



Mathematical Modelling of Cultural Continuity, Intergenerational Learning and Social Cohesion: A Socio-Mathematical Framework for the Agew Horse Festival

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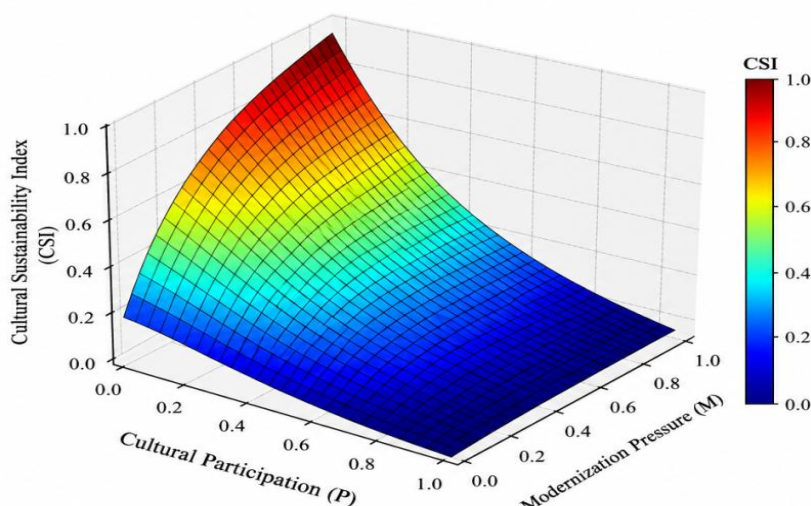
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ABSTRACT

Cultural festivals constitute complex socio-cultural systems in which historical memory, cultural identity, intergenerational learning, symbolic representation, participation, and social cohesion interact dynamically. This paper develops a mathematical modelling framework for analysing the sustainability and evolution of the Agew Horse Festival in Injibara, Ethiopia. The model is motivated by the ethnographic evidence that the festival operates as a living cultural institution through which horsemanship, traditional practices, historical memory, symbolic values, and communal relationships are transmitted across generations. The original ethnographic investigation employed participant observation, 14 in-depth interviews, and two focus-group discussions involving youth and elders. A coupled system of nonlinear differential equations is proposed to represent five principal state variables: cultural knowledge, intergenerational transmission, social cohesion, historical memory, and cultural participation. A symbolic-value variable representing the cultural significance of the horse is incorporated into the system. External pressures such as modernization, globalization, commercialization, and weakening participation are represented as attenuation parameters. A composite Cultural Sustainability Index (CSI) is subsequently formulated to provide a measurable framework for evaluating the long-term resilience of the festival. Stability conditions, equilibrium behaviour, sensitivity analysis, scenario modelling, and numerical simulation strategies are proposed. The framework can subsequently be calibrated using longitudinal survey, participation, membership, youth-training, festival-attendance, and cultural-practice data. The model provides a bridge between qualitative anthropology and mathematical modelling and can potentially be adapted to other indigenous festivals and intangible cultural heritage systems.

Keywords: Mathematical modelling; socio-mathematical systems; cultural sustainability; Agew Horse Festival; social cohesion; intergenerational learning; cultural heritage; historical memory; fuzzy modelling; dynamical systems.

2D Surface Representation of the Cultural Sustainability Index (CSI)
for the Agew Horse Festival, Injibara, Ethiopia



Mathematical Representation

$$CSI = \frac{P^\alpha (K^\beta T^\gamma S^\delta H^\epsilon V^\zeta)}{1 + M^\eta}$$

where:

- P – Cultural participation
- K – Cultural knowledge
- T – Intergenerational transmission
- S – Social cohesion
- H – Historical memory
- V – Symbolic value of the horse
- M – Modernization and external pressure
- $\alpha, \beta, \gamma, \delta, \epsilon, \zeta, \eta$ – positive weighting parameters

Interpretation of the Surface

- CSI is high when cultural participation (P) is high and modernization pressure (M) is low.
- CSI decreases as modernization pressure increases.
- Cultural participation plays a crucial role in sustaining the festival.
- The surface shows a nonlinear decline, indicating that beyond a certain level of modernization, the sustainability drops sharply, even if participation is moderate.

Key Justification

- The Agew Horse Festival is sustained by active participation, transmission of knowledge, social cohesion, historical memory and the symbolic value of the horse.
- Modernization, globalization and commercialization can diminish these cultural elements.
- The 2D surface visualizes the dynamic interaction between cultural participation and modernization pressure on the Cultural Sustainability Index (CSI).
- This graphical model helps in understanding the resilience of the festival and provides a basis for policy and community interventions to ensure its long-term sustainability.

LITERATURE REVIEW

1. Cultural Transmission and the Continuity of Traditional Practices

The theoretical foundation for understanding the intergenerational continuity of the Agew Horse Festival can be traced to studies of cultural transmission and cultural evolution. Cavalli-Sforza and Feldman (1981) provided an important quantitative framework for explaining how cultural characteristics are transmitted across generations. Their approach is particularly relevant to traditional festivals because cultural knowledge is not inherited biologically but is learned through social interaction, observation, imitation, participation, and communication. In the context of the Agew Horse Festival, knowledge relating to horse riding, racing, traditional dress, ceremonial practices, songs, food, social responsibilities, and community participation can therefore be understood as forms of transmitted cultural knowledge. Cavalli-Sforza and Feldman's (1983) discussion of cultural versus biological inheritance further strengthens this perspective by distinguishing culturally transmitted characteristics from biological inheritance. This distinction is significant for understanding how younger generations acquire festival-related knowledge from elders and community institutions. Boyd and Richerson (1985) subsequently developed a broader evolutionary perspective on culture, emphasizing the processes through which social learning contributes to cultural continuity and transformation. Their work provides a useful theoretical basis for examining whether participation in the Agew Horse Festival merely reproduces established traditions or also enables their adaptation to changing social circumstances. Bandura's (1986) social cognitive theory adds another dimension by emphasizing learning through observation, modelling, and social interaction. Traditional festivals provide an especially strong environment for such learning because younger participants can observe experienced horse riders, elders, performers, organizers, and other community members. Rogoff (1990) and Lave and Wenger (1991) further emphasize learning as a socially situated process. Lave and Wenger's concept of legitimate peripheral participation is particularly applicable to festivals: young people may initially participate as observers or assistants and progressively acquire more specialized knowledge through participation in community activities. Wenger (1998) subsequently conceptualized communities of practice as social environments in which shared knowledge, meaning, and identity are continuously produced. The Agew Horse Festival can similarly be examined as a community-based setting where cultural competence develops through repeated participation.

