Software Impacts 19 (2024) 100627

Contents lists available at ScienceDirect

Software Impacts

journal homepage: www.journals.elsevier.com/software-impacts

Original software publication

Sahelian transhumance simulator (STS)

Cheick Amed Diloma Gabriel Traore [a,e,1,*], Etienne Delay [c,e], Djibril Diop [b], Alassane Bah [d,e]

[a] University Cheikh Anta Diop, Faculty of Science and Technic, Department of Mathematics and Computer Science, Dakar, Senegal
[b] Institut Sénégalais de Recherches Agricoles (ISRA), Bureau Analyses Macroéconomiques (BAME), Dakar, Senegal
[c] CIRAD UMR SENS, Montpellier, France
[d] University Cheikh Anta Diop, Département de Génie Informatique, Ecole Supérieure Polytechnique, B.P.15915, Dakar-Fann, Senegal
[e] University Cheikh Anta Diop, UMMISCO, Dakar, Senegal

ARTICLE INFO

Keywords:
Multi-agent
Agent based modeling
Distributed artificial intelligence
Sahel
Pastoral mobility software

ABSTRACT

Sahelian transhumance is a seasonal movement of herds based on strategies. These strategies are based on environmental and socio-economic factors. However, it is empirically difficult to establish the influence of each factor on the spatio-temporal distribution of herds. This paper presents a microsimulation software Sahelian transhumance simulator (STS). STS determines the spatio-temporal influence of each factor on herd movements. It also proposes scenarios for developing and securing the Sahelian pastoral space.

Code metadata

Current code version	v1.0
Permanent link to code/repository used for this code version	https://github.com/SoftwareImpacts/SIMPAC-2024-9
Permanent link to Reproducible Capsule	https://codeocean.com/capsule/2352311/tree/v1
Legal Code License	MIT License
Code versioning system used	comses
Software code languages, tools, and services used	Gama, python, numpy, matplotlib, matplotlib-inline, pandas, seaborn
Compilation requirements, operating environments & dependencies	conda 23.1.0, jupyter 1.0.0, python
If available Link to developer documentation/manual	https://github.com/cheickamed/transhumance_simpact.git
Support email for questions	cheickameddiloma.traore@ucad.edu.sn

1. Introduction

Transhumance is a seasonal pastoral mobility covering hundreds of kilometers. During transhumance, the livestock is moved from their terroir of origin to one or more host terroirs [1]. These movements depend on strategies based on vegetation quality, water outlets, veterinarian centers, markets, perturbators (robbers, cattle thieves), and the transhumant's socio-economic network (people helping the transhumant) [2,3]. However, it is empirically difficult to establish the influence of each movement factor on the spatio-temporal distribution of herds. To fill this gap, this paper performs microsimulations of herd movement strategies.

Microsimulation is the modeling of a subset of a phenomenon's strategies. This technique is used to analyze or test the hypotheses of the studied phenomenon by computer simulations [4,5]. For each hypothesis, the modeler runs one or more microsimulations. The modeling results are then compared with empirical data or results to draw conclusions applicable to the real world [4,6].

In this paper, we present Sahelian transhumance simulator (STS). STS is a set of microsimulations with two purposes. Firstly, to determine the spatio-temporal influence of each movement factor on the spatio-temporal distribution of herds. Secondly, it is a decision-making tool for politicians, NGOs, and security agents (gendarmes, water and forestry officers). Ultimately, it will tell: (1) where it would be efficient to install boreholes, markets, veterinary centers, and prohibited areas; and (2) how to secure the movements of transhumants. To achieve these goals, microsimulations conceptualize and simulate transhumant

The code (and data) in this article has been certified as Reproducible by Code Ocean: (https://codeocean.com/). More information on the Reproducibility Badge Initiative is available at https://www.elsevier.com/physical-sciences-and-engineering/computer-science/journals.

* Corresponding author at: University Cheikh Anta Diop, Faculty of Science and Technic, Department of Mathematics and Computer Science, Dakar, Senegal.
E-mail address: cheickameddiloma.traore@ucad.edu.sn (C.A.D.G. Traore).
1 Réseau des Enseignants chercheurs et Chercheurs en Informatique du Faso (RECIF).

https://doi.org/10.1016/j.simpa.2024.100627
Received 18 February 2024; Accepted 19 February 2024

Table 1
Input parameters.

