International Journal of Asian Social Science Research; Vol.2, No.3; 2025
E-ISSN: 3006-2179 P-ISSN：3006-754X
DOI: https://doi.org/10.70267/ijassr.250203.3042
Published by: Zeus Press

Beyond Linear Causality: How Cultural Resilience Emerges from Nested Agency in Japan's Road Maintenance Traditions

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Abstract

This study investigates the traditional activity known as “Doro Hinpyoukai” (Road Competition) in Nishihara Village, Aso District, Kumamoto Prefecture, Japan. Employing Complex Adaptive Systems (CAS) theory as the analytical framework, this study explores how local traditional practices contribute to sustainable rural landscape sustainability and community resilience through multi-agent interactions, self-organizing processes, and dynamic feedback mechanisms. A mixed-methods approach is employed, which adopts Structural Equation Modeling (SEM) to analyze data obtained through in-depth interviews and structured questionnaires.. The results reveal that the Road Competition exhibits hallmark CAS characteristics, that is shaped by nonlinear interactions across three levels—individuals, community groups, and the village—manifesting emergence, self-organization, and environmental adaptability. Further analysis indicates that a bidirectional reinforcement mechanism between community ethical norms and practical actions plays a critical role in maintaining the system stability. Continuously evolving local rules enhance the community's resilience to external pressures such as population aging and natural disasters. This study introduces a three-dimensional “actors-ethics-practice” analytical framework, providing novel insights into the survival mechanisms of traditional activities and their functions within rural governance systems. These findings offer valuable reference points for advancing sustainable community development in regions prone to natural disasters.

Keywords

complex adaptive systems (CAS), local traditional activities, road competition, rural landscape management, community resilience

1. Introduction

In recent years, countries across Asia have encountered significant sustainability challenges, including environmental degradation and rapid urbanization. In Japan, the combined effects of urbanization and

population aging have led to pronounced rural depopulation, vacancy rates increase, and community resilience diminution. As a country highly prone to natural disasters, Japan frequently experiences severe damage to its infrastructure such as roads and housing due to earthquakes and typhoons, which exacerbate social vulnerability. Post-disaster survey data from the 2016 Kumamoto Earthquake (Kumamoto City Policy Bureau, 2016) indicate that traditional community networks in affected regions collapsed, while mental health challenges (such as post-traumatic stress disorder, depression, and post-disaster loneliness) impeded recovery, undermining social cohesion and local identity.

Against this backdrop, sustaining strong connections between people and their local environments, and simultaneously enhancing community resilience, has become a critical challenge. Despite the implementation of rural revitalization policies by local governments in Japan, the trend of population decline persists. Notably, traditional activities rooted in local culture show unique value in preserving community cohesion. For instance, the tradition of "Road Competition" in Nishihara Village can be traced back to the pre-war era, which facilitated routine social interactions and was a critical mechanism for disaster preparedness and response. During the 2016 Kumamoto Earthquake, residents utilized the collaborative networks established through these traditional activities to coordinate evacuation and reconstruction efforts. Even amid the COVID-19 pandemic (2020–2021), communities sustained road-cleaning efforts and maintained social communication channels. These practices underscore the vital role of traditional activities in reinforcing community resilience and local identity. However, systematic academic research on this subjec remains limited.

To fill this research gap, this study adopts Complex Adaptive Systems (CAS) theory to examine the Road Competition as a dynamic, multi-agent system encompassing individual villagers, community groups, and village-level institutions. Through an analysis of nonlinear interactions and self-organizing dynamics, the study seeks to uncover the mechanisms underpinning local resilience, thereby offering theoretical foundations for preserving traditional practices and advancing sustainable community development.

2. Theoretical Framework: Coupling Analysis of CAS and Local Traditional Activities

2.1 Core Elements of CAS Theory

CAS theory, originally proposed by Holland (1995), posits that system-wide complexity emerges from local interactions among "adaptive agents". The core features of CAS include the following:

Multi-agent Interaction: Heterogeneous agents form system behaviors through nonlinear interactions.

Self-organization and Adaptability: Local rules and feedback drive dynamic system adjustments.

Emergence: System-level behaviors exceed the simple sum of individual actions.

Path Dependence: Historical trajectories shape future evolutionary directions.

These interrelated elements collectively constitute the foundational framework of CAS theory, facilitating explanations of complex system operations and evolutionary dynamics. In recent years, CAS theory has gained widespread application in the study of social-ecological systems (SES). Representative applications include the following:

Adaptive Cycle: Gunderson and Holling (2002) proposed a four-phase cycle (exploitation-conservation-release-reorganization) to explain post-disaster recovery in rural communities.

