties. Hence, when only 20% of the community is inclined to share exclusively with strong ties, the decentralized resource allocation scheme achieves a higher coverage in Laurelhurst, leading to relatively greater satisfaction. Based on this observation, we will explore the influence of the number of social ties on decentralized resource allocation in section 4.2.2.

Furthermore, as evident from Figure 16, the resource coverage within the community varies under different sharing preference distributions. In extreme cases, if no one is willing to share, the existence of sharing hubs becomes redundant. As the community's sharing preference distribution shifts from [0.6, 0.2, 0.2, 0] to [0.4, 0.2, 0.2, 0.2], there is a substantial increase in resource coverage, moving from approximately 50% to nearly 95% for Southpark and approximately 69% to nearly 98% for Laurelhurst. This aligns with the significant increase in residents' average satisfaction at the [0.4, 0.2, 0.2, 0.2] point, as depicted in Figure 15. While the distribution of sharing preferences in this sensitivity analysis is artificially set and may deviate from real-world scenarios, this simulation underscores a key insight: In our proposed decentralized resource-sharing scheme, it's crucial for a small segment of the population willing to share with the majority in the community. However, it doesn't necessarily have to reach the ideal state where everyone is willing to share with everyone else.

5.2.2. *Social ties number*

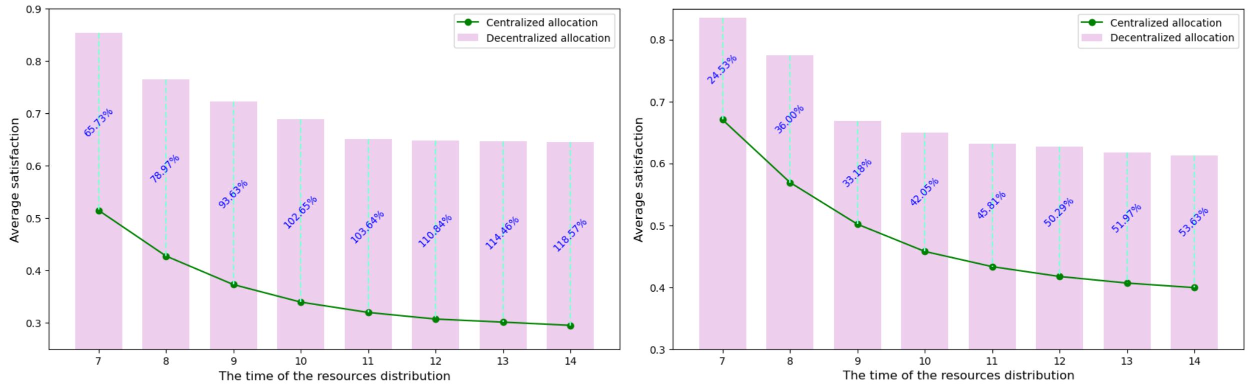


(a) Laurelhurst community

(b) Southpark community

Figure 17: Satisfaction rate under different social ties number ratio

Further, we investigated the influence of social ties on average satisfaction by varying the number of social ties during the generation of social networks, as depicted in Figure 17. It's evident that the number of social ties has a limited impact on the average resident satisfaction. In the extreme scenarios where the sharing preference is [0, 0, 0, 1], it's intuitive that increasing the number of social ties within the community does not alter the average satisfaction, given that no one is inclined to share. When the distribution of sharing preference is at [0.8, 0.2, 0, 0] and [0.6, 0.2, 0.2, 0], the community's willingness to share remains relatively low, the addition of more social ties proves beneficial in enabling more individuals to access resources, leading to higher average satisfaction. However, when a segment of the community is willing to share with everyone, as in sharing preference distributions like [0, 0.2, 0.2, 0.6] and beyond, the addition of social ties does not result in a significant boost in average satisfaction. Surprisingly, as the average number of social ties per resident increases, the average satisfaction exhibits fluctuations, suggesting that a higher number of social ties isn't always a promoting factor for decentralized resource allocation. This conclusion aligns with the findings of Choo and Yoon (2022) in their study on the correlation between disaster response capabilities and community social capital among residents of Seoul, South Korea, where informal social networks weren't identified as a key determinant in disaster response capabilities.



