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Identifying the Multiplex Network of Collaborative Decision-Making in Municipal Disaster Preparation and Response

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Actors in the real world are affected by multiple relations, and therefore, so are actions in the web of collaboration. As such, it is crucial to take account of these multiple, intertwined relations when evaluating any network constituted by various types of cooperative and collaborative activity: For example, the collaborative decision-making carried out in municipal disaster preparedness and management. Occupying the front line of disaster management, municipal governments rely on multiple actors and a variety of resources in their efforts to respond swiftly and effectively; and how well such an organization assembles these various aspects of its collaborations will determine how robust its organizational resilience is. However, collaborative relations are often embedded in cross-layer interactions, which makes them hard to perceive, and may lead to blind spots in emergency-planning education and training. By applying social network analysis—specifically, a multiplex network approach—this paper aims to identify and verify the characteristics embedded in the multiplex network that delineate collaborative decision-making in a municipal disaster-management setting. Its results show that decision-making collaboration among New Taipei's municipal agencies tasked with disaster preparedness and reduction constitutes a complex multiplex network, containing cross-layer effects derived from trust, resources, and decision-making interactions. The study concludes that a clear understanding of municipal decision-making in the context of disaster preparation and response needs to take account of the multiple dimensions of agency collaboration and the interdependencies that emerge from those dimensions.

Keywords: multiplex network, collaboration, municipal disaster preparedness, exponential random graph model (ERGM), resilience

Introduction

The management of disaster preparedness and response—collectively, "disaster governance" (Tierney, 2012)—often involves multidimensional interactions among heterogeneous actors. Such actors and interactions are easiest to discern graphically, arguably as either multiple types of nodes, or as lines. The term "multilevel network" is used to highlight that a network is composed of heterogeneous actors. In such a network, distinct

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types of nodes are categorized into different levels, and lines may connect among nodes, whether within a level or across levels (Wang, Robins, Pattison, & Lazega, 2013). Such a structure closely parallels a well-known concept in the field of disaster governance and risk management: multilevel governance, which arises from the urgent need to harness complex socio-ecological systems to perform concerted actions (Berkes, Colding, & Folke, 2003). Numerous real-world cases have shown that disaster resilience is best increased via partnerships among NGOs, local and national agencies, international allies, and donors—precisely because collaboration among varied actors and multiple levels of organizations are conducive to the coordination of information, engagement and resource allocation (Matous, 2015; Ostrom, 1990; Wilson, Ahmed, Siar, & Kanagaratnam, 2006).

However, relations within a network are far more obscure when it links a relatively homogenous group of actors who interact with one another via various types of relations. This alternative type of multiplicity, from the perspective of graph theory, is called a "multiplex network" or sometimes multi-relational network (Kivelä et al., 2014; Wasserman & Faust, 1994). Though both multiplex and multilevel networks highlight the existence of interactions that span different layers of the network system, they differ in their structural arrangements of "layers", which in a multiplex network represent different types of relations rather than heterogeneous groups of actors. Network scientists have striven to construct analytic frameworks comprising multiple networks in which actors are tied by multiple types of relations (Kivelä et al., 2014; Nicosia & Latora, 2015). Since different types of interactions in a policy network are found to operate in complementary rather than congruent ways (Leifeld & Schneide, 2012), it is important to take account of multilayer relations when seeking to understand the complexity of disaster responses, with the wider aim of improving disaster-related planning and preparedness.

This paper aims to identify and verify the multidimensional and cross-layer effects embedded in a multiplex network, as a means of gaining a clearer understanding of collaborative decision-making in a municipal disaster-management setting. To evaluate and test its multiplicity, attention must be focused on the unobserved effects arising from the interdependencies of various dimensions of collaborative decision-making activities. In the following sections, we introduce our case and data, and set out our hypotheses regarding the multidimensionality of collaborative decision-making. We then systematically apply correlation and regression based on a quadratic assignment procedure (QAP; Borgatti, Everett, & Johnson, 2013) and exponential random graph modeling's (ERGM's) multilayer variant, i.e., MERGM (Chen, 2019; Lusher, Koskinen, & Robins, 2013) to identify and verify the cross-dimension or cross-layer effects in multiplex networks reflecting collaborative decision-making in municipal disaster governance.