Multi-level Governance: Ostrom (2009) emphasized coordinating rules across "operational level, collective choice level, and constitutional level" to avoid the "tragedy of the commons".

Resilience Building: Folke et al. (2010) underscored that resilience is contingent upon system learning capacity, redundancy, and transformative potential, emphasizing the significance of multi-level cooperation and adaptive learning in SES frameworks.

While most existing CAS research were concentrated on natural ecosystems and urban networks, comparatively little attention has been devoted to the self-organizing evolution of traditional activities.

Nevertheless, as integral elements of regional socio-cultural systems, local traditional activities inherently reflect CAS principles, thereby offering rich theoretical potential and novel analytical perspectives for inquiries into traditional practices based on CAS. Such theoretical frameworks facilitate more nuanced insights into the operational logic underlying traditional activities.

Adopting the CAS perspective, this study systematically investigates the emergent mechanisms, self-organizing dynamics, and adaptive cycles of the Road Competition, aiming to address both theoretical and empirical gaps in understanding the evolutionary trajectories of community based traditional activities.

2.2 CAS Attributes of Local Traditional Activities

As living carriers of regional culture, local traditional activities naturally align with CAS theory through three core dimensions:

2.2.1 Nested Interactions Among Multiple Agents

Traditional activities involve interactions among diverse agents, institutions, cultures, and environments across scales. Consequently, their persistence cannot be adequately explained through single-cause relationships. The nonlinear and emergent characteristics of CAS provide a robust framework for capturing such complexity. Whereas traditional theories tend to employ linear causality to interpret social phenomena, they often fall short in accounting for the multifaceted outcomes arising from complex interactions in traditional practices. CAS theory effectively addresses this analytical limitation. Through its emphasis on nonlinear interactions and emergence, CAS theory elucidates how agent-based complexity gives rise to novel functions and systemic order beyond the aggregation of individual behaviors. This represents an analytical strength not available in conventional theoretical models.

The dynamic perspective of CAS also offers valuable insights into how tacit knowledge is transmitted within traditional activities. Through interactions, agents disseminate experiential and localized knowledge via dynamic information flows. Such knowledge transfer is inherently nonlinear, evolving iteratively through continuous feedback and adjustment processes, thereby underscoring the dynamic evolution of traditional activities as complex systems.

2.2.2 Adaptive and Resilient Practice Systems

Faced with external pressures such as globalization, demographic aging, and natural disasters, traditional activities must continuously adapt to ensure their survival. The adaptability–self-organization mechanisms within CAS offer dynamic analytical tools to examine such evolutionary processes. CAS further underscores the importance of maintaining systemic balance at the so-called edge of chaos, enabling systems to resist external shocks such as earthquake-induced infrastructure damage while remaining flexible through adaptive rule modifications, such as the temporary adjustment of cleaning areas. This perspective provides a valuable analytical lens through which to examine how traditional practices endure in uncertain environments marked by demographic decline and recurrent disasters.

2.2.3 Dynamic Evolution of Ethical Norms

Local ethics norms and rules serve as micro-level vehicles for transmitting regional culture. The CAS concept of diversity-tagging offers a framework for interpreting how regional uniqueness is formed and transmitted. These tags denote specific attributes and behavioral patterns associated with agents involved in traditional activities. For instance, within Nishihara Village's Road Competition, the distinctive cleaning rules adopted by community groups and the diverse participation methods of villager's function as identifying tags. Such tags contribute to agent differentiation and facilitate cultural transmission, thereby supporting the continuity of local traditions.

The CAS principle of emergence asserts that system-level characteristics cannot be deduced solely from the behaviors of individual agents. For example, social phenomena such as community festivals and post-cleaning gatherings emerge organically from the interaction between routine maintenance practices and embedded local cultural norms. These emergent dynamics not only enrich the symbolic and functional

significance of the Road Competition but also reinforce social cohesion and broaden avenues for community self-organization.

In conclusion, CAS theory, with its unique analytical perspective and core concepts, not only clarifies the complex mechanisms of local traditional activities but also provides robust theoretical support for understanding their adaptive evolution in modern contexts. This establishes a solid foundation for building analytical frameworks tailored to studying traditional activities.

