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RESEARCH ARTICLE

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Pentahelix-based collaborative governance model for sustainable waste management in Medan Amplas District, Indonesia

Riana Lumbanraja[1]*, Marlon Sihombing[1], Heri Kusmanto[1] & Hatta Ridho[1]

[1]Faculty of Social and Political Sciences, Universitas Sumatera Utara, Indonesia

*Correspondence: rianalumbanraja@students.usu.ac.id

ABSTRACT

Urban waste management continues to be hampered by inadequate infrastructure and the weak integration of non-governmental actors. This article develops and empirically tests the RIANA model a penta-helix-based collaborative governance framework comprising Responsive Governance, Integrative Penta-helix, Adaptive Technology, Network Collaboration, and Action Sustainability. The study employs a mixed-methods design, combining qualitative interviews with a quantitative survey of 69 respondents. The analysis includes descriptive statistics, validity and reliability testing, AHP-based priority indexing, SEM-PLS-oriented composite modelling, and qualitative-quantitative integration. The descriptive results show that the most severe barriers are community participation and culture (mean=3.764; index=75.3), budget and infrastructure (mean=3.568; index=71.4), and human resource capacity (mean=3.431; index=68.6). The AHP priority analysis confirms community participation and culture as the highest priority criterion (weight=0.217), followed by budget and infrastructure (0.206). The measurement model shows acceptable reliability for institutional barriers, resource barriers, community barriers, and collaborative performance, with Cronbach's alpha ranging from 0.824 to 0.900 for the main multi-item constructs. The SEM-PLS structural model explains 47.1% of the variance in collaborative performance. Institutional design and coordination barriers have a significant negative effect on collaborative performance (β=-0.475; p=0.039), whereas technology adaptation has a significant positive effect (β=0.401; p<0.001). The findings suggest that sustainable waste governance requires institutionalized multi-actor forums, community-based behavioural change, digital monitoring, and action-oriented sustainability mechanisms.

KEYWORDS: AHP, collaborative governance, Medan Amplas, pentahelix, RIANA model, SEM-PLS, sustainable waste managementsocial cohesion

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1. Introduction

Urban waste management is a governance problem rather than merely a technical matter of collection, transportation, and disposal. Rapid urbanization increases waste generation while local institutions frequently experience coordination gaps, limited infrastructure, and low participation in household-level sorting [1], [2]. In Indonesian cities, these challenges are intensified by uneven service coverage, behavioural issues, and limited integration between formal waste management institutions and informal actors such as waste pickers and community collectors [3], [4].

Medan Amplas District represents an urban-peri-urban context where residential density, mobility, markets, schools, religious institutions, and small-scale businesses create diverse waste streams. The dissertation materials show that the research problem focuses on low coordination effectiveness among stakeholders, limited community participation, and suboptimal implementation of collaborative policy in waste management. The uploaded dissertation abstract explicitly frames the pentahelix-based collaborative governance approach as a potential solution involving government, private sector, academia, community, and media. This article translates that dissertation direction into a journal article with quantitative calculation in the results section.

The proposed contribution is the RIANA model. RIANA stands for Responsive Governance, Integrative Pentahelix, Adaptive Technology, Network Collaboration, and Action Sustainability. Rather than treating pentahelix as a general stakeholder list, the model operationalizes each component into empirical indicators and priority actions. The article therefore contributes to the literature by combining collaborative governance theory, pentahelix actor structure, AHP priority weighting, and SEM-PLS-oriented path testing in a single waste governance framework.

2. Literature Review and Hypothesis Development

Collaborative governance refers to an arrangement in which public agencies engage non-state actors in collective decision-making processes to achieve public purposes that cannot be effectively addressed by a single organization [5]. Ansell and Gash emphasize starting conditions, institutional design, facilitative leadership, and collaborative processes as key conditions for collaboration [5]. Emerson et al. further conceptualize collaborative governance as a dynamic system involving principled engagement, shared motivation, and capacity for joint action [6].