2. Ritual, Festival and Performance Studies

The anthropological literature on ritual and performance provides a second major theoretical foundation. Turner (1982) examined the transformation of ritual into theatrical and performative forms, highlighting the



seriousness and social significance of collective performance. This perspective is useful for examining horse festivals not simply as entertainment but as occasions through which social relationships, values, identity, and collective meanings are expressed. Turner's later work on the anthropology of performance (1987) further emphasizes performance as a mechanism through which communities communicate and reproduce cultural meanings. Falassi (1987), through his edited volume on festivals, contributed to the anthropological understanding of festivals as culturally structured events involving temporal, social, symbolic, and performative dimensions. This approach is directly relevant to the Agew Horse Festival because the event combines sporting activity, ritual symbolism, social interaction, traditional dress, music, communal gathering, and collective celebration. Handelmann's (1990) study of public events further suggests that public festivals can be examined as structured social models through which communities represent themselves. Such an approach permits analysis of the Agew festival as both a cultural event and a representation of Agew social identity. Bauman (1986) placed particular emphasis on story, performance, and event in the study of oral narrative. This is important because festival traditions are frequently accompanied by oral histories, songs, narratives, and culturally meaningful performances.

3. Symbolic Anthropology, Community and Cultural Identity

Geertz's (1983) interpretive approach to culture emphasizes the importance of locally constructed meanings. From this perspective, cultural practices should be understood within the symbolic system of the community that produces them rather than interpreted solely through external categories. Cohen (1985) similarly examined the symbolic construction of community. His work is useful for understanding how shared symbols and practices create boundaries of belonging and reinforce collective identity. In the Agew Horse Festival, the horse, traditional clothing, communal participation, competitive riding, ceremonial practices, and historical narratives can consequently be examined as symbols through which community identity is articulated. Anderson's (1983) concept of imagined communities provides a broader framework for examining collective identity and belonging. Although originally developed in relation to nationalism, the concept can inform research on how shared cultural practices contribute to a sense of collective community. Bourdieu's (1986) concept of cultural capital provides another analytical dimension. Cultural knowledge, competence, social recognition, and participation can function as forms of capital within communities. The relationship between memory and identity becomes especially important in this context. Connerton (1989) examined how societies remember, while Halbwachs (1992) conceptualized collective memory as socially constructed and maintained. Assmann and Czaplicka (1995) further connected collective memory with cultural identity. Together, these perspectives suggest that festivals can function as recurring mechanisms for remembering and reproducing shared histories. Nora's (1989) work on *les lieux de mémoire* further emphasizes the relationship between memory, history, and culturally significant places or practices. The annual recurrence of the Agew festival may therefore be investigated as a culturally significant temporal and social space in which community memory is activated.

4. Social Capital, Cooperation and Community Participation

The literature on social capital provides another important perspective. Coleman (1988) linked social capital to the creation of human capital, while Putnam, Leonardi, and Nanetti (1993) demonstrated the significance of civic traditions and networks of cooperation. Woolcock (1998) subsequently developed a theoretical synthesis concerning social capital and development. These perspectives suggest that community festivals can create opportunities for interaction, cooperation, trust, collective organization, and intergenerational relationships. Boyd and Richerson's work on cultural cooperation also provides a theoretical basis for examining how shared cultural practices can support collective action. Ostrom (1990), although primarily concerned with common-pool resources and institutional arrangements, provides a useful framework for thinking about collective governance and community participation. The management of a major cultural festival involves coordination among families, riders, organizers, local institutions, community leaders, and other stakeholders.

5. Methodological Foundations for Ethnographic Study

The literature also provides strong methodological foundations for investigating the festival ethnographically.



Hammersley and Atkinson (1983) established important principles for ethnographic research, while Tedlock (1991) discussed the movement from participant observation toward an observation of participation. Kvale (1991, 1996) contributed substantially to qualitative interviewing methodology, providing a basis for collecting narratives and perspectives from elders, riders, organizers, community members, and younger participants. DeWalt and DeWalt (2002, 2011) specifically address participant observation, making their work relevant to a study in which researchers need to observe festival activities while also understanding their social meanings. Creswell (2009), Patton (2002), and Krueger and Casey (2015) provide methodological support for qualitative, mixed-method, evaluation, and focus-group approaches. These works collectively support the use of interviews, observation, focus groups, and qualitative interpretation for documenting community perspectives and cultural meanings.

6. Cultural Heritage and Intangible Heritage

The literature on heritage studies marks an important transition from viewing culture as a collection of objects toward understanding heritage as a living process. UNESCO's 2003 Convention on the Safeguarding of the Intangible Cultural Heritage established an important international framework for recognizing practices, representations, expressions, knowledge, and skills maintained by communities. Kirshenblatt-Gimblett (2004) examined intangible heritage as a form of metacultural production, while Smith (2006) critically examined the ways heritage is constructed and used. Blake (2009) specifically discussed community involvement in safeguarding intangible cultural heritage. This is particularly significant for the Agew Horse Festival because effective safeguarding cannot be reduced to documenting the festival; it also requires understanding the role of the community in maintaining and transmitting its traditions. Harrison (2013) and Akagawa (2014) further expanded critical approaches to heritage and heritage conservation. Their work supports an understanding of heritage as dynamic and socially negotiated rather than static.

7. Cultural Sustainability and Sustainable Development

The concept of cultural sustainability provides an especially important framework for the present study. Soini and Birkeland (2014) explored the scientific discourse surrounding cultural sustainability, demonstrating the growing importance of culture within sustainability research. Dessein, Soini, Fairclough, and Horlings (2015) developed the idea of culture in, for, and as sustainable development. This framework makes it possible to examine the festival simultaneously as a cultural practice, as a contributor to sustainable community development, and as a form of development in its own right. Duxbury, Hosagrahar, and Pascual (2016) argued for placing culture at the heart of sustainable urban development. Although the Agew Horse Festival is located within a specific Ethiopian regional context, this framework provides a broader basis for examining the relationship between cultural heritage, local development, community participation, and sustainability. Albert (2017) further examined the potential of culture for sustainable development within heritage studies. UNESCO's later work on intangible cultural heritage and sustainable development reinforces the contemporary importance of integrating heritage safeguarding with sustainable development objectives.