Description	Value	Reference
Number of herds	200	Empirical
Rate of herds vaccinated	70%	[9]
Herd speed	$\mathcal{N}(15.5, 2)$ km day^{-1} (Outward phase)	[10,11]
	$\mathcal{N}(17.5, 2)$ km day^{-1} (Return phase)	[10,11]
Number of perturbators	20	Empirical
Rate of mobile perturbators	35%	Empirical
Rainfall	$r \in \{good, average, low\}$	[12]

herd movement strategies. These microsimulations are based on multi-agent systems. In addition, herd movement strategies consider a single movement factor: vegetation quality, water outlets (boreholes, antennas, ponds), veterinarians, markets, perturbators, and socio-economic network.

2. Description and features

In STS, herd movements are carried out on a six-hour time step. Indeed, transhumant herds have two daily movement phases of six hours each. The simulator has a time horizon of 10 months to consider the duration of the outward and return phases of transhumance.

2.1. Input data

STS is a simulator incorporating data such as rainfall, a map of the study area, animal characteristics, and an approximate number of perturbators (Table 1). The study area map contains the locations of the herds' terroir of origin and host terroir. In addition, it contains the locations of water points, veterinary centers, markets, the spatial distribution of vegetation, land use such as built-up areas, and the prohibited areas for herds location (Fig. 1). These data are georeferenced in geographic information systems as shapefiles. After the input data loading, the simulation space is partitioned into grid cells [7,8]. For example, to use STS in Senegal, the cells were 9.6 km × 9.6 km with the topology of Moore. This cell size is close to the average daily distance covered by the herds.

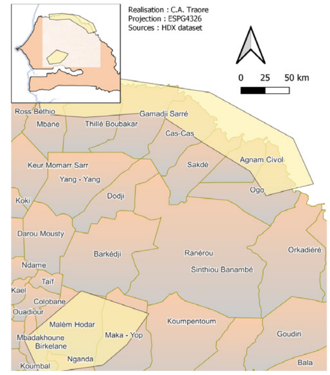
2.2. Extensive parameter control

An STS user can control the parameters of Table 1, the locations of the herds' origin and host terroirs, and the size of the grid cells. In addition, a user can control the experiment's number of replications and exploration scenarios, allowing exhaustive exploration of different scenarios.

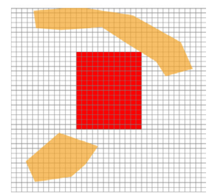
2.3. Exploration strategies

Each microsimulation of STS is an exploration strategy (Table 2). Each strategy is based on a single movement factor and prohibited areas for herds (Fig. 2). A movement factor can be vegetation quality, water outlets, veterinarians, markets, perturbators, and the transhumant's socio-economic network. When a herd is in a prohibited area, it implements a process to leave it.

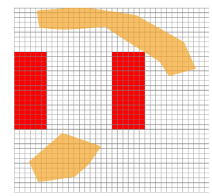
There is no scenario on vegetation quantity, as the design of STS assumes that there is sufficient vegetation and water on the rangelands. Indeed, transhumants gather daily information before determining the herd's path. As a result, they will not choose a path where there are not enough pastoral resources.



(a) The terroir of origin of the herds is the top orange polygon and the host terroir is the bottom orange polygon



(b) One prohibited area in red



(c) Two prohibited areas in red

Fig. 1. Example of study area in Senegal and grid of simulation space with prohibited areas for herds.

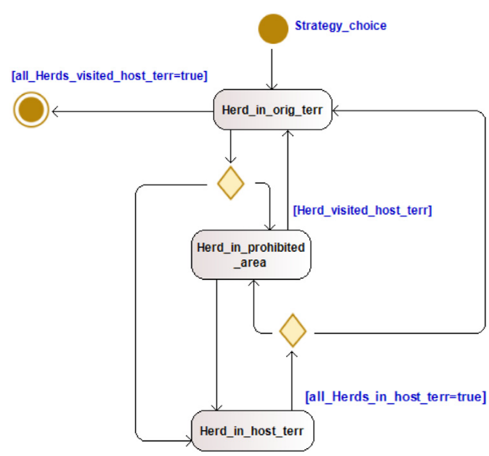


Fig. 2. Activity diagram of transhumant herd movements.