The pentahelix approach extends collaborative governance by positioning five actor groups as integral components: government, academia, business, community, and media. In the waste management context, government provides regulation and coordination; academia supports knowledge and evaluation; business contributes CSR, recycling markets, and circular economy mechanisms; communities participate in sorting and monitoring; and media provides public communication, campaigns, and social control [7], [8].

The study develops four empirical propositions. First, institutional design and coordination barriers are expected to reduce collaborative performance. Second, resource capacity barriers are expected to reduce collaborative performance. Third, community participation and socio-cultural barriers are expected to reduce collaborative performance.

Fourth, technology adaptation is expected to improve collaborative performance by strengthening information flow, complaint handling, monitoring, and public education.

Hypothesis	Statement
H1	Institutional design and coordination barriers negatively affect collaborative performance.
H2	Resource capacity barriers negatively affect collaborative performance.
H3	Community participation and socio-cultural barriers negatively affect collaborative performance.
H4	Technology adaptation positively affects collaborative performance.

3. Methodology

This study uses a mixed-method sequential explanatory orientation. Qualitative data are represented by interview instruments for the camat, lurah, community actors, religious leaders, media representatives, waste pickers, and municipal leadership. These instruments cover the dimensions of collaborative governance, pentahelix actor roles, obstacles, innovation, and expected governance models. Quantitative data were obtained from an

uploaded Google Form response spreadsheet containing 69 valid responses and 83 variables.

The quantitative analysis proceeded in five stages. First, descriptive statistics were calculated for respondent characteristics, barrier items, and collaborative performance items. Second, ordinal responses were transformed into numerical scales. Agreement-type barrier items were coded from 1 = strongly disagree to 5 = strongly agree. Positive performance items were coded from low to high performance, depending on the available response options. If a respondent selected multiple adjacent categories, the score was averaged. Third, validity and reliability were examined using outer loadings, Cronbach's alpha, composite reliability, and average variance extracted. Fourth, AHP was used to prioritize the main barriers based on survey-derived severity scores. Fifth, SEM-PLS-oriented composite path modelling was used to test the effects of barriers and technology adaptation on collaborative performance.

Construct	Definition	Indicators
IDB	Institutional design and coordination barriers	Q48, Q49, Q50, Q57, Q58, Q59
RCB	Resource capacity barriers	Q51, Q52, Q54, Q55, Q56
CPB	Community participation and socio-cultural barriers	Q53, Q60, Q61, Q62
TA	Technology adaptation	Q42, Q78
CPERF	Collaborative performance	Q25, Q65, Q68, Q72, Q74, Q76

The AHP procedure used five criteria: coordination and institutional design, human resource capacity, budget and infrastructure, community participation and and policy support and implementation consistency. Because no separate expert pairwise questionnaire was uploaded, the pairwise comparison matrix was derived transparently from the survey severity means using the ratio aij = severity_i / severity_j. This produces a fully consistent reciprocal matrix and avoids inventing unobserved expert judgments. The consistency ratio is therefore 0.000.

4. Results

4.1 Respondent Profile and Descriptive Statistics

The survey contains 69 respondents. Women represent 46 respondents (66.7%), and men represent 23 respondents (33.3%). Respondents are mostly younger than 25 years old (42 respondents; 60.9%), followed by 25-35 years old (11 respondents; 15.9%). A total of 38 respondents (55.1%) reported prior involvement in waste management, while 31 respondents (44.9%) reported no prior involvement.

Profile variable	Category	Frequency	Percentage
Gender	Perempuan	46	66.7
Gender	Laki-laki	23	33.3
Age	<25	42	60.9
Age	25–35	11	15.9
Age	36–45	7	10.1
Age	46–55	5	7.2
Age	>55	4	5.8
Education	Senior high school/equivalent	34	49.3
Education	Undergraduate/S1	19	27.5
Education	Diploma	10	14.5
Education	Student/in education	3	4.3
Education	Postgraduate/S2	2	2.9
Education	Doctoral/S3	1	1.4
Prior involvement	Yes	38	55.1
Prior involvement	No	31	44.9

The descriptive statistics of the barrier items show that the strongest item-level problems are community-

related. The highest mean is found in the statement that people still have a habit of disposing of waste carelessly (mean=3.906), followed by low community awareness to participate in waste management (mean=3.870), limited budget (mean=3.674), inadequate infrastructure (mean=3.674), and low participation in environmental cleanliness activities (mean=3.652).

