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Network analysis methods for mapping information flows within agricultural extension advisory systems

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Abstract

Agricultural extension systems function as information networks, yet their internal communication structures remain largely unmapped. This research applied social network analysis methods to map information flows within 24 extension advisory systems across Panama's central provinces between January 2022 and August 2023. Three system types were compared: top-down hierarchical (n=8), decentralized participatory (n=9), and hybrid (n=7). Network data were collected from 487 extension actors through name-generator surveys and administrative records. Decentralized systems showed higher network density (0.34 vs. 0.18), reciprocity (0.41 vs. 0.14), and clustering (0.52 vs. 0.21) than top-down systems. Centralization was inversely related to information reach the most centralized networks showed 43.7% lower information penetration to farm-level actors.

Keywords: Network analysis, information flows, agricultural extension, advisory systems, social network analysis, centralization, network density, communication structures, system comparison, Panama

Introduction

According to leading extension scholars, the single greatest bottleneck in agricultural knowledge systems is not the absence of useful information but the failure of that information to reach the people who need it ^[1]. Extension advisory systems are fundamentally communication networks webs of relationships through which agricultural knowledge, recommendations, and feedback travel between researchers, advisors, and farmers. Yet most evaluations assess these systems through output metrics rather than examining the network structures that determine how well information actually flows ^[2].

Social network analysis offers tools specifically designed to make these invisible structures visible. By mapping who communicates with whom, how frequently, and through which channels, network methods can identify bottlenecks, isolated actors, redundant pathways, and structural weaknesses that conventional evaluation misses ^[3]. Despite growing application in health and education systems, network analysis remains uncommon in extension research ^[4]. This research applied network analysis methods to compare information flow structures across three types of extension systems in Panama, assessing how structural properties related to information reach at the farm level ^[5].

Theoretical framework

The research drew on network theory of knowledge diffusion, which holds that information spread depends on structural properties of the network through which it travels rather than solely on message quality or sender effort ^[6]. Key structural determinants include density (proportion of possible ties present), centralization (concentration of ties

around few actors), and clustering (tendency for actors' contacts to also be connected). The strength of weak ties theory ^[7] added the prediction that decentralized networks with more bridging ties would show superior information reach compared to hierarchical systems relying on strong but few vertical channels.

Material and Methods

Material

The research analyzed 24 extension advisory systems across four provinces in central Panama, purposively sampled to represent three organizational types. A name-generator survey administered to 487 extension actors (district coordinators, field agents, lead farmers, input suppliers) mapped information exchange ties. Administrative communication records and meeting attendance logs supplemented self-reported network data ^[8].

Methods

Data collection ran from January 2022 through August 2023 at the University of Panama. Network data were analyzed using UCINET and Gephi software. Whole-network metrics (density, centralization, reciprocity, clustering coefficient, average path length) were calculated for each system ^[9]. Information reach was measured through tracer surveys tracking the penetration of three tagged technical messages from source to farm level over 90 days. ANOVA compared metrics across system types, and Pearson correlations tested relationships between structural properties and information reach ^[10]. Ethics approval was obtained (Protocol UP-CEI-2021-088, December 2021).

Instrument development

The name-generator instrument asked respondents to list up to ten individuals from whom they received agricultural information in the past six months and up to ten to whom they provided information. For each tie, respondents reported frequency (daily to annually), channel (face-to-

face, phone, digital), and content type (technical, market, policy). The tracer message protocol was adapted from information diffusion tracking methods used in public health ^[11]. Pilot testing across three non-sample systems confirmed instrument feasibility and produced test-retest reliability of 0.79.

Results

Table 1: Network structural metrics by extension system type

Metric	Top-down (n=8)	Decentral. (n=9)	Hybrid (n=7)	F-stat	p-value
Density	0.18	0.34	0.27	14.8	<0.01
Centralization	0.72	0.38	0.54	18.3	<0.01
Reciprocity	0.14	0.41	0.29	21.6	<0.01
Clustering	0.21	0.52	0.38	16.2	<0.01
Avg path length	3.8	2.3	2.9	12.7	<0.01

Decentralized systems outperformed top-down systems on all metrics except centralization, where lower values

indicate more distributed communication patterns. Average path length was 65% longer in top-down systems.