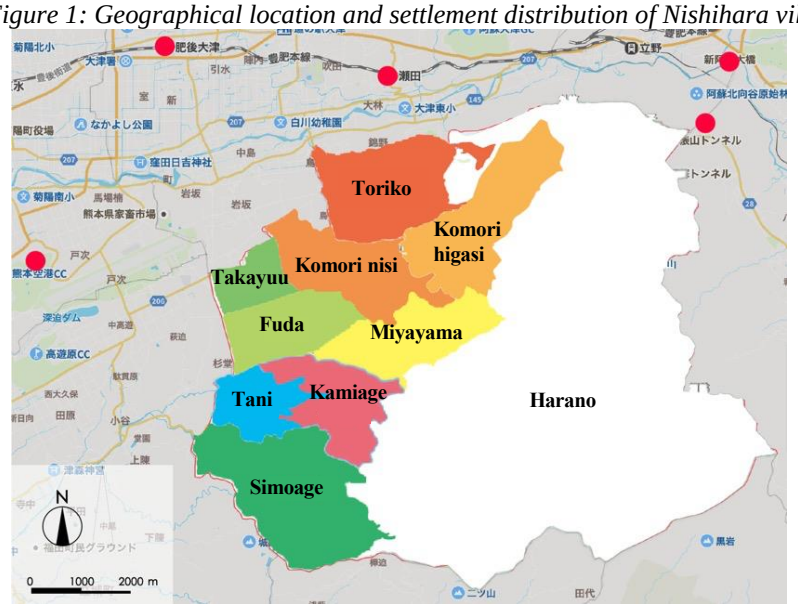
3. Study Area and Methodology

3.1 Overview of the Study Area

3.1.1 Profile of Nishihara Village

Nishihara Village is located on the southern foothills of the Aso Caldera. The village's natural terrain includes farmland in the west and wild grasslands in the east, known as the Tawarayama Wildfire Area. As shown in Figure 1, the village consists of nine administrative districts and 44 communities, with an economy primarily based on agriculture—such as potatoes, peanuts, and beef cattle—and tourism. Following the merger with Kyūyamanishi Village, Nishihara Village expanded its agricultural infrastructure. To improve farmland utilization, farm roads were constructed throughout the region, while major transportation routes were developed to facilitate access between Kumamoto City and Aso Kumamoto Airport. Furthermore, the completion of the Tawarayama Tunnel in 2003 significantly enhanced regional connectivity within Aso County. However, due to its location along the Futagawa Fault, Nishihara Village sustained extensive damage during the 2016 Kumamoto Earthquake, notably the collapse of the Tawarayama Tunnel. The tunnel was restored in September 2019.

Figure 1: Geographical location and settlement distribution of Nishihara village



According to population estimates by Kumamoto Prefecture (2024); Nishihara Village and Kumamoto Prefecture (2024), Nishihara Village had 6,802 residents prior to the 2016 earthquake, reflecting a pattern of steady demographic growth. Post-earthquake, the population temporarily declined to 6,641 in 2017 and 6,513 in 2018. However, reconstruction efforts have reversed this trend, with recent population recovery and growth. In recent years, the village's advantageous geographic location has drawn a growing influx of migrants. The average aging rate in the village stands at 33.1%, notably higher than Kumamoto City's 32.6% during the same period. Aging rates differ substantially among communities, ranging from 8% in Kawahara Danchi of the Tani District to 82% in Sarugaeri of the Shimoage District.

Despite demographic aging and the impacts of seismic disasters, the traditional activity known as the "Road Competition" has endured for more than six decades. Residents voluntarily participate in road-cleaning activities, which are subject to village-level evaluations, positioning the practice as a central element in preserving community identity. The village's roads traverse farmland and residential zones, serving purposes of both agricultural transport and routine social interactions. These distinctive spatial characteristics position the Road Competition not merely as a landscape maintenance initiative but also as a vital mechanism for sustaining local social networks. Over the decades, the Road Competition has evolved into a hybrid model that integrates traditional values with modern adaptability, offering a practical basis for examining its operational mechanisms using diverse methodological approaches.

3.1.2 Overview of the Road Competition

As shown in Figure 2, the Road Competition is a community-based system in which each group cleans its designated roads. These efforts are evaluated by the village office, and rewards are provided for outstanding performance. In NisiharaNishihara Village, all communities clean village roads twice a year. Residents regard this activity as Kuyaku, a term originating from public service obligations instituted during the Edo period, denoting communal efforts to manage shared regional resources. This tradition continues to be preserved in Nishihara Village today.