Code	Item focus	Mean	SD	Index
B1	1	3.246	0.793	64.9
B2	2	3.116	0.982	62.3
B3	3	3.268	0.972	65.4
B4	Item 51	3. 529	0.951	70.6
B5	Item 52	3.333	0.86	66.7
B6	Item 53	3.87	0.942	77.4
B7	Item 54	3.674	0.857	73.5
B8	Item 55	3.674	0.907	73.5
B9	Item 56	3.355	0.866	67.1
B10	Item 57	3.152	0.921	63.0
B11	Item 58	3.246	0.995	64.9
B12	Item 59	3.551	1.068	71.0
B13	Item 60	3.906	1.102	78.1
B14	Item 61	3.652	1.044	73.0
B15	Item 62	3.63	0.93	72.6
B3	3	3.268	0.972	65.4
B4	Item 51	3. 529	0.951	70.6

For the performance-oriented items, the current collaboration model is generally assessed as moderately effective (mean=3.058 on a 1-4 scale). Coordination among the district, kelurahan, community, and private sector is also in the moderate range (mean=3.058 on a 1-5 scale). Technology influence on efficiency is moderate (mean=2.775 on a 1-4 scale), while actual digital system use remains weak because the binary technology-use item has a mean of 1.348 on a 1-2 scale.

Code	Performance item	Mean	SD S
EFF	10. In your opinion, is the currently implemented collaboration model...	3.058	0.684
TECH	8. To what extent does the use of technology influence efficiency?	2.775	0.968
COORD	1. How do you rate the coordination between the district (kecamatan) and sub-district (kelurahan) levels?	3.058	1.097
LEAD	3. What is the role of the District Head (Camat) in supervising, directing, and facilitating?	3.072	1.005 1
PART	5. What is the level of community participation in cleanliness activities?	2.725	0.816
BUS	6. To what extent are private sector entities (MSMEs, waste collection points, companies) involved?	2.681	0.887
INFRA	7. What is the condition of waste management facilities and infrastructure?	2.841	0.914
DIG	8. Has the district implemented a digital system or application?	1.348	0.48

Validity and Reliability Test

The measurement model was evaluated using Cronbach's alpha, composite reliability (CR), average variance extracted (AVE), and outer loadings. The main multi-item constructs show acceptable internal consistency: IDB alpha=0.881, RCB alpha=0.867, CPB alpha=0.900, and CPERF alpha=0.824. Technology adaptation has a lower alpha (0.532) because it consists of only two heterogeneous indicators, one measuring perceived technology influence and the other measuring actual digital application use. However, its CR=0.842 and AVE=0.728 are acceptable for exploratory research.

Code	Construct	Items	Cronbach alpha	CR	AVE	Mean	SD
IDB	Institutional design and coordination barriers	6	0.881	0.911	0.631	3.263	0.759
RCB	Resource capacity barriers	5	0.867	0.904	0.654	3.513	0.718
CPB	Community participation and socio-cultural barriers	4	0.9	0.93	0.77	3.764	0.883
TA	Technology adaptation	2	0.532	0.842	0.728	2.062	0.631
CPERF	Collaborative performance	6	0.824	0.872	0.534	2.906	0.663

The outer loading results indicate that most indicators load adequately on their constructs. CPERF is retained as an exploratory composite because several indicators capture different dimensions of performance, including effectiveness, coordination, leadership facilitation, participation, private-sector involvement, and infrastructure condition.