Case and Hypotheses

In a municipal-government setting, disaster prevention and response involve complex interactions among departments and leverage various managerial capacities. Because collaborative decision-making can enhance the quality of communication, resource exchanges, and coordinative actions (Comfort, 1999), evaluation methods able to capture the complexity of municipal decision mechanisms are critical to maximizing both ecological and organizational resilience (Thorne et al., 2015). Collaborative decision-making, defined here as cross-agency deliberation on possible strategic options for disaster mitigation, is key to maintaining organizational resilience in complex, rapidly changing disaster-management contexts. And, just as organizational resilience usually comprises multiple dimensions (Bruneau et al., 2003), so the exercise of collaborative decision-making to ensure such resilience requires not only the cooperation of multiple actors, but also various inter-organizational interactions. For the purposes hereof, organizational resilience is defined as the ability of social units to mitigate hazards, contain disaster impacts, and carry out recovery activities (Bruneau et al., 2003, p.735).

It has been argued that, in a severely time-constrained decision-making situation, such as a natural-disaster response effort, trust reduces decision costs for those seeking reliable information, and that such reduction, in turn, enhances the quality and speed of collaborative decision-making (Berardo & Scholz, 2010; Siciliano & Wukich, 2017). Trust, which underpins organizational robustness—i.e., organizations' ability to withstand external stress (Bruneau et al., 2003)—can thus be seen as an important ingredient of collaborative decision-making. A municipality is simultaneously responsible for maintaining critical infrastructure and lifeline services, such as power, water, hospitals, and response and recovery systems, all of which entail costly decision times and heavy management burdens. Having both the authority and the network of relationships to mobilize resources helps to reduce decision and communication costs, and determine organizational capacity to identify problems, establish priorities, and allocate funds and goods (Bruneau et al., 2003; Thorne et al., 2015). In theory, then, for the sake of maintaining organizational resilience when responding to disasters, it is better for municipal decision mechanisms to incorporate trust-based interactions and resource exchange. Accordingly, this paper evaluates a collaboration network involved in disaster-related decision-making from the perspective of trust and resource-exchange networks.

More specifically, trust, resource, and decision interactions are all incorporated into our multiplex network model (Figure 1), which depicts the multifarious character of collaborative decision-making by municipal government.

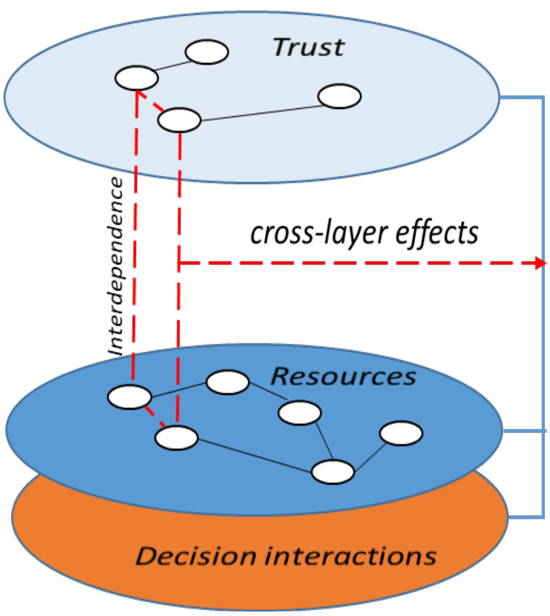

Figure 1. The modelled multiplex network of collaborative decision-making with trust-connection and resource-exchange dimensions.