3. Software function

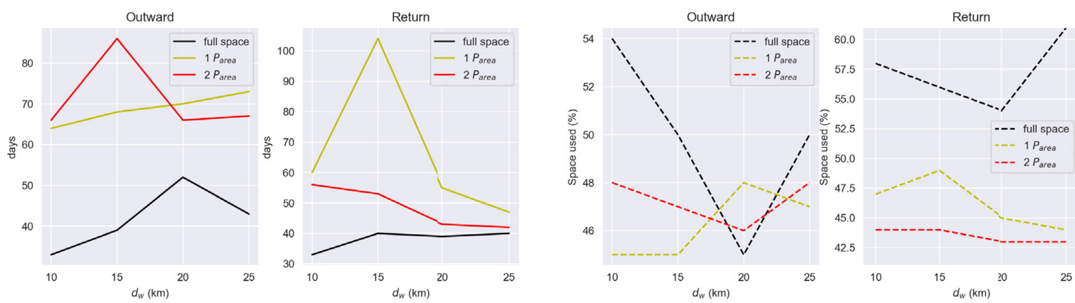
STS simulates transhumant herd movements based on Table 2 strategies in the Gama multi-agent simulation platform. During Gama simulations, we save:

- The average duration of the outward and return phases of transhumance and the average proportion of space used by herds during their movements (Fig. 3);
- Herd locations and spatial distribution, to determine: (1) the paths used by herds and the conditions in which transhumance corridors emerge; (2) the influence of prohibited areas on the duration of transhumance and the proportion of space used by herds (Fig. 4). The location of prohibited areas can influence the spatial distribution of herds because they must avoid these areas.

In addition, analysis of the saved data is used both to compare the results of the exploration scenarios with each other and with reality

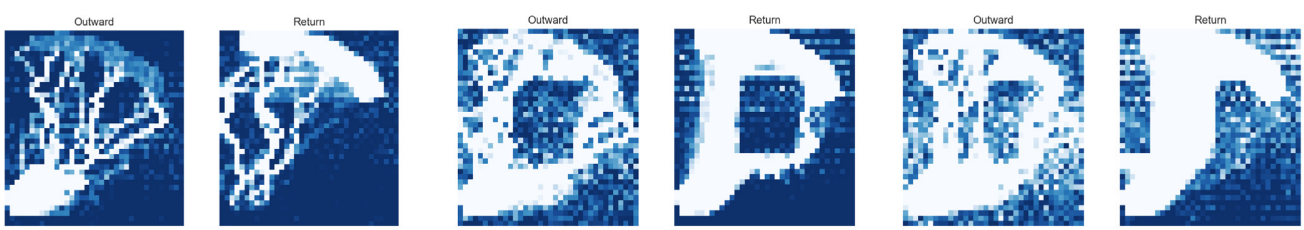
Table 2
Exploration strategies.

Herd movement strategies based on	Parameter	Reference
Vegetation quality	$d_{veg} \in [12, 26]$ km (distance between herd and vegetation)	[10]
Water outlets	$d_w \in [10, 25]$ km (distance between herd water outlets)	[13]
Veterinarians	$d_v \in [14, 26]$ km (distance between herd and veterinarians) $j_v \in [\![0, 6]\!]$ (length of stay in days)	
Markets	$d_m \in [1, 25]$ km (distance between herd and markets) $j_v \in [\![1, 14]\!]$ (time for animal saling)	[14] [15]
Perturbators	$d_p \in [0, 19]$ km (distance between herd and perturbator) $j_p \in [\![0, 4]\!]$ (number of waiting days)	
Socio-economic network	$j_{rs} \in [\![2, 6]\!]$ (length of stay in days) $N'_{rs} \in [\![5, 11]\!]$ (number of elements)	[11] Empirical



(a) Average duration (b) Average proportion of space used

Fig. 3. Average duration of transhumance phases and proportion of space used by herds (in Senegal) during their movements based on water outlets. P_{area}: Prohibited area; d_w: maximum distance between herd location and water outlet.