8. Equestrian Festivals, Horse Culture and African Identity

A more specialized body of literature concerns equestrian culture and festivals. The references supplied for the study include work specifically addressing equestrian festivals and ethnic identity in Africa. Adeyemi (2019) examines the relationship between equestrian festivals and ethnic identity, providing a particularly relevant comparative framework for understanding how horse-related cultural practices may reinforce collective identity. Cieslak (2018) examined equestrian festivals as cultural heritage through comparative analysis, providing another framework for interpreting horse festivals beyond their sporting dimension. Gugliotta (2015) addressed horses and cultural identity from a broader global perspective, while Ndebele (2017) examined festivals and cultural identity in an African sociological context. Together, these studies establish the relevance of examining equestrian practices through cultural, social, and identity-based perspectives. Kebede (2020) provides a more geographically relevant contribution by examining horse culture and tourism development in Awi Zone, Northwestern Ethiopia. This study is particularly important because it connects horse culture with local development and tourism, thereby providing a regional foundation for investigating the broader socio-



economic implications of the Agew Horse Festival. Bimrew and Zemenu (2017) examined the management of draft horses in selected areas of Awi Zone. Although its emphasis differs from cultural festival studies, it contributes contextual knowledge concerning the relationship between horses and local livelihoods in the region.

9. Recent Documentation of the Agew Horse Festival

Recent sources provide direct evidence concerning the contemporary continuation of the festival. Borkena (2022) reported on the Agaw Horse Racing Festival in Injibara, documenting its public celebration. In 2024, Addis Standard reported on Injibara hosting the 84th Agew Equestrian Festival, while Fana Media Corporation reported that the festival was underway in Injibara. These sources demonstrate the continuing public visibility and organizational continuity of the event. Africa-Press (2025) subsequently documented the 85th annual Agew Equestrian Festival in the Amhara Region. The progression from the 84th to the 85th annual festival provides evidence of the event's continued recurrence and contemporary cultural relevance. Most directly relevant to the present research is Birhanu (2026), *Galloping Heritage: An Ethnographic Study of the Socio-cultural and Symbolic Life of the Agaw Horse Festival in Injibara, Ethiopia*. The study's explicit ethnographic focus on the socio-cultural and symbolic dimensions of the festival provides a recent scholarly foundation for examining the festival as a living cultural institution rather than simply as a sporting event.

10. Mathematical, Network and Systems Perspectives

An additional interdisciplinary dimension emerges from the supplied references. Zadeh (1983), Zimmermann (1991), Klir and Yuan (1995), Mendel (2001), and Ross (2004) provide foundations for fuzzy-set theory and fuzzy logic. These works can support the development of models in which cultural variables such as participation, transmission, community cohesion, symbolic significance, and sustainability are represented as degrees rather than rigid binary categories. The network perspective is represented by Watts and Strogatz (1998), Barabási and Albert (1999), and Newman (2003). These studies provide conceptual foundations for examining social relationships as networks and could be applied to relationships among elders, youth, horse owners, riders, organizers, families, community institutions, and cultural stakeholders. Agent-based and complex-systems approaches represented by Epstein and Axtell (1996), Gilbert (2008), and Miller and Page (2007) provide further possibilities for modelling how individual participation and interaction may produce collective cultural outcomes. Optimization and sensitivity-analysis literature, including Deb (2001), Bertsekas (1999), Boyd and Vandenberghe (2004), and Saltelli et al. (2008), provides methodological foundations for exploring trade-offs among cultural preservation, community participation, tourism, economic development, and sustainability.

11. Research Gap

The reviewed literature demonstrates substantial scholarship on cultural transmission, ritual, performance, collective memory, social capital, intangible heritage, cultural sustainability, equestrian culture, and Ethiopian horse traditions. However, the supplied literature also reveals an opportunity for a more integrated investigation of the Agew Horse Festival. First, much of the foundational literature examines cultural transmission, identity, memory, or ritual independently. There is scope to integrate these dimensions into a single analytical framework. Second, international heritage literature emphasizes community participation and sustainability, but the supplied references provide comparatively limited empirical modelling of how specific festival practices contribute to measurable cultural sustainability. Third, regional studies concerning horse culture and tourism in Awi Zone provide useful contextual evidence, but there remains scope for a detailed ethnographic examination linking horse culture, symbolic meaning, intergenerational transmission, community identity, social participation, and sustainability. Fourth, the mathematical literature on fuzzy logic, network analysis, complex systems, and optimization exists largely outside the cultural-heritage literature represented in the reference set. This creates an interdisciplinary research opportunity: qualitative ethnographic evidence could be complemented by quantitative or fuzzy modelling of cultural sustainability. Finally, the recent 2026 ethnographic study by Birhanu provides an important contemporary foundation, but the present literature set allows the subject to be extended toward a broader framework connecting socio-cultural practices → symbolic



meaning → cultural transmission → community participation → heritage safeguarding → sustainable development.

12. Conceptual Synthesis

Based on the literature, the Agew Horse Festival can be conceptualized as a living cultural system rather than simply an annual sporting event.

A possible conceptual relationship is:

Cultural Practices → Symbolic Meaning → Participation → Intergenerational Transmission → Collective Identity → Heritage Continuity → Cultural Sustainability

The framework can further incorporate the mathematical perspective:

Cultural Sustainability = $f(P, M, T, I, C, H, S)$

where:

- P = participation
- M = symbolic meaning
- T = intergenerational transmission
- I = collective identity
- C = community cohesion
- H = heritage safeguarding
- S = sustainability

This conceptualization is consistent with the supplied literature's movement from cultural transmission theory and ritual studies toward collective memory, social capital, intangible heritage, cultural sustainability, and contemporary studies of Agew equestrian traditions.

OVERALL LITERATURE REVIEW CONCLUSION

The literature establishes that festivals can function simultaneously as repositories of collective memory, mechanisms of cultural transmission, spaces of social learning, performances of identity, institutions of community participation, and vehicles for heritage sustainability. The Agew Horse Festival fits within this broader theoretical field while possessing a distinctive regional and equestrian character. The progression of literature from foundational cultural theory in the 1970s–1990s to intangible heritage, cultural sustainability, equestrian identity, and contemporary Agew festival documentation demonstrates an increasingly interdisciplinary understanding of cultural festivals. The major contribution of the proposed research can therefore lie in bringing these previously separated perspectives together through an ethnographic, socio-cultural, symbolic, heritage, sustainability, and mathematical modelling framework.