The implications of the network illustrated in Figure 1 are not confined to a single dimension of decision-related interactions, either theoretically or methodologically. Rather, its multilayered aspect implies the multiplicity of its collaborative decision mechanisms, broadly following Cozzo's (Cozzo, Arruda, Rodrigues, & Moreno, 2018) concept of a "supra (-adjacency) network" of collaborative decision-making. However, it will be referred to here by the more commonly used term multiplex network.

A multiplex network is regarded as a single network system. The essential difference between multiplex and monoplex networks lies in the former's *node-layer pairs*, derived from cross-layer interactions, which fundamentally distinguish it from the latter, which features ties of just one type (Chen, 2019; Cozzo et al., 2018). Networks of all types are normally conceived of as being constituted by a set of *nodes* connected to one another by *ties*, forming an *adjacency matrix* within which a tie Y between node i and node $j = \{Y_{ij}\}$. However, in the multiplex network illustrated in Figure 1, three dimensions of interactions are grouped into a single 3 × 3 level matrix, as follows:

$$Y = \begin{bmatrix} Y^{tt} & Y^{tr} & Y^{td} \\ Y^{rt} & Y^{rr} & Y^{rd} \\ Y^{dt} & Y^{dr} & Y^{dd} \end{bmatrix}$$

Where Y^{tt}, Y^{rr}, and Y^{dd} denote trust, resource, and decision-interaction networks respectively, each with its intra-layer ties placed in the main diagonal block. In the so-called supra-adjacency matrix (Cozzo et al., 2018), the off-diagonal blocks containing interlayer ties denote the effects of cross-dimensional or cross-layer interaction, such as the dashed lines shown in Figure 1, or Y^{td}, which refers to the reinforcement effects between trust and decision interaction, as will be further explained below. Crucially, the unique node-layer pairs in the matrix impose a model specification that is very different from that of traditional statistical inference: with the verification model needing to accommodate not only the three individual dimensions, but also all the cross-dimensional effects. The present study is intended to identify, based on real-world data, the multiplicity and therefore the cross-dimensional effects in such a matrix of collaborative decision-making, which are otherwise obscure, if not unobservable: a problem that could lead to ineffectual emergency-response education and training.

Data collection commenced in 2017 with an examination of the governmental minutes and archives of several municipalities in Taiwan, with the initial aim of pinpointing the key agencies in the country's disaster governance (Li & Chen, 2019). In the end, it was decided to concentrate on just one of these places, New Taipei, which as well as having the biggest population of any Taiwanese city is home to 12 agencies documented as key in the response to recent disasters, including the Fire Bureau, Police Department, Department of Health, etc. Having identified these key agencies, the researchers conducted interviews in which informants from each agency were asked to identify whom they interacted with and the interactive strength (or frequency) of three interactive relations in the exercise of disaster management: namely, trust connection (in terms of risk-sharing), resource exchange, and decision collaboration[1].

The interview data were then used to create three networks of agency interactions. While the decision interactions may seem to be the target in question, the underlying assumption of the verification model as illustrated in Figure 1 is that these three seemingly different kinds of network are in fact a single multiplex network, and that any truly meaningful evaluation of collaborative decision-making in municipal disaster governance must attend not only to the individual networks but also their cross-layer effects.

1 Though these data were mainly based on municipal agency officials' self-perceptions, the authors recognize that various other plausible ways for collecting the relevant indicators could have been utilized.