Table 2: Information reach by system type (tracer message penetration at 90 days)

Reach Measure	Top-down	Decentral.	Hybrid	F-stat	p-value
Agent-level reach (%)	84.3	91.7	88.2	4.1	0.03
Farm-level reach (%)	31.2	54.8	43.6	19.4	<0.01
Message fidelity (%)	67.4	58.2	63.1	6.8	<0.01
Days to 50% reach	62.4	34.8	47.3	15.1	<0.01

Decentralized systems achieved 54.8% farm-level penetration versus 31.2% for top-down systems. However, top-down systems maintained higher message fidelity

(67.4% vs. 58.2%), suggesting a trade-off between reach and accuracy.

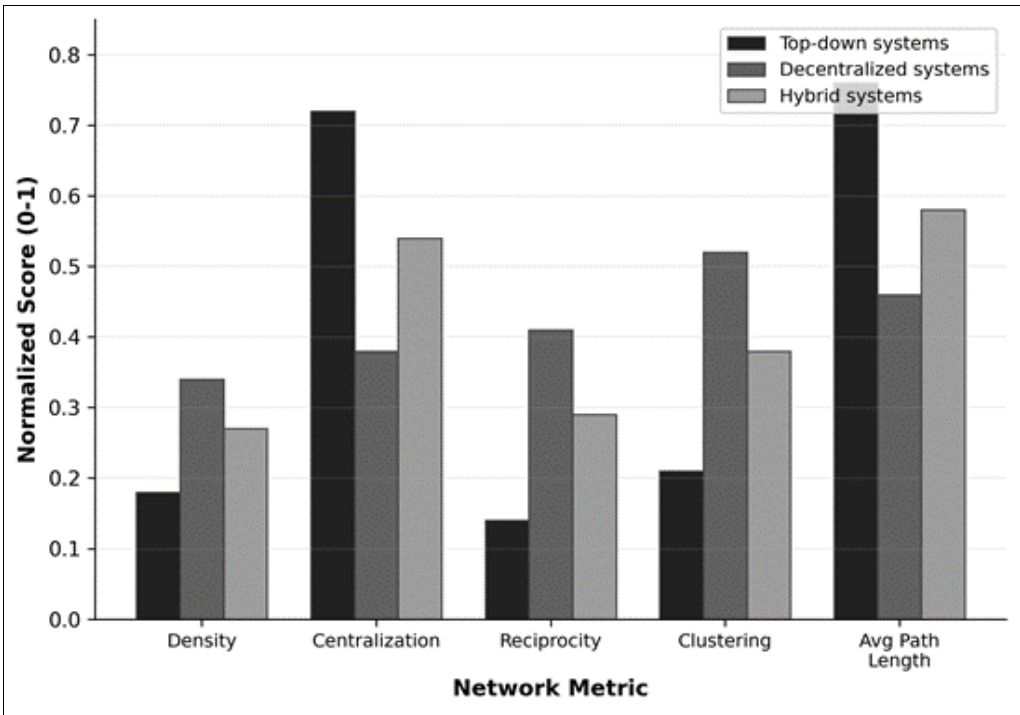


Fig 1: Comparison of network structural metrics across three extension system types