(a) Full space (b) One prohibited area (c) Two prohibited areas

Fig. 4. Spatial distribution of herds (in Senegal) based on water outlets and prohibited areas. In white, traces of the herds. $d_w = 20$ km, d_w: maximum distance between herd location and water outlet.

and to forecast issues such as the development of pastoral areas and optimization of the carbon footprint of transhumant herds.

4. Impact overview

STS is a set of microsimulations. Each microsimulation is designed on the macroscopic spatial scale of the Sahel and simulated in a more restricted study area (northern Senegal, for example). This approach guarantees that the software is generic and can be used anywhere in the Sahel. In addition, STS can be used to determine the spatio-temporal distribution of herds and the conditions under which transhumance corridors emerge. As a result, STS is valuable for experimental validation, reducing the time and resources traditionally required for empirical studies. In the case of the pastoral zone of northern Senegal, STS was used to confirm or establish (without going into the field) that:

- The socio-economic network of the transhumant was the factor that allowed a significant spatiotemporal distribution of herds;
- Water outlets allowed a significant spatial distribution of herds. Transhumance corridors generally emerge when herd movements are based on water outlets;
- Veterinarian centers, markets, and perturbators have no significant spatial impact on herd movements. However, veterinary centers can have a significant temporal impact on transhumance. Due to waiting times of several days at a Veterinarian;
- Prohibited areas may be flora or fauna reserves. These areas play their role if they are located where vegetation is of average or lower quality.

In addition, these results obtained in Senegal inspired the design of the model of Traore et al. in [16]. In this model, herds move according to the social network of transhumants and veterinary centers. This model studies the impact of transhumant herds on vegetation depending on rainfall and the proportion of grazeable vegetation.

Beyond the academic and research fields, STS can be used by politicians or NGOs to determine where to build a livestock market, veterinarian center, or borehole to distribute herds more widely in space. Indeed, a wide spatial distribution of herds enables vegetation to sequester greenhouse gases from herds more effectively. Furthermore, markets and veterinarian centers that are too close or too far apart are of no real interest to transhumants and local populations.

Gendarmes can use STS to anticipate the movements of transhumants in a prohibited area. In Sahelian countries facing attacks by armed terrorist groups, a prohibited area can be considered a place controlled by terrorists. If a transhumant goes into such an area, either his animals are likely to die, or he is tied to terrorists.

Water and forestry officers can use STS to determine the location of protected areas that are prohibited to herds.

5. Limitation

STS has two main limitations. The size of the grid cells can influence the results of statistical analysis when the herds only touch the cells at the edges of the prohibited areas. For small grid cells ($3\ \text{km}\times 3\ \text{km}$), the impact of herds on the edges of prohibited areas will be insignificant. On the other hand, the impact of herds on the edges will be significant for large cells ($10\ \text{km}\times 10\ \text{km}$).

The second limitation of STS is that herd movement strategies do not consider all factors simultaneously. This limitation limits the numerical reproduction of Sahelian transhumance. Nevertheless, the methodology and concepts developed in this research allow us to carry out prospective studies. Moreover, the results could be used to design holistic models of Sahelian transhumance.

Funding

This paper has been produced with the assistance of the European Union. Its content is the sole responsibility of (name of the beneficiary or beneficiaries) and can in no way be taken to reflect the position of the European Union.

CRediT authorship contribution statement

Cheick Amed Diloma Gabriel Traore: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing. **Etienne Delay:** Funding acquisition, Supervision. **Djibril Diop:** Investigation, Project administration. **Alassane Bah:** Project administration, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Andrè Kiema, Ghislain Bambara Tontibomma, Nouhoun Zampaligrè, Transhumance et gestion des ressources naturelles au Sahel : contraintes et perspectives face aux mutations des systèmes de productions pastorales, VertigO - La Revue Èlectron. En Sci. L'environnement 14 (3) (2015) 16, Publisher: Les èditions en environnements VertigO.

[2] J. McCabe, Cattle Bring Us To Our Enemies: Turkana Ecology, Politics, and Raiding in a Disequilibrium System, University of Michigan Press, Ann Arbor, MI, 2004.

[3] Takuto Sakamoto, Computational research on mobile pastoralism using agent-based modeling and satellite imagery, PLoS One 11 (3) (2016) e0151157.