(a) Laurelhurst community

(b) Southpark community

Figure 18: Satisfaction rate of decentralized and centralized resource allocation under different rescue times

5.2.3. Sharing priority

Sharing priority, subjective to each sharing hub, affects the order in which resources are allocated to other families. In this study, we consider that the priority consists of two parts: relational-related factor $\xi_1$and resource-related factor ξ_2, as described in Chapter 3.3, and change the weight of the two factors $[\xi_1, \xi_2]$ from [0,1] to [1,0], representing the different situations of people from completely rational to completely emotional in the methodology framework, the results of community average satisfaction are shown in Table 4.

Communicty	relational-related and resource-related factors	Average satisfaction	Reduction
Laurelhurst	[0,1]	85.14%	0
	[0.5,0.5]	84.15%	-0.99%
	[1,0]	82.53%	-2.61%
Southpark	[0,1]	86.76%	0
	[0.5,0.5]	85.78%	-0.98%
	[1,0]	85.61%	-1.15%

Table 5: Average satisfaction under different perceptual and rational factors in two communities

The findings indicate that when all sharing hubs within the community prioritize the scarcity of resources in other households for resource allocation, the average satisfaction of residents in both communities is maximized. This observation stems from the understanding that resident satisfaction is both time-sensitive and quantity-sensitive during times of disaster. Conversely, when all sharing hubs in a community prioritize the strength of social ties to other households for resource distribution, the average satisfaction of residents in both communities drops to its lowest. This is attributed to the potential overlook of households in dire need of resources. However, it's noteworthy that the decline is not substantial. For the Laurelhurst community, there's only a reduction of 2.61%, while for the Southpark community, the decrease stands at a mere 1.15%. When sharing hubs consider both social ties with those families and the resource situation of those families, the average community satisfaction falls in between the two extremes.

5.2.4. Rescue time

Rescue time is also a factor affecting residents' satisfaction. We set the rescue time to vary from the seventh to the fourteenth day, exploring the difference in satisfaction between decentralized and centralized rescue plans. It is evident that as the rescue time extends, there is a downward trend in community satisfaction. This decline is attributed to the prolonged arrival of rescue supplies, leading to a decrease in the remaining resources and an increased urgency for resource replenishment among more people. However, it is noteworthy that the decentralized distribution plan achieved significant and stable improvements across different rescue times in both communities, demonstrating the robustness of the decentralized distribution plan that considers social capital.

This highlights the importance of valuing the social capital within communities, which stimulates peer-to-peer sharing among residents, especially when external rescue takes longer.

6. Conclusion

This study explored the distribution of emergency supplies during the last mile of disaster response, focusing on the potential of peer-to-peer sharing driven by community social capital. First, we gathered data from two communities in Seattle, Washington, Laurelhurst and Southpark. The survey responses provided a firsthand understanding of pre-disaster preparedness, disaster response, and the general landscape of social ties within these communities – serving as a foundation for evaluating community social capital. Subsequently, we introduced a theoretical framework for the decentralized resource allocation scheme. This framework encompasses (1) Social-capital-based community model construction, (2) Determination of sharing hubs and sharing sets, (3) Determination of sharing hubs' sharing priority, (4) Decentralized resource allocation model, (5) Evaluation of the resource allocation scheme.

Our experiments and sensitivity analysis revealed:

The feasibility of the decentralized resource allocation scheme.

(1) Compared to traditional centralized allocation methods, the decentralized approach resulted in higher average satisfaction within both communities. Notably, the performance of the decentralized scheme is influenced by the number of sharing hubs: few are inefficient, leading to longer waiting times, while too many make it scarcely distinguishable from the centralized approach. For communities the size of Laurelhurst (1,873 households during our survey) and Southpark (1,739 households during our survey), the ideal range is 50-80 hubs.

(2) The decentralized resource allocation scheme enables 100% resource coverage in a shorter duration than traditional methods, even accounting for households who cannot access relief centers due to injuries or age. This satisfactory outcome relies on the community's willingness to share and the established social ties we know from the survey data.

