SAND2022-15203R

Grey Zone Test Range Social Model

Casey Doyle
Thushara Gunda
Michael Bernard

October 2022

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

ACKNOWLEDGEMENTS

The authors would like to thank the entire DARPA team for their support and funding for this effort: Fotis Barlos, Ashley Calder, Sri Kumar, Anna Skinner, Scott Peeke, and Wade Pulliam.

CONTENTS

ACRONYMS AND DEFINITIONS

Abbreviation	Definition
DYMATICA	DYnamic Multi-Scale Assessment Tool for Integrated Cognitive-behavioral Actions
GZTR	Grey Zone Test Range
SES	Socioeconomic Status
TAZ	Transportation Analysis Zone

1. INTRODUCTION

The Grey Zone Test Range (GZTR) social model operates as a piece of the overall GZTR modeling effort [1]. It works in conjunction with supply models for resources, an electric grid model for power availability, and a traffic model for road congestion, as well as a general controller framework that allows external system effects. The social model functions as an aggregate model where the entire population of the city is divided into groups based on the Transportation Analysis Zones (TAZs), a common geospatial boundary present in all GZTR models. These groups will act as a singular community; each time step the state of the system around them will be assessed and then community will come up with a general plan of action that they will attempt to follow for the day. Additionally, they will track values for their general emotional state and memory about negative impacts in the near past.

2. IMPLEMENTATION

The current modeling framework is informed by DYnamic Multi-Scale Assessment Tool for Integrated Cognitive-behavioral Actions (DYMATICA) [2], incorporating many years of research in psychological theory and application to various problem domains. The simulation is executed in Python.

3. GROUP STRUCTURE

Groups are defined based on member's home TAZ, forming communities that are affected by their local food and fuel availability, traffic patterns, and power situation. The TAZs are predefined for the system and thus the communities are set, there will be no migration into or out of communities throughout the simulation. Each community is roughly the same size, with some allowance for general variation but not enough to affect the social dynamics of the group (i.e., all groups will select behaviors in the same way regardless of variations in their population sizes). Additionally, regardless of the current locations of portions of the group (caused by travel to work, stores, etc.), their behavior will always be dictated by the conditions in their home TAZ. Groups will have both static and dynamic properties, as described in the following subsections.

Note: Much of the high level verification is baked into the equation development, ensuring that there are no runaway effects or permanent problems via the decay processes.

3.1. Static properties

- **Group (TAZ) ID:** Unique identifier for each group
- **Socioeconomic status (SES):** Contains the percentage of poor and non-poor individuals within the group. This makeup will not change due to migration or economic effects throughout the simulation. Groups will be categorized as 'poor', 'non-poor', or 'mixed' based on the percentage of each SES in the TAZ. This categorization will be used to modify the groups actions in certain situations, but the group will still act as a whole once behavior is decided upon with no fragmentation of behaviors within the group.

3.2. Dynamic properties

- **Infrastructure Sentiment:** This is the result of interpreting the current state of the infrastructure with respect to its baseline value. It is meant to represent frustrations that individuals have regarding each infrastructure. There are four of these values, one for each infrastructure, measuring the amount of *negative* sentiment associated with the infrastructure. High values indicate extreme displeasure, while low values indicate contentment or lack of issues.

Each of these values will persist through time as a decay process, such that

$$M_{new} = (M_{prior} + 2D_{current})/3 \tag{1}$$

Where M is the memory value and D is the current sentiment value before memory considerations. All three values are bounded by [0,1]. The current parameters and weightings are chosen for the simplicity of the current value having twice the impact of prior values but can easily be adjusted for stronger/weaker memory effect. For such alterations the weighted averaging sequence above follows the form

$$y(t) = \frac{(A)x(t) + y(t-1))}{A+1} \tag{2}$$

Where x(t) is the current sentiment, y(t) is the memory sentiment, and A is the memory parameter (larger values of A correspond to weaker memory). The scaling of the sentiment of the model can be studied in this case by looking at the recurrence equation for the sequence in the worst-case scenario where x(t) = 1 each timestep. In this case, with the initial condition M(t=0)=0,

$$M(t) = 1 - (A+1)^{-t} \tag{3}$$

which provides a neat, self-bounded system that approaches 1 without ever reaching or exceeding it. In the case of A=2 as is currently used it has a fast ramp up, and within three days of 'worst case' values, the simulation yields a sentiment greater than 95% of the max. Similarly, it readjusts quickly back to low sentiment values when issues are fixed and steady inputs of 0 are provided.

- **General Sentiment**: This is a combination of the four infrastructures into a single frustration/emotional state component. It weights the largest infrastructure sentiment value heaviest to allow for poor general sentiment even if only one infrastructure is severely compromised. It does this by averaging the largest value with the mean of the others, or in this case with four infrastructures weighting the max three times as heavily as the others. For instance, if food had the highest value it would be calculated as

$$M_{new} = \frac{M_{food} + (M_{fuel} + M_{transport} + M_{power})/3}{2} \tag{4}$$

The 'memory' portion of this value is inherited via the calculations of its constituent values; this value is calculated fresh each time step in order to not create a general sentiment that moves more slowly than the individual infrastructure sentiments.

4. UPDATE PROCESS

Each time step, the model will be called to update based on the current state of the system. It will read in the system states, update the relevant dynamic group properties, and output three things to be included in the overall system state: 1) sentiment values for each infrastructure, 2) a generalized sentiment value, and 3) a prioritized list of activities/desires for the day. These will then be sent back to the system state controller as the state of the social system and can be referenced by the individual infrastructure models as needed.