Construct	Indicator	Loading	Item wording
IDB	Q48	0.77	Weak camat-kelurahan communication
IDB	Q49	0.758	No routine collaborative forum
IDB	Q50	0.793	Inter-agency miscommunication
IDB	Q57	0.855	Unclear cross-sector collaboration policy
IDB	Q58	0.78	Limited city-government support
IDB	Q59	0.807	Inconsistent rule implementation
RCB	Q51	0.765	Limited sanitation workers
RCB	Q52	0.802	Limited integrated waste-management training
RCB	Q54	0.815	Limited waste-management budget
RCB	Q55	0.858	Inadequate transport/TPS infrastructure
RCB	Q56	0.801	No special collaborative funding
CPB	Q53	0.801	Low community awareness
CPB	Q60	0.909	Careless waste-disposal habit
CPB	Q61	0.92	Low participation in environmental cleanliness
CPB	Q62	0.876	Blaming attitude among stakeholders
TA	Q42	0.853	Technology influence on efficiency
TA	Q78	0.853	Use of digital system/application
CPERF	Q25	0.672	Perceived effectiveness of current collaboration
CPERF	Q65	0.819	Coordination among actors
CPERF	Q68	0.773	Camat facilitation and supervision role
CPERF	Q72	0.639	Community participation level
CPERF	Q74	0.749	Private-sector involvement
CPERF	Q76	0.718	Infrastructure condition

Discriminant validity was assessed using the Fornell-Larcker logic. The diagonal values in the following table represent the square root of AVE; off-diagonal values represent inter-construct correlations. Most diagonal values exceed the correlations with other constructs, although RCB and CPB are highly correlated. This high correlation is substantively reasonable because resource limitations and community participation problems tend to appear together in local waste governance.

4.2 AHP Priority Analysis

AHP was used to determine the priority order of governance barriers. The normalized severity means show that community participation and culture is the most urgent criterion (index=75.3; weight=0.217), followed by budget and infrastructure (index=71.4; weight=0.206), human resource capacity (index=68.6; weight=0.198), policy support and implementation consistency (index=66.3; weight=0.191), and coordination and institutional design (index=65.3; weight=0.188). The consistency ratio of the reciprocal matrix is 0.000 because the matrix is ratio-derived from observed severity means.

AHP criterion	Mean severity	Severity index	AHP weight	Priority (%)
Coordination and institutional design	3.263	65.3	0.188	18.8
Human resource capacity	3.431	68.6	0.198	19.8
Budget and infrastructure	3.568	71.4	0.206	20.6
Community participation and culture	3.764	75.3	0.217	21.7
Policy support and implementation consistency	3.316	66.3	0.191	19.1

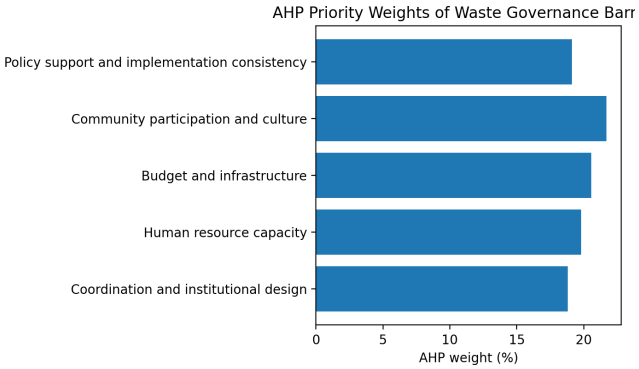


Fig. 1. AHP priority weights of waste governance barriers.

The AHP result means that the first intervention priority should not be limited to procurement of trucks or temporary disposal facilities. Infrastructure remains important, but the highest priority is behavioural and participatory: household sorting, community discipline, environmental norms, collective monitoring, and incentives for participation. This finding is consistent with the qualitative interview guides that emphasize community involvement, forum communication, trust, and the role of social and religious leaders.
strengthen collaborative performance.

4.3 SEM-PLS-Oriented Structural Model

The SEM-PLS-oriented model uses collaborative performance as the endogenous construct and institutional design barriers, resource capacity barriers, community participation barriers, and technology adaptation as exogenous constructs. The model explains 47.1% of the variance in collaborative performance (R^2=0.471). This is a moderate explanatory power for exploratory governance research with a small sample.