Decentralized allocation isn't universally optimal.

From the sensitivity analysis, the state of social capital within a community can influence the effectiveness of a decentralized distribution scheme, as reflected in residents' average satisfaction and resource coverage rates. The most direct factor influencing the decentralized resource allocation strategy is the residents' sharing preference. We can see that: (1) A community where the majority are unwilling to share with others is unsuitable for a decentralized distribution approach. (2) Having a minority within the community willing to share resources with the majority is crucial for implementing a decentralized resource allocation scheme. However, it is not necessary to achieve an ideal state where everyone is willing to share, which is also hard to achieve. (3) The number of social ties within the community has a limited impact on implementing the decentralized resource allocation scheme, only proving beneficial when a minority is willing to share and the majority is not.

The sharing priority of sharing hubs isn't as critical as we assume.

When sharing hubs make decisions on the order of resource sharing, comparing absolute resource demand priority with absolute relationship priority, although the overall community satisfaction is higher when the resource demand is prioritized, the difference is minimal. Results from 4.2.3 showed only a marginal satisfaction difference (1%-2%) between complete resource need prioritization versus complete relational prioritization in Laurelhurst and Southpark neighborhoods.

The decentralized scheme is versatile across different rescue stages.

For communities with a social capital structure suitable for decentralized allocation, such as Laurelhurst and Southpark, our analysis in 4.2.4 demonstrated that the decentralized approach consistently outperforms centralized methods in average household satisfaction under different rescue times, as resources are covered more quickly and extensively.

7. Discussion

The primary intention of this research is to propose a method for quantifying and assessing community social capital and to explore the potential for spontaneous mutual aid and peer-to-peer sharing displayed by families driven by social capital during disasters. Our ultimate goal is to offer recommendations for community disaster response. Based on our findings, we put forth several policy and technological suggestions:

Community Disaster Response Recommendations:

In emergency disaster response, a decentralized approach, utilizing peer-to-peer sharing among residents, could be considered. It is important to note that the implementation of the decentralized resource distribution scheme should consider the population of the community to determine the appropriate number of sharing hubs. Additionally, it is not necessary to overly focus on sharing hubs' sharing priorities. The community can encourage but does not need to demand that they act completely rationally and equally in sharing resources with people in the community since prioritizing resource needs over social relationships in decision-making at sharing hubs has a minimal impact on enhancing overall community satisfaction, which is also challenging during a disaster (Perry Jr et al., 1983).

Community Disaster Preparedness Recommendations:

(1) Enhance community social capital: The community's social capital situation is crucial for implementing decentralized resource distribution. According to our analysis of survey questionnaires, people's sharing preferences and the number of social ties are correlated with trust and belonging. Communities can organize regular community team-building activities and provide platforms for residents to interact and become familiar with each other, helping to build trust and a sense of community belonging. Encouraging more residents to participate in public affairs and building more social connections can improve community cohesion and strengthen social networks (Alesina and La Ferrara, 2002). An example worth noting is the Laurelhurst Emergency Action Plan (LEAP, 2022), a volunteer organization dedicated to bringing people together through various training and preparedness courses, educating Laurelhurst residents about steps to take before, during, and after an earthquake.

(2) Focus on potential sharing hubs: Identifying and authorizing potential sharing hubs in the community during the disaster preparedness phase is important. Our research shows that having a small portion of community residents have a broader willingness to share is crucial for implementing decentralized emergency resource distribution. These residents are likely to be members of the sharing hubs. Therefore, the focus of community disaster preparedness should be on identifying and training them to respond orderly in the event of a disaster. For example, in the LEAP of Laurelhurst community, they divide the community into zones (LEAP, 2023) and assign a "captain" to each zone, who can play a key role as sharing hub in emergencies and coordinate resource distribution. However, the community does not need to put much effort into encouraging each individual to share with everybody in the community or to establish many more social relationships beyond their willingness, as these factors have limited enhancement on emergency resource distribution and are difficult to achieve.