Figure 2: Road landscape before and after cleaning

Nishihara Village consists of 44 settlements encompassing 2,358 households, with approximately 82% actively participating in road-cleaning activities. Settlements that participate in road cleaning receive public subsidies from the village, categorized into four types: standard bonuses, performance-based bonuses, special bonuses, and summer cleaning subsidies. The standard bonus is calculated based on the length of roads maintained by each village. The graded bonus corresponds to the ranking received during evaluations. The special bonus offsets fuel expenses for equipment such as lawn mowers and trucks. The summer cleaning subsidy is provided to settlements that conduct additional cleaning activities during the summer season, particularly before the Obon festival. The total allocated budget for these community subsidies is 6.2 million yen, in stark contrast to the estimated 60 million yen required to hire external contractors for the same tasks. The length of village roads maintained by individual settlements varies considerably. For example, the Takayuuhigashi settlement in the Takayuu area manages 276.5 meters, while Miyayama Village in Miyayama County is responsible for 7,510.3 meters. Overall, the total length of all village roads is approximately 106 kilometers.

The cleanliness of roads maintained through the Kuyaku system is regularly evaluated by the town government. The Road Appraisal Competition is held twice a year, in spring and autumn. In autumn, evaluations are conducted by the village head or deputy head in conjunction with five village council members. In spring, this judging panel is expanded to include nine appointed district heads. As detailed in Table 1, awards are distributed in the following order: Excellence Award, First Prize, Second Prize, and Third Prize. Each village is guaranteed to receive at least one form of recognition. On the day of judging, the evaluators drive along all the village roads and score each entry. The total scores from the judges determine the recipients of the Excellence Award, First Prize, Second Prize, and Third Prize. Judges utilize scoring sheets with grades ranging from A to I. For example, grade A represents exceptionally outstanding cleaning

work that serves as a community model (100 points). Grade C reflects high-quality performance that falls short of grade A (90 points). Grade E denotes satisfactory work meeting basic expectations (80 points), while grade G reflects standard performance (70 points). Cleaning efforts that are below standard or absent receive the lowest grade (60 points).

Table 1: Road Competition Expenses List

Awards	Content		
Prizes by grade	Excellent	50,000 yen	2 villages
	1st place	35,000 yen	4 villages
	2nd place	20,000 yen	6 villages
	3rd place	15,000 yen	26 villages
Special incentive	2,020,000 yen/total extension x district extension		
Summer Cleaning Bonus	Only for participating villages 8,000 yen + (350,000 yen/total extension x district extension)		

Settlements in Nishihara Village show substantial geographical variation in terms of area and location, along with marked differences in population size and demographic composition. Maintaining road-cleaning activities imposes a considerable burden on communities, especially in those experiencing population aging or demographic decline. Nevertheless, road cleaning remains a collective responsibility actively upheld by all communities in the village.

Based on fieldwork and interviews, Shigeta et al. (2022) identified the Road Competition as a foundational mechanism in the governance structure of the village. They argued that the Road Competition has institutionalized two distinct categories of local rules: one governing road-cleaning practices and the other regulating settlement-level operations. These local rules also serve as the foundation for two types of social capital: bonding social capital and bridging social capital. By fostering civic pride among residents, they help cultivate a cooperative spirit and reinforce the sense of community within the village.

3.2 Research Methods

3.2.1 Data Collection

In-depth Interviews: Researchers conducted semi-structured interviews with two village office staff members and ten representatives from representative settlements involved in the Road Competition. The interviews were conducted on May 23 and August 3, 2024. The interviews aimed to understand the operational mechanisms and local rules of the Road Competition. Additionally, the research team accompanied officials from the Nishihara Village Office during road inspections to directly observe the evaluation process. Interview discussions centered on several key topics, including the origin and historical evolution of the Road Competition, its daily organizational structure, residents' participation experiences, and its relevance to the Kumamoto earthquake. Comprehensive records were maintained to capture critical insights shared by interviewees concerning the organizational structure, rule development, and community role of the Road Competition. These firsthand data offered in-depth empirical material essential for analyzing the operational logic and rule systems underpinning the Road Competition.

Questionnaire Surveys: A preliminary survey indicated that participants mainly engaged at individual and community levels, which posed challenges in designing a questionnaire applicable to the village scale. To address this limitation, in-depth interviews were also conducted to elucidate the relationships among actors operating at different scales. The formal survey began on August 3, 2024. During survey period, the research team collaborated with the Reconstruction Department of the Nishihara Village Office and the Aso Sustainable Society Research Institute to refine and optimize the questionnaire design. A total of 80 questionnaires were distributed, with 72 valid responses collected. The survey focused on villagers' participation in road-cleaning activities, ethical perceptions, and the associated social impact. The questionnaire included items on participation frequency in road cleaning and involvement in collective cleaning events organized by settlements. Respondents were also asked about their agreement with ethical values such as environmental responsibility and community honor, as well as the influence of the Road Competition on their sense of belonging and social interaction. This design facilitated comprehensive data collection for the study, as detailed in Table 2.