Path	Beta	SE	t-value	p-value	% bootst rap CI	f^2
DB -> CPER F	- 0.475	0.23	-2.068	0.039	1.076, -0.177]	0.207
CB -> CPER F	- 0.001	0.2003	-0.005	0.996	[-0.303, 0.495]	0.0
CPB -> CPER F	0.009	0.168	0.054	0.957	[- 0.359, 0.310]	0.0

TA -> CPER F	0.401	0.113	3.557	<0.001	[0.168, 0.610]	0.263

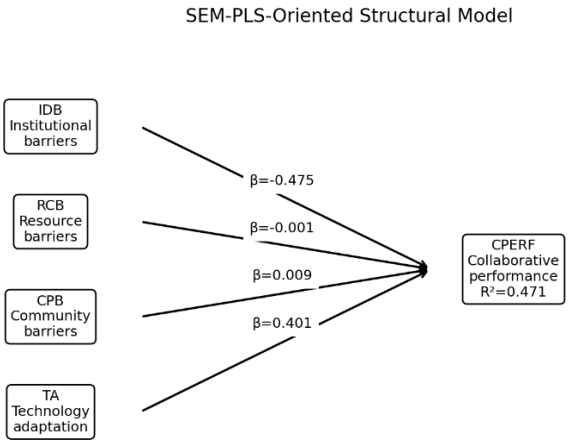


Fig. 2. SEM-PLS-oriented path model.

The structural model supports H1 and H4. Institutional design and coordination barriers have a significant negative effect on collaborative performance (β=-0.475; p=0.039). This indicates that when forum routines, communication channels, policy clarity, and consistency of rule implementation are weak, the perceived performance of collaborative waste governance decreases. Technology adaptation has a significant positive effect (β=0.401; p<0.001), suggesting that digital communication, public information, complaint reporting, and monitoring tools can structural model. Resource capacity barriers and community participation barriers have weak and insignificant direct effects after institutional design barriers and technology adaptation are included. This does not mean that resources and community participation are unimportant. The AHP results show that community participation and budget-infrastructure are the highest priorities. The SEM result suggests that their influence may be mediated by institutional design, coordination, and technology-enabled collaboration. In other words, resources and public participation become effective when they are organized through credible collaborative institutions and supported by adaptive technology.

4.4 Qualitative-Quantitative Integration

Qualitative theme	Quantitative evidence	Integrated interpretation
Weak institutionalized forum and communication	IDB significantly reduces CPERF (β=-0.475; p=0.039)	Formal collaborative forums and coordination SOPs are central to improving performance.
Community behaviour and participation are persistent challenges	AHP ranks community participation and culture first (weight=0.217; index=75.3)	Behavioural change must become the first priority of the RIANA action agenda.
Infrastructure and budget constraints are visible in the field	Budget and infrastructure rank second in AHP (weight=0.206; index=71.4)	Resource allocation is needed but should be linked to accountable collaboration mechanisms.
Technology is still limited but needed for monitoring and communication	TA significantly improves CPERF (β=0.401; p<0.001)	Adaptive technology should be inserted as a governance tool, not merely an administrative application.
Media and academia are underutilized	Interview instruments explicitly include media and academia as pentahelix actors	The RIANA model must formalize media campaigns and academic evaluation.

5. Discussion

The results reveal an important governance paradox. AHP ranks community participation as the highest priority, but the SEM model shows that community participation barriers are not a significant direct predictor of collaborative performance once institutional barriers and technology adaptation are considered. This suggests

that community participation is not simply an individual behavioural variable; it is an institutionalized practice. Communities become active when institutions provide routines, incentives, social recognition, clear communication, and accessible channels for action.

The significant negative effect of institutional barriers supports collaborative governance theory. Dialogue, trust building, institutional design, and shared understanding are not abstract concepts; they influence perceived collaborative performance in local waste management. The finding also supports the pentahelix argument that the presence of multiple actors alone is insufficient. What matters is how the actors are connected, how responsibilities are distributed, and whether coordination mechanisms are credible and continuous.

The positive effect of technology adaptation strengthens the Adaptive Technology component of the RIANA model. In Medan Amplas, technology should be understood as a governance enabler: digital complaint channels, public dashboards of waste schedules, WhatsApp-based neighbourhood coordination, geotagged illegal dumping reports, digital waste bank records, and social media campaigns. These instruments can improve information symmetry and reduce coordination costs between the camat, kelurahan, DLH, communities, businesses, media, and academic partners.