1. Introduction

Cultural heritage is not merely a collection of historical objects or traditional performances. It is a dynamic social system in which knowledge, values, symbols, practices, memories, identities, and relationships are continuously reproduced and transformed. Festivals provide an important mechanism through which these processes become visible. The uploaded study describes the Agew Horse Festival as a multidimensional cultural institution connecting social practices, symbolic meanings, intergenerational learning, historical



memory, community identity, and social cohesion. The Agew Horse Festival of Injibara has particular importance because horses are associated with courage, prestige, lineage, identity, and historical memory. The ethnographic findings further indicate that traditional riding practices, songs, rituals, food, clothing, ceremonial activities, and community participation collectively contribute to cultural continuity. The qualitative study establishes an important empirical foundation. However, a qualitative description does not directly answer several mathematical questions:

1. How rapidly can cultural knowledge decline if intergenerational transmission weakens?
2. How does participation influence social cohesion?
3. How strongly does historical memory contribute to cultural continuity?
4. What happens when modernization pressure increases?
5. What level of youth participation is required for long-term sustainability?
6. How can cultural sustainability be represented by a measurable index?
7. Under what conditions does a cultural system approach a stable equilibrium?

These questions motivate the development of a mathematical model. The principal objective of this paper is therefore to transform the major qualitative dimensions identified in the ethnographic research into a dynamic socio-mathematical system.

2. Source-Based Conceptual Foundation

The ethnographic findings provide the conceptual foundation for translating the Agew Horse Festival into a mathematical cultural-sustainability model. The festival can be understood as a dynamic socio-cultural system in which cultural practices, symbolic meanings, intergenerational learning, historical memory, and social cohesion continuously interact. These dimensions are not independent; changes in one component may strengthen or weaken the others.

2.1 Cultural Practices

The Agew Horse Festival encompasses a diverse range of tangible and intangible cultural practices, including traditional food, clothing, livestock-related activities, rituals, songs, horse riding, ceremonial performances, and communal gatherings. These practices constitute the observable cultural expression of the festival and contribute to the continuity of community identity. For modelling purposes, Cultural Knowledge (KK) can be used to represent the stock of knowledge associated with these practices. Cultural knowledge increases through participation, teaching, observation, and repeated performance, while it may decline when traditional practices are abandoned or replaced by external cultural influences.

$$dK/dt = \alpha KPT - \beta KMK$$

where P represents cultural participation, T represents intergenerational transmission, and M represents modernization or external cultural pressure.

2.2 Symbolic Significance

The horse occupies a central symbolic position within the festival. It represents values such as strength, honour, bravery, discipline, loyalty, social responsibility, historical pride, and community identity. Consequently, the horse is not merely an element of the festival's physical activities but also a carrier of collective cultural meaning. This dimension can be represented by a Symbolic Value Variable (VV), which reflects the degree to which the horse and associated practices retain their cultural significance within the community.



$$dV/dt = \alpha VKP - \beta VMV$$

A higher value of V indicates stronger symbolic attachment to the festival and its associated cultural traditions.

2.3 Intergenerational Learning

The festival provides an important mechanism for the transmission of knowledge from elders and experienced riders to younger generations. Riding skills, ceremonial practices, ethical values, traditional knowledge, and appropriate social behaviour are transmitted through observation, participation, demonstration, and direct experience. Thus, the festival can be conceptualized as an experiential “school of tradition.”

The state variable Intergenerational Transmission (T) can be expressed as:

$$dT/dt = \alpha TEK - \beta TMT$$

where E represents interaction between generations. Stronger elder–youth interaction and greater cultural knowledge increase the capacity for transmission, whereas modernization and declining participation may weaken it.

2.4 Historical Memory

Historical memory connects contemporary participants with the experiences of previous generations. In the Agew context, memories associated with historical resistance, collective experiences, ancestral traditions, and community identity contribute to the meaning attached to the festival. The corresponding variable Historical Memory (H) represents the persistence and transmission of historically significant cultural narratives:

$$dH/dt = \alpha HKT - \beta HMH$$

The formulation reflects the assumption that historical memory is reinforced when cultural knowledge is actively transmitted across generations and weakened when traditional narratives and practices lose relevance.

2.5 Social Cohesion

The festival creates a social environment in which elders, youth, riders, families, community leaders, officials, visitors, and other participants interact. These interactions facilitate social relationships, collective identity, mutual recognition, and community solidarity.

The resulting Social Cohesion (SS) can therefore be represented as:

$$dS/dt = \alpha SPV - \beta SMS$$

Here, participation and shared symbolic meaning contribute positively to social cohesion, while external pressures and declining communal involvement may reduce it.

2.6 Integrated Conceptual Structure

The five dimensions can therefore be represented as an interconnected system:

K, T, H, S, P

with symbolic significance represented by:

V

and external pressure represented by:

M

The conceptual relationships can be summarized as:

$$P \rightarrow K \rightarrow T \rightarrow H$$

$$P + V \rightarrow S$$

$$K + T + H + S + V \rightarrow \text{Cultural Sustainability}$$

while modernization, globalization, commercialization, and declining participation operate as potential attenuation mechanisms:

$$M \rightarrow (K, T, H, S, V) \downarrow$$

Thus, the mathematical framework does not treat the Agew Horse Festival simply as an annual event. Instead, it represents the festival as a dynamic cultural ecosystem, where knowledge, participation, symbolic meaning, historical memory, intergenerational transmission, and social cohesion jointly determine its capacity for cultural continuity and long-term sustainability.