Interdependence and Causal Relations

The analytical framework laid out in the previous section, which aims to capture the multidimensionality of collaborative decision-making by New Taipei City's disaster-governance agencies, assumes that such agencies' trust, resource, and decision networks are interconnected, and therefore exert some cross-layer effects. However, it should be noted that each of the three general types of interactions represented by those networks has its own interaction logic, and therefore some disparities among them are expected. Table 1 presents some descriptive statistics for the three networks that indicate some similarities and dissimilarities among them. In it, *average degree* implies the extent to which agencies interact with each other. The resource network's "average degree" of 2.5 suggests that it has relatively low interaction activity, while its higher score for "centralization" at 0.927, which signals that a relatively small number of strong agencies dominate resource exchange in disaster response and prevention. While the three types of interactive relations share similar overall natures, Table 1 shows that the trust network displays the greatest number of divided clusters—as revealed by its "fragmentation" score of 0.083—and that the decision network has the tightest relationship among agencies, as denoted by its "closure" score of 0.507. To further discern the difference, information about each agency's resource capacity was derived from the above-mentioned interview data and analyzed, to reflect the homophily of the network members. Such analysis indicated a distinct dispersion of homophily among different relations as shown in Table 1.

Table 1

Descriptive statistics for the multiplex network's individual networks

	Trust network	Resource network	Decision network
Average degree	3.333	2.500	3.250
Centralization	0.727	0.927	0.736
Fragmentation	0.083	0.159	0.167
Closure	0.471	0.415	0.507
Homophily (resource capacity)	0.012	-0.012	-0.056

Note. Homophily is based on Pearson's phi coefficient, ranging from 1 to -1, where +1 indicates perfect homophily and -1 denotes perfect heterophily.

Despite the disparities, the researchers hypothesize that these individual networks are interconnected, constituting a single multiplex network of collaborative decision-making. To verify this, we first conducted a correlation analysis based on QAP via UCINET (Borgatti, Everett, & Freeman, 2002). A QAP correlation computes Jaccard scores for each pair of matrices, and tests the significance of the correlation by comparing the observed network with the randomly distributed network that results from synchronously permuting rows and columns of the observed matrix thousands of times (Borgatti et al., 2013, pp. 126-129).

As Table 2 indicates, the trust and resource networks were found to be significantly correlated with the monoplex network of decision interaction, confirming these two interaction types as additional dimensions that shape municipal decision-making. And the dyadic coefficients, ranging from 0.522 to 0.717, verified the interdependence among these networks, meaning that one cannot rule out any possible joint impacts of dimensions on overall decision collaboration.

Though correlation analysis is a rather naive test, it clearly highlights the multifarious nature of municipal collaborative decision-making for disaster governance. In particular, it reveals the interdependence among the three monoplex networks that make up the multiplex network. However, the verification model may not be sustained if the interdependencies *within* each monoplex network are not also taken into account, since actors in networks are always interconnected (Lusher et al., 2013, pp. 19-21; Prell, 2012, pp. 47-49). We therefore applied QAP logistic regression to accommodate these within-network dependencies, selecting two structural terms—*transitivity* and *reciprocity*—to reflect important endogenous dependencies that might have causal impacts on network generation.

Table 2

Correlation analysis, multiplex network of collaborative decision-making in New Taipei disaster governance

	Trust network	Resource network	Decision network
Trust network	—	0.522 (0.067)***	0.717 (0.063)***
Resource network	—	—	0.568 (0.015)***
Decision network	—	—	—

Note. Coefficients are Jaccard values. Significance levels: 0.05 ≥ * > 0:01 ≥ ** > 0:001 ≥ ***.

Transitivity refers to the growth of closely connected subgroups, and reciprocity, to the tendency for interactions in an observed network to be mutual (Lusher et al., 2013). Specifically, if *i*, *j* and *k* are the nodes of network *Y*, transitivity is calculated as $\sum_{i,j,k} y_{ij}\, y_{jk}\, y_{ik}$ and reciprocity as $\sum_{i,j} y_{ij}\, y_{ji}$. Because our collected interview data contained information regarding agencies' resource capacity based on their mutual perceptions, we were able to add a homophily term to test whether greater resource capacity on the part of an agency was associated with more decision-making participation. Accordingly, our QAP logistic regression was designed to confirm: (1) the exogenous effects derived from trust connection and resource exchange, (2) the homophily effect in terms of resource capacity, and (3) two endogenous structures, transitivity and reciprocity. The relationship between QAP logistic regression and QAP correlation is the same as between their analogues in ordinary statistics; that is, the logistic regression model goes further than correlation by addressing the causal effects of exogenous and endogenous variables. However, that model can only handle within-network structural effects, the drawbacks of which will be further explored below.