4.1. Reading in system state and determining cues

Before the process of updating emotions and choosing actions begins, the current state of the infrastructure (and other system variables) must be ingested in a way that is distilled down to the relevant information for each TAZ. This can be accomplished in two ways; either these variables are generated by various random number generators meant to mimic the general distribution shape of the real parameters in the absence of companion models, or they can be read in directly from integrated model runs for the various infrastructures in question.

4.2. Evaluating perceptions

If the cues represent the real-world impacts on the individuals, the perceptions are a further step into the abstraction of how the group understands them. Each infrastructure will have its own perception, which is a single number that represents how bad that TAZ perceives that system to be. Each perception is also scaled based on the general sentiment values so that a general frustration amplifies perceptions of problems in the next time step. Perceptions are bounded by [0,1] and generally aim to have a mean of 0.5 and a standard deviation of 0.25 during normal operation.

4.3. Expectations and discordance

It has been noted that protests and other severe behavioral patterns mostly arise not necessarily when conditions are the worst, but when they are significantly different from what people expect them to be [3]. To capture this phenomenon, we compare the individual's perceptions of what the system state is with some baseline evaluation of what they would expect in a 'sunny day' scenario. This is a simple difference calculation, scaled to the maximum difference possible. For instance, if the baseline perception for an infrastructure is 0.5, the discordance will be calculated by taking the difference and multiplying by two since the maximum difference between the perception (bounded to [0,1]) and the baseline is 0.5. Generally, the baseline perception and the mean operating perception outlined above should be the same so that there are only small variations between the two and the discordance is low. This allows outstanding events and infrastructure issues to easily show in the discordance calculations.

4.4. Decision factors

This step is the final calculation of the sentiment values as described above. The discordance is the 'current' or memory-less sentiment and is combined with the prior values to form the reported value for each timestep. This is done for each infrastructure then combined into the overall sentiment. These calculated values are used to quantify the feelings and frustrations with each relevant system and determine a hierarchy of emotions to be considered when making final decisions on behaviors.

4.5. Intentions and behaviors

Finally, once the sentiment values are calculated, the group formulates the final 'priorities' output. This list represents the priorities for activities/places to go for the upcoming time step. The priorities are normalized and such that all entries add to one and consist of

- Work
- Buy gas
- Buy food/cooking fuel
- Stay home

The values can be interpreted by other models as the maximum effort the group will expend to take that action before moving to the next priority. The values of these priorities are to be interpreted by the other models as a generalized demand; for instance, if 'buy gas' is high then the transportation model may build in extra trips from homes to gas stations while the fuel exchange model may reflect the spike in demand for fuel.

The values are calculated as follows. There is an AM/PM split in the model. In the AM the baseline is priority 100 for work and 0 for all other locations, while the baseline for PM is 100 for home and 0 for all else. It should be noted here that this baseline does not include trips to stores as these are included as normal movement in the associated models and not as a special priority. Thus, the non-work and non-home priorities are added in to represent behavior outside of ordinary movement, such as making special trips to the store because of the perception of an impending shortage. It is assumed there is always the baseline movement and demand on resources, but when perceptions change it represents an abnormal increase in demand that puts pressure on the corresponding infrastructures. Thus, starting from the baseline values of all-work or all-home, the values for these priorities are then modified based on the general sentiment of the TAZ:

$$P_{work} = P_{work}/(1 + M_{general}) \quad (5)$$
$$P_{home} = P_{home} * (1 + M_{general})$$

The specific infrastructure values are then taken into account:

$$P_{grocer} = P_{grocer} + 200 * M_{food} \quad (6)$$
$$P_{gas} = P_{gas} + 200 * M_{gas}$$

$$P_{home} = P_{home} + 100 * M_{power} \quad (7)$$
$$P_{work} = P_{work} - 100 * M_{power}$$

$$P_{home} = P_{home} + 100 * M_{transport} \quad (8)$$
$$P_{work} = P_{work} - 100 * M_{transport}$$
$$P_{grocer} = P_{grocer} - 50 * M_{transport}$$
$$P_{gas} = P_{gas} - 50 * M_{transport}$$

Accounting for the desire to do things when specific infrastructures are compromised. These scaling values are tuned to the initial integration mode, but would need readjusting for application to a new suite of models or scenario. After these scores are calculated, any that are below zero are set to zero and the remaining are normalized such that all priorities add up to one.

5. OUTPUTS

As previously mentioned, the two outputs from the social model regarding the general system state are: 1) emotion/frustration as a general value and for each infrastructure and 2) action priorities of groups within each TAZ. At each time step, each social group will evaluate and output both of these values, and once a part of the general system state they can be sampled and drawn upon for either other models or for probes/performer information.

The GZTR allow users to view a public or private datastream within the simulation environment. Public information is that which could easily be observed, for example, power outages, overall state of traffic, and average pricing of a commodity. Public data includes only a categorization of the [0,1] general sentiment value into ‘high’, ‘medium’, and ‘low’ categories; all sentiment data is included in the private datastream.

REFERENCES

[1] Kelic, A., Beyeler, W., Mitchel, R., Bernard, M., Doyle, C., Rogers, A., Frazier, C., Gunda, T., and Klise, K. (2020). The Grey Zone Test Range Integrated Urban Simulation Environment. Sandia National Laboratories, Albuquerque, NM. SAND2020-4198. https://www.osti.gov/servlets/purl/1763525

[2] Bernard, M. L., M. Aamir, G. Avina, G. Backus, J. Hellier, R. Jeffers, A. Naugle, D. Trumbo, and S. Verzi (2016). DYMATICA Modeling & Assessment. Sandia National Laboratories, Albuquerque, NM. SAND2016-4349R. https://www.osti.gov/servlets/purl/1561486

[3] Singer, M. S. (1992). The application of relative deprivation theory to justice perception of preferential selection. Current Psychology, 11(2), 128-144.