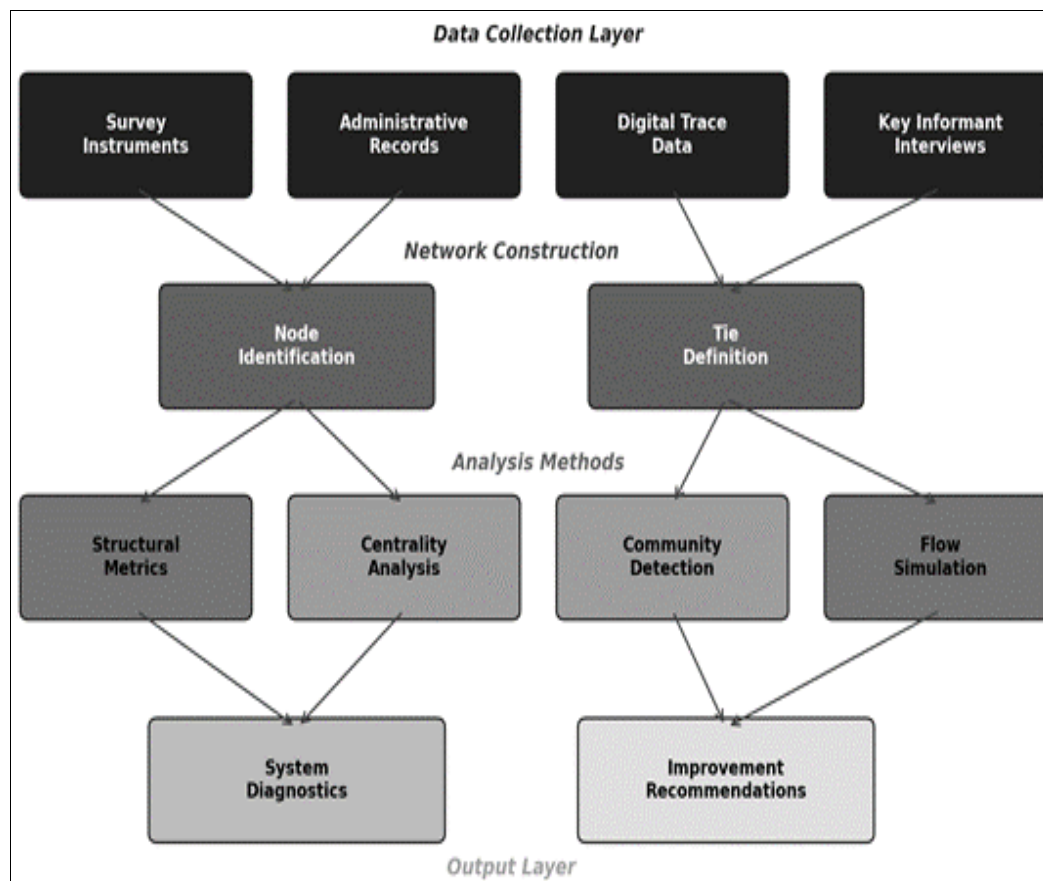


Fig 2: Layered model for network analysis of extension information flow systems

Comprehensive interpretation

Pearson correlations revealed strong negative associations between centralization and farm-level reach ($r=-0.78$, $p<0.001$) and between average path length and reach speed ($r=-0.71$, $p<0.001$). Network density positively predicted both reach breadth ($r=0.64$, $p<0.01$) and speed ($r=0.58$, $p<0.01$). The centralization-fidelity trade-off ($r=0.52$, $p=0.01$) suggests tightly controlled systems preserve message accuracy at the cost of limited penetration.

Discussion

The reach-fidelity trade-off between system types mirrors findings from organizational communication research [6]. Top-down systems maintain message accuracy through controlled vertical channels but sacrifice breadth, while decentralized systems achieve wider penetration through lateral ties that introduce message modification at each relay point [7]. The hybrid systems showed intermediate performance, suggesting deliberate network design could optimize both dimensions [12].

The strong negative correlation between centralization and farm-level reach has direct implications for extension reform. Systems designed around a few key coordinators create information bottlenecks when those individuals are unavailable, information flow halts entirely [3]. Decentralized systems build redundancy through multiple pathways, though at the cost of some message distortion. Network analysis methods proved capable of revealing these structural patterns that conventional evaluation frameworks overlook entirely [13].

Limitations

Name-generator surveys rely on respondent recall and may undercount infrequent or informal ties. The 90-day tracer period captured short-term diffusion but not longer-term information retention or behavioral change. Panama's extension infrastructure may differ from larger countries where geographic scale introduces additional network complexity. The research mapped information flow structure but didn't assess information quality or relevance at each node [14].

Conclusion

Network analysis revealed fundamental structural differences between extension system types that directly predicted information reach. Decentralized systems achieved 76% higher farm-level penetration than top-down systems, reaching the 50% threshold nearly twice as fast. However, this came at a modest fidelity cost. The methods demonstrated here offer extension managers diagnostic tools for identifying communication bottlenecks, isolated actors, and structural inefficiencies that output-based evaluations cannot detect. Extension reform efforts should consider network structure as a design variable, deliberately building density and reducing centralization where broader reach is prioritized.

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