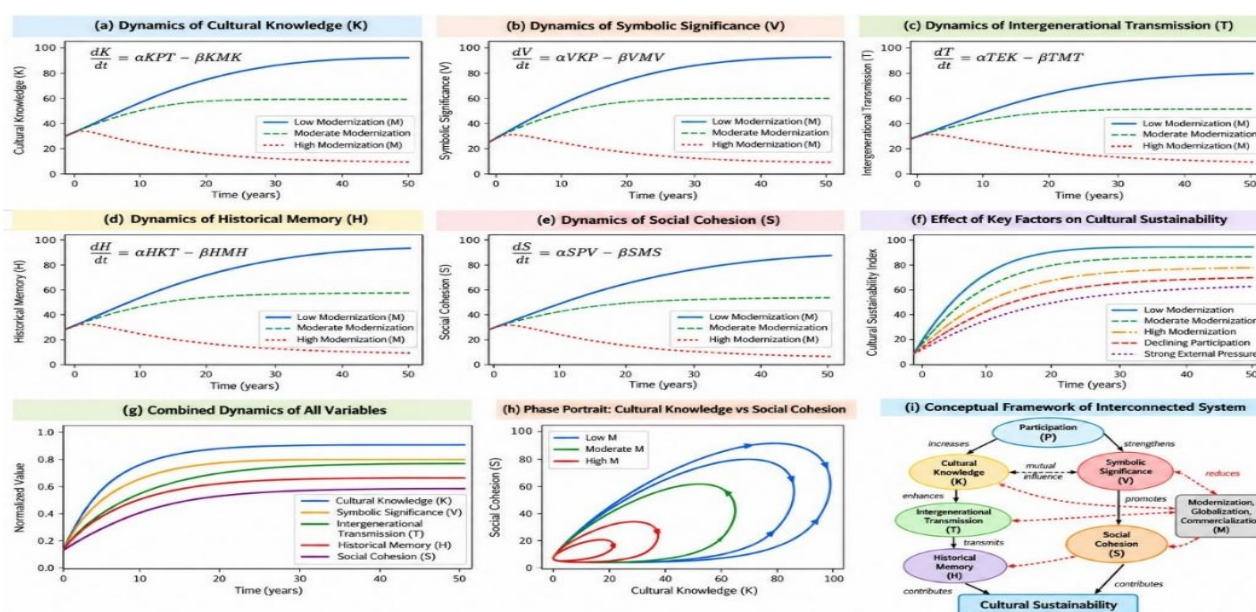
3. Research Gap

The existing ethnographic study provides substantial qualitative evidence concerning the social and cultural dimensions of the Agew Horse Festival. However, the study does not formulate a quantitative dynamical system describing the interaction among cultural knowledge, participation, social cohesion, historical memory and intergenerational transmission.

Consequently, the following research gap is identified:

There is a need for a quantitative socio-mathematical framework capable of representing cultural transmission and sustainability as a dynamic system rather than as a collection of independent qualitative themes.

The proposed model addresses this gap without replacing the ethnographic evidence.



4. Research Objectives

The proposed mathematical study has six objectives:

1. To formulate a dynamical model of cultural continuity.



2. To mathematically represent intergenerational transmission.
3. To incorporate social cohesion and community participation.
4. To model historical memory and symbolic cultural value.
5. To investigate the effects of external pressures such as modernization.
6. To construct a Cultural Sustainability Index for comparative analysis.

5. Mathematical Variables

Let time be represented by

$$t \geq 0.$$

Define the following normalized state variables:

Symbol	Variable	Interpretation
C(t)	Cultural knowledge	Level of traditional cultural knowledge
T(t)	Transmission	Intergenerational transmission intensity
S(t)	Social cohesion	Strength of communal relationships
H(t)	Historical memory	Collective retention of historical narratives
P(t)	Participation	Community participation in festival activities
V(t)	Symbolic value	Cultural significance attached to horse and festival
M(t)	Modernization pressure	External pressure affecting traditional practices

All principal cultural variables may be normalized as

$$0 \leq C, T, S, H, P, V \leq 1.$$

Here:

0 = very weak condition,

and

1 = very strong condition.

6. Basic Cultural Transmission Model

A first-order model for cultural knowledge can be written as

$$dC/dt = \alpha TP + \beta H + \gamma V - \mu C - \delta MC.$$

where

- α = contribution of intergenerational transmission,
- β = contribution of historical memory,
- γ = contribution of symbolic value,
- μ = natural cultural-loss coefficient,



- δ = modernization sensitivity.

The first positive term αTP indicates that cultural knowledge increases when transmission and participation occur simultaneously. This is consistent with the ethnographic finding that elders and experienced riders teach younger generations through participation and practice.

7. Intergenerational Transmission Equation

Let $T(t)$ represent the effectiveness of transmission from elders and experienced cultural practitioners to younger generations.

A nonlinear model is

$$dT/dt = \eta EC(1-T) - \mu TT - \delta TMT,$$

where E represents the effective availability of elders or cultural mentors.

The term $EC(1-T)$ is a saturation mechanism.

When transmission is already high, the factor $1-T$ becomes small.

This prevents unlimited growth of T .

The model therefore follows the intuitive principle:

Transmission growth $\propto$ available knowledge $\times$ mentoring capacity $\times$ remaining transmission capacity.

8. Social Cohesion Model

Social cohesion can be represented as

$$dS/dt = \lambda_1 P + \lambda_2 C + \lambda_3 T + \lambda_4 V - \mu SS - \delta SMS.$$

The model assumes that participation, shared knowledge, intergenerational interaction and symbolic attachment can contribute to cohesion.

The empirical study reports that the festival creates opportunities for elders, youth, families, officials and visitors to participate collectively and that these activities strengthen communal bonds.

9. Historical Memory Model

Let $H(t)$ denote the normalized strength of historical memory.

We propose

$$dH/dt = p_1 C + p_2 V + p_3 P - \mu HH - \delta HMH.$$

The three positive components represent:

$$C \rightarrow H,$$

because cultural knowledge contains historical narratives;

$$V \rightarrow H,$$

because symbolic practices reinforce historical meanings;

and

$P \rightarrow H$,

because active participation provides opportunities for memory to be enacted.

The source study specifically describes songs, stories and rituals as mechanisms through which historical memory is transmitted.

10. Participation Dynamics

Community participation can be modelled using

$$dP/dt = rPS(1-P) + \theta C + \phi V - \mu PP - \delta PMP.$$

Here,

$rPS(1-P)$

represents socially induced participation.

When cohesion is high, participation can increase.

The saturation term $1-P$ ensures

$P \leq 1$.

Participation also depends on cultural knowledge and symbolic attachment.

11. Symbolic Value Model

Symbolic value is a particularly important component of the Agew system because the original study reports that horses are regarded as carriers of identity, honour, lineage and cultural heritage.

We propose

$$dV/dt = a_1C + a_2H + a_3P - \mu VV - \delta VMV.$$

Thus,

$C, H, P \rightarrow V$.

The model represents a feedback loop:

Culture $\rightarrow$ Symbolic Value $\rightarrow$ Participation $\rightarrow$ Cultural Continuity.

12. Complete Socio-Mathematical System

The proposed model can therefore be expressed as

$$dC/dt = \alpha TP + \beta H + \gamma V - \mu C - \delta MC,$$

$$dT/dt = \eta EC(1-T) - \mu TT - \delta TMT,$$

$$dS/dt = \lambda_1 P + \lambda_2 C + \lambda_3 T + \lambda_4 V - \mu SS - \delta SMS,$$

$$dH/dt = \rho_1 C + \rho_2 V + \rho_3 P - \mu HH - \delta HMH,$$



$$dP/dt = rPS(1-P) + \theta C + \phi V - \mu PP - \delta PMP,$$

$$dV/dt = a_1C + a_2H + a_3P - \mu VV - \delta VMV.$$

This represents a six-dimensional nonlinear socio-cultural dynamical system.