The AHP results show that action priorities should follow the sequence of community participation and culture, budget and infrastructure, human resource capacity, policy implementation consistency, and coordination design. However, the SEM results suggest that implementation should begin by strengthening institutional design and technology, because these two factors have statistically detectable effects on collaborative performance. Therefore, the article recommends a two-layer strategy: first, establish the collaborative governance architecture; second, mobilize community and infrastructure programs through that architecture.

6. Proposed RIANA Model

The RIANA model is proposed as a pentahelix-based collaborative governance framework for sustainable waste management. RIANA consists of five integrated components. First, Responsive Governance requires local government to act not only as regulator but also as facilitator of rapid, data-based, and participatory problem solving. Second, Integrative Pentahelix requires the formal inclusion of government, academia, business, community, and media in a standing collaborative forum. Third, Adaptive Technology requires the use of digital tools for reporting, monitoring, education, and waste bank administration. Fourth, Network Collaboration requires stable coordination among kelurahan, heads of neighbourhoods, waste banks, waste pickers, religious leaders, businesses, universities, and media. Fifth, Action Sustainability transforms sustainability from a normative idea into measurable actions: waste reduction from the source, sorting, recycling, circular economy partnerships, public education, and periodic evaluation.

Code	Component	Operational meaning	Suggested indicators
R	Responsive Governance	Camat and local government facilitate rapid, participatory, and data-based waste responses.	Response time, coordination frequency, follow-up rate
I	Integrative Pentahelix	Government, academia, business, community, and media are integrated into a formal forum.	Number of active actors, joint programs, MoUs/SOPs
A	Adaptive Technology	Digital communication, complaint reporting, monitoring, and education are used as governance tools.	Digital reporting use, social media campaign frequency, digital waste bank records
N	Network Collaboration	Stakeholder networks connect formal and informal waste actors.	Active network ties, bank waste partnerships, meeting regularity
A	Action Sustainability	Sustainability is translated into reduction, sorting, recycling, circular economy, and community empowerment.	Waste reduction, household sorting, recycling value, community participation

7. Conclusion

This revised article provides explicit AHP and SEM-PLS calculations in the results section. The descriptive

analysis shows that the most severe barriers in Medan Amplas waste governance are community participation and culture, infrastructure-budget limitations, and human resource capacity. The validity and reliability analysis indicates that the main constructs are acceptable for exploratory SEM-PLS-oriented modelling. The AHP analysis ranks community participation and culture as the highest priority, while the SEM-PLS model identifies institutional design barriers and technology adaptation as significant predictors of collaborative performance.
The empirical implication is that local government should not only increase infrastructure or run sporadic community campaigns. Sustainable improvement requires an institutionalized collaborative forum, clear role sharing, digital coordination tools, community behavioural change, business-linked circular economy mechanisms, academic support, and continuous media campaigns. The RIANA model offers this integrated framework and can be further tested in other districts of Medan City or comparable Indonesian urban areas

8. Policy Implications

No.	Recommendation
1	Establish a district-level pentahelix waste governance forum with regular meetings and documented decisions.
2	Create a digital monitoring and complaint system linked to kelurahan, heads of neighbourhoods, and DLH.
3	Prioritize community behaviour change through religious leaders, schools, neighbourhood groups, and media campaigns.
4	Link CSR and local businesses to waste banks, recycling markets, and circular economy initiatives.
5	Use universities to conduct baseline studies, socialization modules, pilot technologies, and periodic evaluation.
6	Develop a simple performance dashboard including waste volume, collection schedule, illegal dumping points, bank sampah activity, and citizen participation.

9. Limitations and Future Research

This study uses 69 survey responses and exploratory composite modelling. The results should therefore be interpreted as an empirical draft suitable for journal development rather than a final confirmatory SEM-PLS result. The AHP pairwise matrix was derived from observed severity means because a separate expert judgment matrix was not uploaded. Future research should collect a larger respondent sample, conduct expert-based AHP or ANP, validate the RIANA model using SmartPLS, test mediation among institutional design, technology, participation, and performance, and compare Medan Amplas with other districts.

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