Table 3

Quadratic assignment procedure logistical regression for delineating the structure of New Taipei's municipal decision network

Intercept	Model I		Model II		Model III	
	-3.514		-3.056		-4.211	
Trust network	4.124	(0.609)***			3.509	(0.716)***
Resource network			3.617	(0.808)***	2.674	(0.945)**
Resource capacity	-0.025	(0.189)	0.124	(0.190)	0.089	(0.194)
Transitivity	0.807	(0.281)**	0.956	(0.280)**	0.966	(0.297)**
Reciprocity	-0.072	(0.638)	0.121	(0.650)	-0.024	(0.663)
r-square	0.609		0.492		0.687	
Sig.	0.001		0.001		0.001	

Note. Significance levels: 0.05 ≥ * > 0.01 ≥ ** > 0.001 ≥ ***.

Table 3 presents the results of our QAP logistic regression analysis, in which model I and II were designed to verify the roles of the trust and resource networks, while model III combined those two dimensions to estimate their joint impacts upon the decision interactions of the focal municipal agencies. Each of the three models encompassed two structural terms, and reached model fitness; and their results confirm that the trust and resource networks had positive impacts on the decision network, once the effects of transitivity and reciprocity, as well as the attribute of agencies' resource capacity have been taken into account (see Table 3). The coefficients of the trust and resource networks in model I and II, at 4.124 and 3.617 respectively, indicate such networks' strong influences on the monoplex network of decision interactions. And, when the trust and resource networks were combined in model III, as shown in Table 3, those causal associations did not change. In all the models, the effects of transitivity were more decisive than those of reciprocity, meaning that open-oriented clustering was critical to decision interactions, whereas agencies' resource capacity was less important. Accordingly, it can be concluded that trust and resource networks are capable of depicting the structure of New Taipei's municipal decision network.

Cross-Layer Effects

From the correlation and regression analysis results described above, it is clear that dependencies existed both within and across layers in the focal multiplex network. However, those verification approaches treated the individual dimensions as independent ties rather than as parts of a single compound interaction. In other words, in the QAP model, the decision network *per se* is conceived of as a dependent variable: an arrangement that overlooks both the impact of the decision network on the multiplex network, and the cross-layer effects that may stem from combined interactions, such as Y^{td} and Y^{rd}, as mentioned above. On the other hand, if we specify the monoplex decision network and its related cross-layer effects as exogenous covariates, the specification is subject to simultaneity bias, in which the same variables are specified as both independent and dependent variables (Chen, 2019).

Therefore, a model capable of accommodating a multiplex network must incorporate multiplicity and account for the dependence within and across each of its layers. MERGM is a promising tool that satisfies this requirement (Wang et al., 2013). ERGM is a class of statistical model that facilitates the making of inferences about which factors contribute to the generative process of an observed network, including exogenous node attributes and endogenous dependence at the dyadic level and beyond (Lusher et al., 2013). Chen (2019) recently created an R package for MERGM analysis of generalized multilayer frameworks, multilayer.ergm, adoption of which allowed us to observe and estimate the contributions made by the cross-layer interactions, i.e., to take account of the dependencies both within networks and among different dimensions of interactions. Via the MERGM tool, the multiplex network could be seen as a whole system, and its generation targeted as a dependent variable. This, in turn, allowed full estimation of New Taipei's collaborative decision-making for disaster governance.