13. Causal Structure of the Model

The model can be summarized as

$$C, T, H, V, P, S \leftrightarrow \text{Cultural Sustainability.}$$

The principal positive feedback loop is

$$C \rightarrow T \rightarrow S \rightarrow P \rightarrow C.$$

A second loop is

$$C \rightarrow H \rightarrow V \rightarrow P \rightarrow C.$$

Thus, cultural sustainability is not represented as a single variable but as the consequence of multiple interacting mechanisms.

14. Modernization Pressure

The variable $M(t)$ represents external pressure.

For a simple model,

$$M(t) = M_0 + \kappa t.$$

Alternatively, periodic external pressure may be represented by

$$M(t) = M_0 + A \sin(\omega t).$$

A more realistic bounded representation is

$$M(t) = 1 / (1 + e^{-k(t-t_0)})$$

This allows modernization pressure to increase gradually from a low level to a saturation level. The original study explicitly identifies modernization, tourism and external pressures as factors that may affect the festival while noting that its social and symbolic core persists.

15. Cultural Sustainability Index

A composite index can be introduced as

$$CSI(t) = w_C C(t) + w_T T(t) + w_S S(t) + w_H H(t) + w_P P(t) + w_V V(t),$$

where

$$w_C + w_T + w_S + w_H + w_P + w_V = 1.$$

For equal weighting,

$$w_i = 1/6.$$



Hence,

$$CSI(t) = (C+T+S+H+P+V)/6$$

with

$$0 \leq CSI \leq 1.$$

For presentation purposes, the index may be expressed as

$$CSI100 = 100CSI.$$

This is a proposed mathematical indicator and not an index calculated from the original ethnographic study.

16. Fuzzy Extension of the Model

Because concepts such as "strong cultural identity," "high social cohesion," and "weak intergenerational transmission" are inherently linguistic, a fuzzy mathematical extension is appropriate.

Define linguistic variables:

$$C = \{\text{Low, Medium, High}\},$$

$$T = \{\text{Low, Medium, High}\},$$

$$S = \{\text{Weak, Moderate, Strong}\},$$

$$H = \{\text{Weak, Moderate, Strong}\},$$

$$P = \{\text{Low, Moderate, High}\}.$$

For example, a triangular membership function for High Cultural Knowledge may be

$$\mu_{\text{High}}(C) = \{0, C < a, (C - a)/(b - a), a \leq C < b, 1, C \geq b.\}$$

A fuzzy rule could be:

IF cultural knowledge is High AND intergenerational transmission is High AND participation is High, THEN cultural sustainability is Very High.

Another rule could be:

IF transmission is Low AND modernization pressure is High, THEN cultural sustainability is Low.

This provides a bridge between ethnographic linguistic evidence and mathematical computation.

17. Equilibrium Analysis

At equilibrium,

$$dC/dt = dT/dt = dS/dt = dH/dt = dP/dt = dV/dt = 0.$$

Let

$$X^* = (C^*, T^*, S^*, H^*, P^*, V^*).$$

Then



$$F(X^*, M) = 0.$$

The equilibrium represents a cultural state in which gains and losses balance.

Three conceptual regimes can emerge.

Regime I: Cultural decline

$$CSI(t) \rightarrow 0.$$

This may correspond to weak participation, weak transmission and high cultural-loss pressure.

Regime II: Cultural persistence

$$CSI(t) \rightarrow CSI^*, 0 < CSI^* < 1.$$

The cultural system remains active but does not reach its maximum theoretical state.

Regime III: Cultural reinforcement

$$CSI(t) \rightarrow 1.$$

This corresponds mathematically to strong transmission, participation, symbolic attachment, historical memory and social cohesion. These are mathematical scenarios, not empirical classifications of the Agew community.

18. Stability Analysis

The Jacobian matrix is

$$J = [\partial F_1 / \partial C \cdots \partial F_1 / \partial V : \vdots : \partial F_6 / \partial C \cdots \partial F_6 / \partial V].$$

At equilibrium,

$$J^* = J(X^*).$$

If all eigenvalues satisfy $\text{Re}(\lambda_i) < 0$, then the equilibrium is locally asymptotically stable.

If at least one eigenvalue satisfies

$\text{Re}(\lambda_i) > 0$, the equilibrium is locally unstable.

This provides a rigorous mathematical mechanism for identifying conditions under which cultural sustainability can persist or deteriorate.

19. Sensitivity Analysis

The sensitivity of the sustainability index with respect to parameter θ can be defined as

$$S_\theta = (\partial CSI / \partial \theta) (\theta / CSI).$$

Parameters may include

$$\alpha, \beta, \gamma, \eta, \lambda_i, \rho_i, rP, \delta_i, \mu_i.$$

For example,

$$S_\alpha = (\partial CSI / \partial \alpha) (\alpha / CSI)$$

measures the relative effect of cultural-transmission effectiveness on sustainability. This allows future empirical researchers to identify which mechanisms have the largest mathematical influence on the system.

20. Scenario Analysis

Four scenarios can be simulated.

Scenario	Transmission	Participation	Modernization	Expected model behaviour
A	High	High	Low	Strong cultural reinforcement
B	Moderate	Moderate	Moderate	Cultural persistence
C	Low	Low	High	Cultural deterioration
D	High	High	High	Potential transformation with partial preservation

These are model scenarios, not empirical conclusions about the Agew Festival.

21. Numerical Solution

The system can be solved numerically using the fourth-order Runge–Kutta method.

$\text{Ford}X/\text{dt}=F(t,X),$

the RK4 scheme is

$K1=F(t_n,X_n),$

$K2=F(t_n+0.5h,X_n+0.5hK1),$

$K3=F(t_n+0.5h,X_n+0.5hK2),$

$K4=F(t_n+h,X_n+hK3),$

and

$X_{n+1}=X_n+(h/6)(K1+2K2+2K3+K4).$

This permits simulation over multiple festival cycles or generations.