3.2.2 Structural Equation Modeling (SEM) Construction

Following data collection, the study employed a robust analytical framework to examine the alignment between the Road Competition and Complex Adaptive Systems (CAS) theory. After screening and cleaning, four latent variables and ten observed variables were identified. A structural equation model (SEM), as depicted in Figure 3, was developed to validate the interactions among elements within the CAS theoretical framework. The model fit indices (CFI = 0.91, TLI = 0.89, RMSEA = 0.07, SRMR = 0.06) met social science research standards, confirming the model's sufficient explanatory power and robustness.

Table 2: Measuring framework

Theme	Questionnaire Questions	Measurement Scale
Actors	Q1. What is the name of your settlement?	Fill in the Blanks
	Q2. How long have you lived here?	1: Less than 1 year; 2: 1–5 years; 3: 5–10 years; 4: 10–20 years; 5: Over 20 years
	Q3. Have you ever left the settlement for an extended period?	1: Yes; 0: No
	Q4. What is your age?	0: 20–29; 1: 30–39; 2: 40–49; 3: 50–59; 4: 60–69; 5: 70+
	Q5. What is your gender?	1: Male; 0: Female
	Q6. Do you participate in communal activities in your settlement? If yes, specify.	1: Yes; 0: No (List activities)
	Q7. How well do you get along with members of your community?	1–5 scale
Practice	Q8. How frequently do you participate in road cleaning (grass cutting)?	1–5 scale
	Q9. Has participating in road cleaning increased your social connections?	1–5 scale
	Q10. How often do you participate in other communal activities besides road cleaning?	1: Increased; 2: No increase
	Q11. Has road cleaning strengthened your sense of solidarity with the community?	1–5 scale
Ethics	Q12. Do you feel a sense of achievement from improving the landscape through cleaning?	1–5 scale
	Q13. Does communal road cleaning enhance your sense of achievement?	1–5 scale
	Q14. Are you happy to fulfill your responsibilities as a community member?	1–5 scale
	Q15. Do you want to engage in activities to beautify the settlement's environment?	1–5 scale
	Q16. Do you feel responsible for fulfilling your duties as a community member?	1–5 scale

4. Results and Analysis

4.1 CAS Agent Structure of the Road Competition

4.1.1 Micro-level Agents: Internalization of Ethics in Individual Participation

The survey revealed that 75% of villagers believe "beautifying the environment is the responsibility of community members" (an ethical norm). Participation in cleaning activities demonstrated a strong positive correlation with villagers' sense of achievement and solidarity ($\beta = 0.59$, $p < 0.001$). This finding aligns with Schwartz's (1977) Norm Activation Theory, which suggests that ethical responsibility motivates individuals to act and attain self-fulfillment through observable environmental improvements. Such behavior forms a closed feedback loop in which ethical awareness leads to action, which in turn generates emotional reinforcement. For example, in an interview, Villager A shared that the pride he experienced upon witnessing cleaned roads strengthened his sense of community responsibility and encouraged continued participation in cleaning efforts. This internalization of ethical values and the resulting practical feedback not

only reinforce villagers' emotional connection to the community but also establish a foundational micro-level basis for the development and refinement of settlement-level rules.

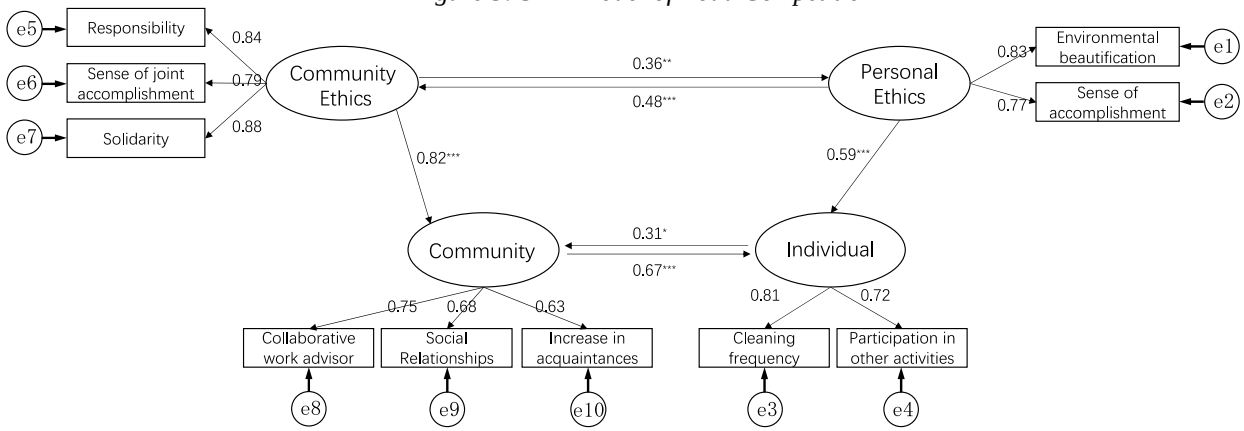
4.1.2 Meso-level Agents: Self-organizing Formation of Settlement Rules