(3) Develop strategies for different communities: Each community's social capital situation is different. According to the survey, Laurelhurst's social ties are three times more than Southpark's. Tailoring a disaster response process to communities' different "personalities" is necessary. As mentioned in the Seattle Neighborhoods Actively Prepare (EM, 2023) program , there is no right or wrong in different community organization methods. The key is to develop a plan and be prepared. Our decentralized resource distribution method provides an example that is theoretically feasible but requires further testing in actual implementation. A suggested implementation process is: i) Community conduct surveys to understand residents' social capital, including their sharing preferences and social ties, trust, participation, etc; ii) Identify sharing hubs based on residents' sit-

uations and will and establish a post-disaster action execution roadmap suitable for the community; iii) Conduct training and drills to improve and adjust the response plan continuously.

References

David M Neal. Reconsidering the phases of disaster. *International Journal of Mass Emergencies & Disasters*, 15(2):239–264, 1997.

Jane Bullock, George Haddow, and Damon Coppola. *Introduction to emergency management*. Butterworth-Heinemann, 2017.

Abderazek Seba, Nadia Nouali-Taboudjemat, Nadjib Badache, and Hamida Seba. A review on security challenges of wireless communications in disaster emergency response and crisis management situations. *Journal of Network and Computer Applications*, 126:150–161, 2019.

Xiao-Bing Hu, Ming Wang, Tao Ye, and Peijun Shi. A new method for resource allocation optimization in disaster reduction and risk governance. *International Journal of Disaster Risk Science*, 7:138–150, 2016.

Yu Guo, Yanqing Ye, Qingqing Yang, and Kewei Yang. A multi-objective inlp model of sustainable resource allocation for long-range maritime search and rescue. *Sustainability*, 11(3):929, 2019.

Florida DEM. County logistics planning, 2016. URL https://www.floridadisaster.org/globalassets/importedpdfs/pod-sog-2355-final-revised-11-16-16.pdf.

FEMA. Multi-agency distribution of emergency supplies plan, 2015. URL https://www.nationalmasscarestrategy.org/wp-content/uploads/2015/06/Multi-Agency-Distribution-of-Emergency-Supplies-Plan-Template-2015.pdf.

Tony Pipa. *Weathering the Storm: The Role of Local Nonprofits in the Hurrican Katrina Relief Effort*. Nonprofit Sector Research Fund of the Aspen Institute, 2006.

Rhoda Margesson and Maureen Taft-Morales. Haiti earthquake: Crisis and response, 2010.

Russell Dynes. Social capital: Dealing with community emergencies. *Homeland Security Affairs*, 2(2), 2006.

Lauren S Fernandez, Deana Byard, Chien-Chih Lin, Samuel Benson, and Joseph A Barbera. Frail elderly as disaster victims: emergency management strategies. *Prehospital and disaster medicine*, 17(2):67–74, 2002.

Eric Klinenberg. *Heat wave: A social autopsy of disaster in Chicago*. University of Chicago press, 2015.

Saileshsingh Gunessee, Nachiappan Subramanian, Samuel Roscoe, and Jothibasu Ramanathan. The social preferences of local citizens and spontaneous volunteerism during disaster relief operations. *International Journal of Production Research*, 56(21):6793–6808, 2018.

Joseph Scanlon, Ira Helsloot, and Jelle Groenendaal. Putting it all together: Integrating ordinary people into emergency response. *International Journal of Mass Emergencies & Disasters*, 32 (1):43–63, 2014.

Stanley Wasserman and Katherine Faust. Social network analysis: Methods and applications. 1994.

Daniel P Aldrich and Michelle A Meyer. Social capital and community resilience. *American behavioral scientist*, 59(2):254–269, 2015.

Daniel P Aldrich. The power of people: social capital's role in recovery from the 1995 kobe earthquake. *Natural hazards*, 56:595–611, 2011.

Jenny Moreno, Alejandro Lara, and Mauricio Torres. Community resilience in response to the 2010 tsunami in chile: The survival of a small-scale fishing community. *International Journal of Disaster Risk Reduction*, 33:376–384, 2019.