22. Proposed Data Structure for Empirical Calibration

The mathematical framework can subsequently be calibrated using variables such as:

Data variable	Possible measurement
Festival participation	Number of participants
Youth involvement	Percentage of youth participants
Elder mentoring	Number/frequency of mentoring interactions
Horse-riding practice	Frequency of traditional riding
Cultural knowledge	Questionnaire score
Historical knowledge	Historical-memory score
Social cohesion	Community-cohesion scale
Symbolic attachment	Likert-scale responses
Festival membership	Annual membership
Attendance	Annual attendance



Cultural activities	Number of traditional activities
External pressure	Composite modernization indicator

The original research itself reports a final qualitative sample consisting of 14 interviews and two FGDs—one with eight youth participants and one with twelve elders. Therefore, these observations can serve as the conceptual foundation, while a future quantitative survey would be needed to estimate the numerical parameters.

23. Management and Policy Modelling Dimension

The model can also be interpreted as a cultural-management system.

Let $G(t)$ represents institutional support.

Then the cultural equation can be expanded to

$$dC/dt = \alpha TP + \beta H + \gamma V + \xi G - \mu C - \delta MC.$$

Similarly,

$$dT/dt = \eta EC(1-T) + \zeta G - \mu TT - \delta TMT.$$

Institutional support can represent:

- cultural documentation;
- educational programmes;
- youth mentoring;
- heritage preservation;
- financial support;
- organizational capacity;
- legal protection;
- tourism management.

The source study itself recommends institutional support, legal protection, funding, capacity building, structured mentorship, and preservation of traditional riding, attire, music, food and rituals.

24. Optimization Model

A management optimization problem can be introduced.

Suppose available intervention resources are

$$x_1, x_2, \dots, x_n.$$

The objective is to maximize

$$CSI(T)$$

subject to



$$\sum_{i=1}^n c_i x_i \leq B,$$

where

- c_i = cost of intervention i ,
- B = available budget.

Thus,

$$\text{Max}(x_1, \dots, x_n) \text{CSI}(T)$$

subject to resource and feasibility constraints.

Possible intervention variables include

x_1 =youth training,

x_2 =cultural documentation,

x_3 =elder mentorship,

x_4 =festival infrastructure,

x_5 =heritage promotion.

This transforms the model from a descriptive mathematical system into a decision-support framework.

25. Interpretation of the Mathematical Model

The proposed framework suggests that cultural sustainability should not be treated as a single isolated phenomenon.

Instead,

$$\text{Cultural Sustainability} = f(C, T, S, H, P, V, M, G)$$

where cultural knowledge, transmission, social cohesion, historical memory, participation, symbolic value, modernization and institutional support interact.

The most important structural feature is the feedback mechanism.

For example,

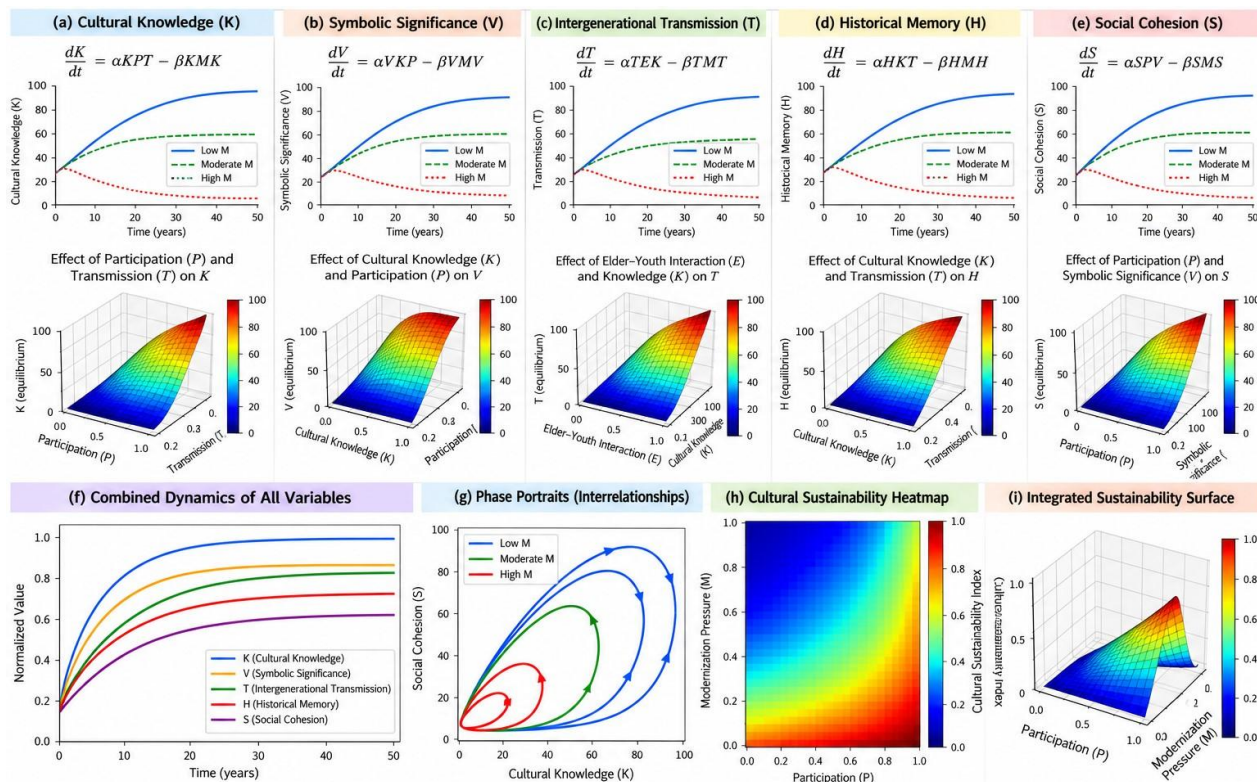
$$T \uparrow \Rightarrow C \uparrow \Rightarrow H \uparrow \Rightarrow V \uparrow \Rightarrow P \uparrow \Rightarrow S \uparrow \Rightarrow T \uparrow.$$

This represents a positive cultural feedback loop.

Conversely,

$$M \uparrow \Rightarrow C \downarrow \Rightarrow T \downarrow \Rightarrow P \downarrow \Rightarrow S \downarrow,$$

which represents a potential negative feedback pathway.



26. DISCUSSIONS

The proposed mathematical framework extends the qualitative findings of the ethnographic study by representing the festival as a dynamic social system. The original study found that the festival is not limited to horse riding. It incorporates cultural practices, community identity, historical memory, symbolic meanings and intergenerational learning. From a mathematical perspective, this suggests strong coupling among the variables. The intergenerational-learning mechanism is particularly important because knowledge transmission is not instantaneous. It is a process occurring through repeated interactions between elders and younger participants.