Each settlement independently developed cleaning rules that show significant diversity and adaptability. These rules are not static; rather, they are continuously modified in response to practical need. For instance, during peak farming seasons, the frequency of cleaning requirements is reduced, while the arrival of new residents prompts flexible adjustments to participation norms. Such flexibility ensures a balance between orderly cleaning practices and the varying needs of different groups, illustrating a high degree of adaptability. Examples of such rule innovation include:

Ono Settlement developed a two-step vegetation trimming method ("rough cutting with standard mowers followed by precision trimming with specialized mowers") through long-term practice and technical exchanges. This efficient approach improves trimming efficiency and has been adopted by other settlements; Ioji Settlement introduced "pre-harvest mowing rules" to balance farming and cleaning. Before crop harvests, pre-mowing zones are strategically planned to protect agricultural schedules and prevent damage to road landscapes; Futa Settlement implemented "simultaneous riverbank cleaning," integrating human and material resources to maintain both riverbanks and adjacent roads.

Provisions such as exemptions for residents over 70 or additional summer cleaning duties exemplify the self-organizing dynamics of individual settlements. localized rules are iteratively refined through intergenerational knowledge transfer and collective consensus, constituting the central mechanism sustaining community-based cleaning efforts.

Figure 3: SEM Model of Road Competition



4.1.3 Macro-level Agents: Institutional Support from Village Administration

The village offers formal institutional support through a bonus allocation system (annual budget: 6.2 million yen) and biannual evaluations conducted in spring and autumn, thereby establishing a structured top-down normative framework. SEM analysis revealed that institutional support has a significant direct effect on settlement participation ($\beta = 0.82$, $p < 0.001$), confirming that the synergy between formal institutions and informal norms is critical for ensuring system stability. This finding aligns with the CAS principle that simple building blocks can combine to produce complex system functions. The village administration also fosters healthy competition and knowledge sharing among settlements through biannual evaluations and regular experience-sharing workshops. This institutional design stimulates innovation in settlement rules, enabling mutual learning and improvement. For instance, meetings organized by the village administration allow settlement representatives to exchange innovative rules, enabling the widespread dissemination of effective, locally developed practices tailored to regional contexts. These horizontal interactions, supported by institutional frameworks and shared resource platforms, drive the collaborative evolution of the Road Competition system, thereby enhancing its structural stability and adaptive capacity while maintaining its local specificity.

4.2 Nonlinear Interactions and Emergent Phenomena

4.2.1 Bidirectional Reinforcement Between Ethics and Practice

The structural equation model identified a significant direct effect of community ethics—specifically, the sense of solidarity and responsibility—on practical behaviors such as cleaning frequency and participation in communal work ($\beta = 0.82$). Conversely, practical engagement also influenced the internalization of personal ethics through the mediating role of a sense of achievement ($\beta = 0.48$). For example, post-cleaning communal gatherings transformed lroutine labor into social rituals, thereby enhancing emotional ties among villagers and establishing a positive feedback cycle in which ethics motivate practice, and practice reinforces ethics. During daily cleaning activities, this bidirectional reinforcement also gave rise to culturally unique phenomena. For example, several settlements-initiated cleaning skill competitions, fostering deeper interpersonal interaction through constructive competition. These supplementary practices enriched the cultural meaning of the Road Competition, amplifying its emergent characteristics and propelling the system toward increased complexity and vitality. At the same time, these activities reinforced cultural identity and a sense of belonging among villagers, establishing a robust social foundation for confronting external pressures.

4.2.2 Adaptive Adjustments in Disaster Response

In response to transportation disruptions following the 2016 Kumamoto earthquake, several settlements independently revised their cleaning strategies, prioritizing main road safety and temporarily consolidating cleaning resources. SEM analysis demonstrated a significant positive correlation between disaster response strategies and perceptions of community resilience ($\beta = 0.36$). This finding suggests that agent-driven adjustments enhanced the system's ability to absorb disturbances, exemplifying a core feature of CAS adaptability. Such adaptive strategies not only mitigated the immediate effects of the earthquake but also encouraged settlements to reassess and refine their governance and operational rule sets. For example, certain settlements integrated disaster response protocols into their routine cleaning rules and simultaneously fostered ongoing awareness of risk prevention. The ability to proactively adapt and continuously evolve in the face of crises illustrates the functional dynamics of complex adaptive systems embedded in traditional practices. Moreover, it offers valuable empirical support for subsequent analyses of the sustainability mechanisms underpinning these traditional systems.