[4] Franck Varenne, La simulation conéue comme expérience concréte, in: J.P. Mèller (dir.) (Ed.), in: 10èmes Journèes de Rencontres Interdisciplinaires sur Les Systèmes Complexes Naturels Et Artificiels, vol. ENST Editions, Paris, 2003, pp. 299–313.

[5] Franck Varenne, Thèorie, Rèalitè, Modèle. Epistèmologie Des Thèories Et Des Modèles Face Au Rèalisme Dans Les Sciences, Sciences & Philosophie, Matèriologiques (Editions), Paris (France), 2012.

[6] J. Ferber, Les Systèmes Multi-Agents: Vers Une Intelligence Collective, 1995.

[7] Frédéric Amblard, Walter Quattrociocchi, Social networks and spatial distribution, in: Bruce Edmonds, Ruth Meyer (Eds.), Simulating Social Complexity: A Handbook, Springer ed., in: Understanding Complex Systems, Springer, Berlin, Heidelberg, 2013, pp. 401–430.

[8] Mamadou Sanè, Jonathan Vayssières, Myriam Grillot, Alassane Bah, Alexandre Ickowicz, État de l'art de l'approche multi-agents pour modéliser le comportement spatial des troupeaux en systémes d'élevage extensif, in: Mobilitè Pastorale Et Dèveloppement Au Sahel, l'Harmattan ed., in: AGRIS, 2017, Publisher: L'Harmattan.

[9] Brigitte THEBAUD, Résiliences Pastorales Et Agropastorales Au Sahel : Portraits De La Transhumance 2014–2015 Et 2015–2016. (Sénégal, mauritanie, mali, burkina Faso, niger) - Inter-Réseaux, Report, Nordic Consulting Group ,ISRA, CIRAD, Dakar, Sènègal, 2017, p. 50, https://www.inter-reseaux.org/ressource/resiliences-pastorales-et-agropastorales-au-sahel-portraits-de-la-transhumance-2014-2015-et-2015-2016-senegal-mauritanie-mali-burkina-faso-niger/.

[10] Hanne Kirstine Adriansen, Thomas Theis Nielsen, The geography of pastoral mobility: A spatio-temporal analysis of GPS data from Sahelian Senegal, GeoJournal 64 (3) (2005) 177–188.

[11] Abdoulaye Dia, Robin Duponnois, Le pastoralisme en Afrique subsaharienne, in: La Grande Muraille Verte : Capitalisation Des Recherches Et Valorisation Des Savoirs Locaux, in: Synthèses, IRD Editions, Marseille, 2013, pp. 12–31, Code: La Grande Muraille Verte : Capitalisation des recherches et valorisation des savoirs locaux.

[12] A. Bah, I. Tourè, C. Le Page, A. Ickowicz, A.T. Diop, An agent-based model to understand the multiple uses of land and resources around drillings in Sahel, Math. Comput. Modelling 44 (5) (2006) 513–534, URL http://www.sciencedirect.com/science/article/pii/S0895717706000100.

[13] Véronique Ancey, Abdrahmane Wane, Andreas Müller, Daniel André, Grégoire Leclerc, Payer l'eau au Ferlo Stratégies pastorales de gestion communautaire de l'eau, Autrepart n° 46 (2) (2008) 51–66.

[14] Abdrahmane Wane, Véronique Ancey, Ibra Touré, Pastoralisme et recours aux marchés: Cas du Sahel Sénégalais (Ferlo), Cahiers Agric. 19 (1) (2010) 14–20.

[15] Andrea Apolloni, Christian Corniaux, Caroline Coste, Renaud Lancelot, Ibra Tourè, Livestock mobility in west africa and sahel and transboundary animal diseases, in: Moustafa Kardjadj, Adama Diallo, Renaud Lancelot (Eds.), Transboundary Animal Diseases in Sahelian Africa and Connected Regions, Springer ed., Springer International Publishing, Cham, 2019, pp. 31–52.

[16] Cheick Amed Diloma Gabriel Traore, Etienne Delay, Alassane Bah, Djibril Diop, Agent-based modeling of the spatio-temporal distribution of Sahelian transhumant herds, in: Kohei Arai (Ed.), in: Intelligent Systems and Applications, vol. 543, Springer International Publishing, Cham, 2023, pp. 630–645, Series Title: Lecture Notes in Networks and Systems.