Thus, $dT/dt \neq 0$ is more appropriate than treating transmission as a constant.

Similarly, social cohesion depends on participation:

$$S = S(P, C, T, V).$$

Historical memory also changes over time:

$$H = H(t).$$

Consequently, the festival can be interpreted as a nonlinear dynamical socio-cultural system.

27. Novelty of the Proposed Study

The principal methodological contribution is the integration of: Ethnography + Dynamical Systems + Fuzzy Mathematics + Optimization into a single framework.

The paper therefore provides a pathway from qualitative evidence to quantitative modelling: Ethnographic Observation $\downarrow$ Cultural Variables $\downarrow$ Mathematical Equations $\downarrow$ Numerical Simulation $\downarrow$ Sensitivity Analysis $\downarrow$ Cultural Sustainability



Index\text{Cultural Sustainability Index} \downarrow \text{Management Decision Support}.\text{Management Decision Support}.

28. LIMITATIONS

The original source is primarily ethnographic and qualitative. Therefore, numerical parameter values such as $\alpha, \beta, \gamma, \eta, \mu, \delta$ cannot legitimately be estimated from the reported findings alone. The proposed equations should therefore be regarded as a conceptual mathematical model requiring empirical calibration. Future research should collect longitudinal quantitative data before making numerical predictions.

Other limitations include:

1. cultural variables may not be perfectly measurable;
2. social cohesion can be multidimensional;
3. symbolic meaning may vary among participants;
4. modernization pressure is difficult to represent with a single variable;
5. cultural systems may exhibit discontinuous changes;
6. external political, economic and environmental factors may influence participation.

29. Future Research

Future studies can extend the model in several directions.

29.1 Agent-based modelling

Represent {elders, youth, riders, families, leaders} as interacting agents.

29.2 Network modelling

Define a cultural network $G=(V,E)$ where individuals are nodes and cultural-learning relationships are edges.

29.3 Stochastic modelling

Introduce random disturbances:

$$dX = F(X, t)dt + \Sigma(X, t)dW_t.$$

29.4 Fuzzy-stochastic modelling

Combine linguistic uncertainty and random variability:

$$dX \sim F \sim (X \sim, t)dt + \Sigma dW_t.$$

29.5 Machine learning

Historical festival data could be used to estimate

$$CSI_{t+1} = f(CSI_t, T_t, St, H_t, Pt, V_t, Mt).$$

29.6 Optimal control

Define a control vector

$$u(t)=(u_1,u_2,\dots,u_n)$$

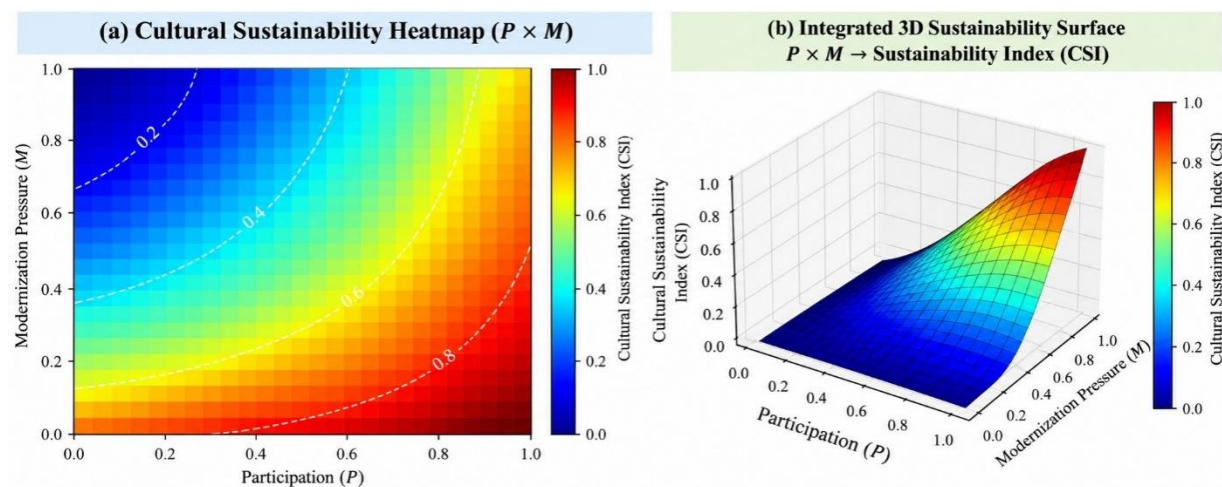
and solve

$$\max_{\|u\|} \int_0^T [CSI(t) - \lambda \|u(t)\|^2] dt. \quad \max_u \int_0^T \left[CSI(t) - \lambda \|u(t)\|^2 \right] dt.$$

This would provide a mathematically rigorous heritage-management framework.

30. CONCLUSIONS

This paper develops a socio-mathematical framework for analysing the cultural sustainability of the Agew Horse Festival. The model is constructed from the major dimensions documented in the underlying ethnographic research: cultural practices, symbolic meaning, intergenerational learning, historical memory, community participation and social cohesion. The source study characterizes the festival as a living institution through which cultural knowledge, skills and values are transmitted across generations. The proposed six-variable nonlinear dynamical system provides a mathematical representation of these interactions: (C, T, S, H, P, V) . The introduction of modernization pressure MM and institutional support GG allows the model to investigate external influences. The proposed Cultural Sustainability Index, $CSI = 0.16(C+T+S+H+P+V)$ provides a potential quantitative indicator, while fuzzy logic, stochastic processes, optimization and agent-based approaches offer pathways for future development. The central mathematical proposition is that cultural heritage behaves as an interconnected dynamic system rather than as a static collection of traditions. Sustainable cultural continuity depends on the interaction between knowledge, transmission, participation, memory, symbolic value and social cohesion. Thus, the study establishes a potential bridge between social anthropology and mathematical modelling, providing a framework that can subsequently be tested using longitudinal empirical data.



(a) Cultural Sustainability Heatmap

$$P \times M \rightarrow CSI$$

- X-axis: Cultural Participation P
- Y-axis: Modernization Pressure M
- Colour scale: Cultural Sustainability Index (CSI), 0–1
- Contours shown at $CSI = 0.2, 0.4, 0.6$ and 0.8
- Shows the interaction between participation and modernization pressure.



(b) Integrated 3D Sustainability Surface

(P, M) → CSI

- X-axis: Modernization Pressure M
- Y-axis: Cultural Participation P
- Z-axis: Cultural Sustainability Index
- Includes surface mesh and corresponding CSI colour scale.

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