5. Discussion: Sustainability Mechanisms of Local Traditional Activities from a CAS Perspective

5.1 Resilient Structure Through Multi-level Agent Co-evolution

The Nishihara case demonstrates that the core strength of CAS lies in integrating three levels of agents: individual responsibility, settlement autonomy, and village-level support.

Individuals act as micro-level drivers by internalizing ethics. Through participation in daily cleaning activities, they adopt norms such as environmental responsibility as personal standards of behavior. This micro-level motivation provides foundational support for the sustained operation of the Road Competition. When individual behaviors converge with self-organizing settlement structures and institutional guarantees at the village level, synergistic evolution across hierarchical agents is initiated. The impact of individual actions extends across levels, facilitating the ongoing development and refinement of the Road Competition system as a whole

Settlements contribute to meso-level coordination by formulating self-organizing rules. These locally derived regulations are continuously adapted to address environmental changes and demographic shifts through processes of inheritance and optimization. This meso-level coordination enhances the flexibility and sustainability of cleaning activities. When self-organizing rules align with macro-level institutional support from the village administration and are complemented by micro-level individual motivation, the three agent levels integrate into a cohesive system. Through continuous information exchange, shared resource utilization, and coordinated behaviors, these agents adapt dynamically during both routine maintenance and

crisis response, facilitating co-evolution. This drives the Road Competition's resilience in complex social environments.

The village ensures macro-level stability through institutional design. This multi-layered synergy transforms the Road Competition from a basic cleaning activity into a cultural platform that preserves collective memory and promotes intergenerational exchange. In daily operations and disaster responses, agents at all levels co-evolve through experience accumulation and knowledge sharing. For example, young villagers learn traditional cleaning techniques while incorporating modern environmental concepts, prompting continuous refinement of settlement rules. The village administration, in turn, updates institutional frameworks based on feedback from the settlements.

This dynamic evolution enables the Road Competition system to adapt to ongoing societal transformations while persistently generating cultural and social value.

Interdependence and mutual reinforcement among the three agent levels are evident. Micro-level individual responsibility fosters innovation, meso-level settlement rules facilitate regional coordination, and macro-level institutions contribute systemic vitality and long-term stability. These three layers are interdependent and mutually reinforcing. When individual innovations are integrated with settlement-specific rules and supported by village-level incentives, they generate strong internal synergies within the Road Competition system. This synergy enhances the system's capacity to address challenges such as population aging and natural disasters. It also strengthens community resilience and promotes the sustainable evolution of traditional activities in contemporary society.

5.2 Practical Transformation of Ethical Norms and Emergent Value

Emotional feedback, such as joy in fulfilling responsibilities and a sense of achievement from landscape improvement, is an emergent outcome of transforming ethical norms into practical actions. According to CAS theory, when individual behaviors align with collective ethics—for example, the belief that cleaning reflects community honor—their influence is amplified through social networks, leading to collective actions that go beyond individual rational calculation. This is critical for understanding the cultural cohesion of traditional activities. The cultural value emerging from such collective actions further reinforces community identification and the intergenerational transmission of local traditions. Through years of Road Competition practice, villagers have developed a stronger sense of community belonging, while regional culture has been sustained and enriched through intergenerational transmission. This process not only reinforces community cohesion but also provides practical insights into rural landscape governance and resilience enhancement. The sustained accumulation of cultural value has allowed the Road Competition to evolve into a distinctive social ecosystem within Nishihara Village. The emotional bonds forged through daily cleaning and collective engagement foster a heightened sense of participation and belonging, simultaneously generating social capital capable of mitigating external shocks. In the face of major challenges such as natural disasters or public health crises, the resilience built through this tradition is rapidly mobilized into effective response mechanisms, thereby safeguarding regional stability and promoting sustainable development.

5.3 Implications for Rural Landscape Management

This study identifies three key sustainability mechanisms for local traditional activities within the framework of CAS:

Adaptive Mechanism: Local rules flexibly respond to external pressures like demographic shifts and disasters. For example, villages may adopt flexible participation strategies to accommodate aging populations and implement emergency cleaning protocols in response to disaster risks. These adaptive strategies can be enhanced by integrating modern technologies, such as big data analytics to assess population structures and cleaning demands, thereby enabling data-informed adjustments to local regulations. In addition, IoT devices can monitor road conditions in real time, facilitating proactive risk prediction and enabling more intelligent and precise rural landscape management.