Daniel P Aldrich and Yasuyuki Sawada. The physical and social determinants of mortality in the 3.11 tsunami. *Social Science & Medicine*, 124:66–75, 2015.

K. Prociv. Pic of the week: People helping people after hurricane matthew, 2016. https://www.washingtonpost.com/news/capital-weather-gang/wp/2016/10/28/ pic-of-the-week-people-helping-people-after-hurricane-matthew/.

M. Martinez. Texans used mutual aid to help their communities through a devastating winter storm., 2021. https://www.texastribune.org/2021/02/23/mutual-aid-texas-storm/.

Michelle A Meyer. Social capital in disaster research. *Handbook of disaster research*, pages 263–286, 2018.

Lyda J Hanifan. The rural school community center. *The Annals of the American Academy of Political and Social Science*, 67(1):130–138, 1916.

Claudia Morsut, Christian Kuran, Bjørn Ivar Kruke, Kati Orru, and Sten Hansson. Linking resilience, vulnerability, social capital and risk awareness for crisis and disaster research. *Journal of Contingencies and Crisis Management*, 30(2):137–147, 2022.

Brenda L Murphy. Locating social capital in resilient community-level emergency management. *Natural Hazards*, 41:297–315, 2007.

Russell R Dynes. The importance of social capital in disaster response. 2002.

Aakil M Caunhye, Xiaofeng Nie, and Shaligram Pokharel. Optimization models in emergency logistics: A literature review. *Socio-economic planning sciences*, 46(1):4–13, 2012.

Zhengyang Li, Anthony Chen, Katherine Idziorek, and Cynthia Chen. Community resilience: the potential of peer-to-peer transportation sharing. In *Transportation Research Board 103rd Annual Meeting*, Washington, D.C., 2023. TRB.

Lucila M Zamboni and Erika G Martin. Association of us households' disaster preparedness with socioeconomic characteristics, composition, and region. *JAMA network open*, 3(4):e206881–e206881, 2020.

Luyan Wang, Yuan Jiang, Liujun Pan, Jiangyuan Ji, and Aoao Xu. Research on household emergency supplies storage from the theory of planned behavior and intention-behavior gap in the context of covid-19. *Frontiers in Psychology*, 13:1069843, 2023.

Robert Putnam. The prosperous community: Social capital and public life. *The american*, 4, 1993.

James S Coleman. Social capital in the creation of human capital. *American journal of sociology*, 94:S95–S120, 1988.

Robert D Putnam. Bowling alone: America's declining social capital. In *The city reader*, pages 188–196. Routledge, 2015.

Yuko Nakagawa and Rajib Shaw. Social capital: A missing link to disaster recovery. *International Journal of Mass Emergencies & Disasters*, 22(1):5–34, 2004.

Robert D Putnam. *Bowling alone: The collapse and revival of American community*. Simon and schuster, 2000.

Roper Center. Social capital community benchmark survey 2000, 2000.

Kevin F Forbes and Ernest M Zampelli. The impacts of religion, political ideology, and social capital on religious and secular giving: evidence from the 2006 social capital community survey. *Applied Economics*, 45(17):2481–2490, 2013.

Helene Joffe, Tiziana Rossetto, Christian Solberg, and Cliodhna O'Connor. Social representations of earthquakes: A study of people living in three highly seismic areas. *Earthquake Spectra*, 29 (2):367–397, 2013.

Mark EJ Newman, Duncan J Watts, and Steven H Strogatz. Random graph models of social networks. *Proceedings of the national academy of sciences*, 99(suppl_1):2566–2572, 2002.

David Liben-Nowell, Jasmine Novak, Ravi Kumar, Prabhakar Raghavan, and Andrew Tomkins. Geographic routing in social networks. *Proceedings of the National Academy of Sciences*, 102 (33):11623–11628, 2005.

Paul Erdős, Alfréd Rényi, et al. On the evolution of random graphs. *Publ. math. inst. hung. acad. sci*, 5(1):17–60, 1960.

Albert-László Barabási and Réka Albert. Emergence of scaling in random networks. *science*, 286 (5439):509–512, 1999.