Unlike in the QAP regression model, the monoplex network of decision interaction in the MERGM model is one of the covariates rather than a dependent variable. Additionally, the MERGM version of the homophily test of agencies' proximity (in terms of their degrees of resource possession) is able to specify its sources by designating the model term for each types of interactions. However, transitivity and reciprocity are still the key measures of the main structural features of all the networks involved. In MERGM, transitivity can be evaluated using two nearly opposite approaches, namely, geometrically weighted edgewise shared partners (GWESP) and geometrically weighted dyad-wise shared partners (GWDSP). GWESP indicates the tendency toward transitivity discussed above, while GWDSP indicates the tendency of interactions to run across two paths but not close a triangle: that is, situations where $i, j, k \in Y$, and $y_{ij}\, y_{jk}$ sustains but not y_{jk}. Usually, a positive coefficient for GWESP together with a negative one for GWDSP constitutes strong evidence for transitivity in the networks (Hunter, 2007).

The final step in MERGM consisted of adding the cross-layer reinforcement effects of the trust, decision, and resource networks. Such reinforcement effects denote that one kind of interaction is associated with another kind. In this case, they can confirm this study’s key assumptions that a robustly resilient system of collaborative municipal decision-making is closely associated with good coordination, both between trust connections and decision interactions, and between resource exchange and decision interactions. Accordingly, it is also worth asking whether active trust-resource interactions, more inclined to securing organizational self-interests than pursuing coordination and shared policy positions, could also facilitate the generation of municipal collaborative decision-making.

The results of MERGM analysis are presented in Table 4. With regard to the individual effects of the three dimensions, no single layer was able to positively predict the links in the multiplex network of collaborative decision-making, and this produced a sharp disparity between the results of the MERGM and QAP models. The straight negative coefficients for the three monoplex networks suggest that trust, resource and decision networks, while each necessary to the generation of the multiplex network, are not decisive in such generation individually. As to the homophily phenomenon, significant coefficients ranging from 0.230 to 0.749 imply that a given agency’s resource capacity is important in all three kinds of monoplex network, and also contributes to the multiplex network. In other words, agencies with higher resource capacity were, on the whole, more likely to have strong interactions during cooperative decision-making. The GWESP figures in Table 4 further indicate that the generation of the multiplex network is driven by transitivity, an open-grouping tendency in both the resource and decision networks, with coefficients of 0.152 and 0.336, respectively. It is likely that this open-grouping tendency also moderates the frequency of reciprocal activities among city departments.

The final section of Table 4 displays the cross-layer effects identified via MERGM. All of the modeled cross-layer effects, two being positive and one being negative, were found to be significant at the 0.001 level, thus verifying the multidimensionality of New Taipei’s municipal collaborative decision-making in disaster governance. The positive effects, with coefficients of 3.539 and 1.818, respectively, suggest that—conditional on all other modeled effects—agencies that have trust and resource relations with a particular partner were 34 and 6 times more likely to make a decision in collaboration with that partner than with a different one. Thus, our decision-cost assumption, i.e., those agencies will tend to seek support for their decisions where trust and resource relations already exist, was upheld.

Despite the positive reinforcement provided by the node-layer pairs that were associated with the decision interactions, the cross-layer effect between trust and resources had a negative outcome. In other words, as Table 4 shows, coordination between the trust and resource domains attenuated municipal decision collaboration to one-third of the value it would otherwise have had (at log-odds of -1.069). One interpretation of this finding is that, despite the advantages of trust connections, resource acquisition and decision coordination are underpinned by different motivations. Thus, cross-layer alignment between trust and resource networks may be less likely to occur in disaster governance than in the normal course of municipal business. Insofar as during disasters, agencies are more concerned with pursuing shared policy goals than with achieving their own narrow aims. Be that as it may, this finding reveals the complexity underlying municipal collaborative decision-making behaviors, which goes far beyond decision-cost concerns and is therefore undetectable in information derived solely from monoplex networks.