Feedback Mechanism: The integration of evaluation systems and emotional experiences creates a "practice → evaluation → optimization" loop. Enhancement of this mechanism can be achieved by

incorporating ecological indicators, such as biodiversity, into assessment frameworks and visualizing cleaning outcomes during community events to promote engagement and pride. Additionally, establishing inter-agent knowledge-sharing platforms can facilitate cross-level learning. For instance, by leveraging the collaborative framework of the Road Competition, external stakeholders such as universities and research institutions could collaborate with villages on ecological restoration initiatives. Landscape designers could offer customized planning guidance, integrating professional expertise with local knowledge to enhance the scientific rigor and systematic planning of rural landscape management.

The collaborative mechanism emphasizes the interaction between formal institutions and informal norms in reinforcing system resilience. Synergizing top-down policies with bottom-up local rules is key. For example, villages and settlements could jointly design flexible bonus allocation schemes and promote inclusive, multi-agent participation in the revision of local rules. Joint cleaning initiatives across settlements can transcend geographical boundaries and strengthen inter-community cohesion. Through such collaborations, villagers exchange cleaning techniques and cultural perspectives, fostering innovation and revitalizing the Road Competition system. This collaborative synergy enhances both rural landscape management and community resilience, providing valuable practical references for other villages confronting comparable challenges.

Through these theoretical explorations and empirical observations, the Road Competition in Nishihara Village exhibits significant vitality and adaptive capacity within the CAS framework. The integration of traditional practices with contemporary governance theory not only supports the ongoing development of the Road Competition but also creates new opportunities for academic inquiry and innovation in rural governance. This multi-level analysis, bridging theory and practice, clarifies the operational logic of the Road Competition as a complex adaptive system and lays the groundwork for further exploration of its sustainability mechanisms and broader relevance. This underscores the dual significance of the study in both academic and practical realms.

6. Conclusion and Future Perspectives

6.1 Research Conclusions

This study reveals the sustainability mechanisms of the Road Competition in Nishihara Village through the theoretical framework of Complex Adaptive Systems (CAS). Guided by ethical norms, multi-level agents constitute a stable, yet adaptive system shaped by nonlinear interactions and self-organizing dynamics.The Road Competition functions not only a practical platform for landscape maintenance but also a mechanism for fostering community identity. Its success validates the effectiveness of CAS theory in explaining the resilience of local traditional activities. Specifically, the co-evolution of agents at the individual, settlement, and village levels, the transformation of ethical norms into practice, and dynamic feedback mechanisms collectively underpin the long-term functionality of the system. By integrating ethical values with interaction-driven dynamics, the Road Competition extends its initial role in landscape maintenance and evolved into a holistic social platform that preserves local knowledge, sustains intergenerational traditions, and fosters community capital. This provides critical insights into how traditional activities facilitate the transformation of values in contemporary rural governance systems.

6.2 Practical Implications and Limitations

The findings suggest practical pathways for rural landscape management and the enhancement of community resilience, highlighting the importance of establishing collaborative governance networks that integrate governmental leadership, community autonomy, and resident participation. Emotionally resonant design strategies and institutional innovations can translate abstract ethical values into concrete incentives, thereby enhancing civic participation and a sense of belonging. Concurrently, flexible policies grounded in CAS principles enable rural communities to adapt effectively to demographic and environmental challenges. However, this study’s focus on a single case limits broader generalizations, and future research should expand to cross-regional comparisons to validate CAS theory’s universality. The integration of digital tools, including GIS-based spatial analysis and participatory social media data, may enhance quantitative

understanding of agent interactions. Moreover, it remains essential to examine the dynamic relationships between traditional activities and broader socioeconomic variables, such as industrial restructuring or national policy changes. Addressing these research gaps will contribute to the refinement of theoretical models and offer more targeted guidance for the strategic application of traditional practices in rural revitalization.

6.3 Future Research Directions

Future studies should prioritize tracking how external interventions, market dynamics, and policy changes influence the sustainability of traditional activities like the Road Competition. By bridging gaps between local practices and modern governance tools, researchers can uncover synergies that enhance both cultural preservation and rural development, ultimately advancing sustainable and resilient rural communities.

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Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

We express profound gratitude to the Reconstruction Department of Nishihara Village Office and the Aso Sustainable Society Research Institute for their indispensable partnership in facilitating fieldwork logistics, cultural mediation, and community access - essential foundations for this research. We further honor the wisdom shared by Nishihara's residents who entrusted us with their lived experiences, embodying the

communal spirit this study documents. This work stands as testament to their collective stewardship of cultural heritage. Any limitations remain our sole responsibility.

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