Yang Xu, Paolo Santi, and Carlo Ratti. Beyond distance decay: Discover homophily in spatially embedded social networks. *Annals of the American Association of Geographers*, 112(2):505–521, 2022.

Frederick P Stutz. Distance and network effects on urban social travel fields. *Economic Geography*, 49(2):134–144, 1973.

Michael Bourgeois and Noah E Friedkin. The distant core: social solidarity, social distance and interpersonal ties in core–periphery structures. *Social networks*, 23(4):245–260, 2001.

Jacob Goldenberg and Moshe Levy. Distance is not dead: Social interaction and geographical distance in the internet era. *arXiv preprint arXiv:0906.3202*, 2009.

Elizabeth Graddy and Lili Wang. Community foundation development and social capital. *Nonprofit and Voluntary Sector Quarterly*, 38(3):392–412, 2009.

Jeffrey L Jordan, Bulent Anil, and Abdul Munasib. Community development and local social capital. *Journal of Agricultural and Applied Economics*, 42(1):143–159, 2010.

Nadine Schreiner, Doreén Pick, and Peter Kenning. To share or not to share? explaining willingness to share in the context of social distance. *Journal of Consumer Behaviour*, 17(4):366–378, 2018.

Sigrid Johansen Rennemo, Kristina Fougner Rø, Lars Magnus Hvattum, and Gregorio Tirado. A three-stage stochastic facility routing model for disaster response planning. *Transportation research part E: logistics and transportation review*, 62:116–135, 2014.

Kai Huang, Yiping Jiang, Yufei Yuan, and Lindu Zhao. Modeling multiple humanitarian objectives in emergency response to large-scale disasters. *Transportation Research Part E: Logistics and Transportation Review*, 75:1–17, 2015.

Merve Ozen and Ananth Krishnamurthy. Evaluating relief center designs for disaster relief distribution. *Journal of Humanitarian Logistics and Supply Chain Management*, 8(1):22–48, 2018.

Merve Ozen and Ananth Krishnamurthy. G-network models to support planning for disaster relief distribution. *International Journal of Production Research*, 60(5):1621–1632, 2022.

Prem C Consul and Gaurav C Jain. A generalization of the poisson distribution. *Technometrics*, 15(4):791–799, 1973.

Zhaopin Su, Guofu Zhang, Yang Liu, Feng Yue, and Jianguo Jiang. Multiple emergency resource allocation for concurrent incidents in natural disasters. *International journal of disaster risk reduction*, 17:199–212, 2016.

Daniel Kahneman and Amos Tversky. Choices, values, and frames. *American psychologist*, 39(4): 341, 1984.

Michael Huang, Karen Smilowitz, and Burcu Balcik. Models for relief routing: Equity, efficiency and efficacy. *Transportation research part E: logistics and transportation review*, 48(1):2–18, 2012.

Daniel Kahneman and Amos Tversky. Prospect theory: An analysis of decision under risk. In *Handbook of the fundamentals of financial decision making: Part I*, pages 99–127. World Scientific, 2013.

Gang Chen. Emergency material distribution model and algorithm considering the limited rationality of disaster victims. *Logistics technology*, 43(9):6–9, 2020.

Mijin Choo and DK Yoon. Examining the effects of the local communities' social capital on disaster response capacity in seoul, south korea. *International Journal of Disaster Risk Reduction*, 75:102973, 2022.

Joseph B Perry Jr, Randolph Hawkins, and David M Neal. Giving and receiving aid. *International Journal of Mass Emergencies & Disasters*, 1(1):171–187, 1983.

Alberto Alesina and Eliana La Ferrara. Who trusts others? *Journal of public economics*, 85(2): 207–234, 2002.

LEAP. Laurelhurst emergency action plan, 2022. https://laurelhurstcc.com/projects/leap/.

LEAP. Leap block cluster map, 2023. https://laurelhurstcc.com/wp-content/uploads/2022/09/LEAP-cluster-map-.pdf.

Seattle EM. Seattle neighborhoods actively prepare, 2023. https://seattle.gov/emergency-management/prepare/prepare-yourself.