Table 4
Multilayer exponential random graph model of the multiplex network of collaborative decision-making in New Taipei's municipal disaster governance

Effects	Coefficient	Standard Error
Individual dimensions:		
Trust (T.) net	-6.702	(0.033)***
Resource (R.) net	-6.103	(0.030)***
Decision (D.) net	-3.722	(0.033)***
Homophily effects:		
Resource capacity in T. net	0.749	(0.087)***
Resource capacity in R. net	0.356	(0.098)***
Resource capacity in D. net	0.230	(0.087)**
Structural effects:		
GWESP in T. net	0.029	(0.048)
GWDSP in T. net	0.107	(0.048)
GWESP in R. net	0.152	(0.065)*
GWDSP in R. net	0.234	(0.206)
GWESP in D. net	0.336	(0.051)***
GWDSP in D. net	-0.138	(0.181)
Reciprocity	-0.378	(0.250)
Cross-layer effects:		
Reinforcement across T.-R. nets	-1.069	(0.002)***
Reinforcement across T.-D. nets	3.539	(0.058)***
Reinforcement across R.-D. nets	1.818	(0.058)***
AIC	6,090	
BIC	6,154	

Note. GWESP = geometrically weighted edgewise shared partners; GWDSP = geometrically weighted dyad-wise shared partners. Significance levels: 0.05 ≥ * > 0.01 ≥ ** > 0.001 ≥ ***.

In sum, our analysis has yielded three important findings. The first is that trust, resource, and decision interactions are all interrelated in disaster governance at the municipal level. The second, arrived at via the use of an approach based on MERGM, is that any individual dimensions of inter-agency interactions are far from sufficient to account for the complexity of and interdependencies in such governance. And lastly, our verification of cross-layer effects reveals that not just decision cost, but also shared policy goals, are key dynamics in municipal collaborative behavior, which can therefore only be meaningfully observed and evaluated using a multiplex-network approach.

Conclusions

This paper has highlighted that the features of municipal collaborative decision-making during disaster response are truly multidimensional, and that any attempt to reveal their interdependence and organizational resilience should apply a method appropriate to those features: specifically, multilayer network analysis. Various network-statistics tools were used to verify these findings.

We proceeded from the assumption that our focal type of collaboration cannot usefully be conceived of as a single dimension of activity. Drawing on organizational resilience, we examined its multidimensionality in terms of trust, resource, and decision interactions. For comparison, a monoplex-network approach using QAP correction and logistic regression was used to verify that New Taipei's disaster-related collaborative decision-making was not only associated with, but actually resulted from, the trust and resource interactions among the agencies dealing with disaster governance. Despite their conventionality, these methods clearly confirmed the multiplicity of municipal decision collaboration, and further, justified decision cost as an underlying principle of inter-agency collaboration. QAP logistic regression also addressed the complexity of collaborative decision-making, by taking account of within-network dependencies, here represented by transitivity and reciprocity, and the homophily effect based on agency attributes, in this case resource capacity.

However, the limitation of QAP in dealing with interdependencies among different kinds of inter-agency interactions underlines the most important feature of a multiplex network. Unlike QAP regression, which in effect treats each linked monoplex network as an independent entity, our multiplex-network approach implemented using MERDM sees trust, resource and decision interactions as intimately connected layers of a single collaborative decision-making matrix. In this way, MERDM estimation yields a sharp contrast to the results of QAP regression, and shows that those agencies with cross-layer associations contribute to municipal collaborative decision-making, without following the generally dyadic patterns of monoplex networks. Among the noteworthy cross-layer effects are those associated with decision interaction, further justifying decision cost as a key dynamic in inter-agency collaboration. The opposite effect jointly produced by trust and resource relations, on the other hand, reveals the complex and nuanced nature of inter-agency collaboration, particularly when each agency's motivations go beyond decision-cost concerns, e.g., when seeking to attain common goals and concerted actions. In sum, using the case of New Taipei's municipal disaster-governance agencies and their collaborative decision-making, this study has highlighted the multidimensionality of social and political collective actions, and that multilayer network analysis can be used effectively to address both within-network and cross-layer dependencies, as well as the attributes of network actors.

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