Systems Engineering with Generalizable Statistical Demographics, Sentiment & Social Identity

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Abstract

Sociotechnical systems are important for the future of systems engineering practice, but generalizable structures are lacking. This paper introduces three recent enhancements to the emerging-state actor model (E-SAM) simulation that can generalized as methodological blueprints for system engineers to include social systems as part of their modeling. These enhancements improve the fidelity of statistical demographics, sentiment, and social identity. These also include the identification of credible, publicly available, and reliably updated data sources, allowing E-SAM to be instantiated in over 80 countries through the World Values Survey (WVS). We demonstrate the methods with three experiments. These include recreating the original ISIS case study in Syria & Iraq 2010-2020; a Ukrainian War hypothetical post-conflict stabilization scenario 2022-2032, and a hypothetical humanitarian aid mission after a major natural disaster in Myanmar in 2028. The experiments demonstrate the wide versatility of E-SAM to model different patterns of conflict, and we discuss how demography, social identity and sentiment can also be used in other systems engineering domain applications.

1 Introduction

Guided by the [INCOSE] Vision 2035, the systems engineering community has endorsed a commitment to include to include sociotechnical systems as part of systems engineering practice[1], [2]. To make progress towards this vision, academic literature in systems engineering needs to demonstrate how this can be done. This paper provides a case study and generalizable model structures to facilitate this process. In this case study, this paper provides a sociotechnical update to the Emerging-State Actor Model (E-SAM) simulation capabilities and demonstrates its ability to instantiate to a wider variety of regions and conflict scenarios. The E-SAM simulation is a system dynamics model originally developed to study the so-called Islamic State of Iraq & Syria (ISIS)[3],[4]. In the sociotechnical systems update, we provide both an empirical contribution through the case study application and a methodological contribution to systems engineering literature, regarding how demography, sentiment, and social identity can be made a part of model building in systems engineering practice.

Our research question is twofold: (1) how do we improve the fidelity of statistical demographics, social identity, and sentiment from the original model, and (2) how do we use data sources that would be both widely available and speed the instantiation of an E-SAM simulation to a variety of regions and both historical and future time periods?

This paper addresses three identified opportunities for improvement in the original E-SAM simulation. First, a meta-analysis of ~60 insurgency simulations evaluated the theoretical basis of E-SAM, along with 11 other models' papers, across eleven criteria. E-SAM was marked as not demonstrating four of those criteria, including grievance, social identity, cohesion, and structural adaptation[5]. We characterize this criticism as failing to include a sociotechnical dimension to the E-SAM model. We addressed grievance in a prior peer-review publication not included in the meta-analysis[4], and will address social identity in the case study presented in this paper. Cohesion, the inner group dynamics of a non-state actor, are below the level of aggregation we modeled. Likewise, structural adaptation refers to an evolutionary adjustment to those group dynamics to, in effect, change the operating model of the group at the time. In addition to being below the level of our aggregation, it is questionable whether system dynamics is best capable of modeling truly adaptive and evolutionary emergent structures. These two of the four factors are best handled through an Agent Based Model (ABM) focused on that aspect.

In addition, the original E-SAM simulation was labor intensive to instantiate, with a high degree of uncertainty as to whether necessary data would even be available for a given region of conflict. Time consuming manual data collection was needed to instantiate the simulation in the original case study of the so-called Islamic State of Syria & Iraq (ISIS) from 2010-2020.

This paper addresses these sociotechnical deficiencies with an update to E-SAM that includes greater fidelity of grievance and social identity along with the leveraging of credible, regularly updated, publicly available data sources. This sociotechnical systems update included larger functionality to add capabilities and data acquisition for civilian daily patterns of life depicted in the Figure 1, concept drawing.

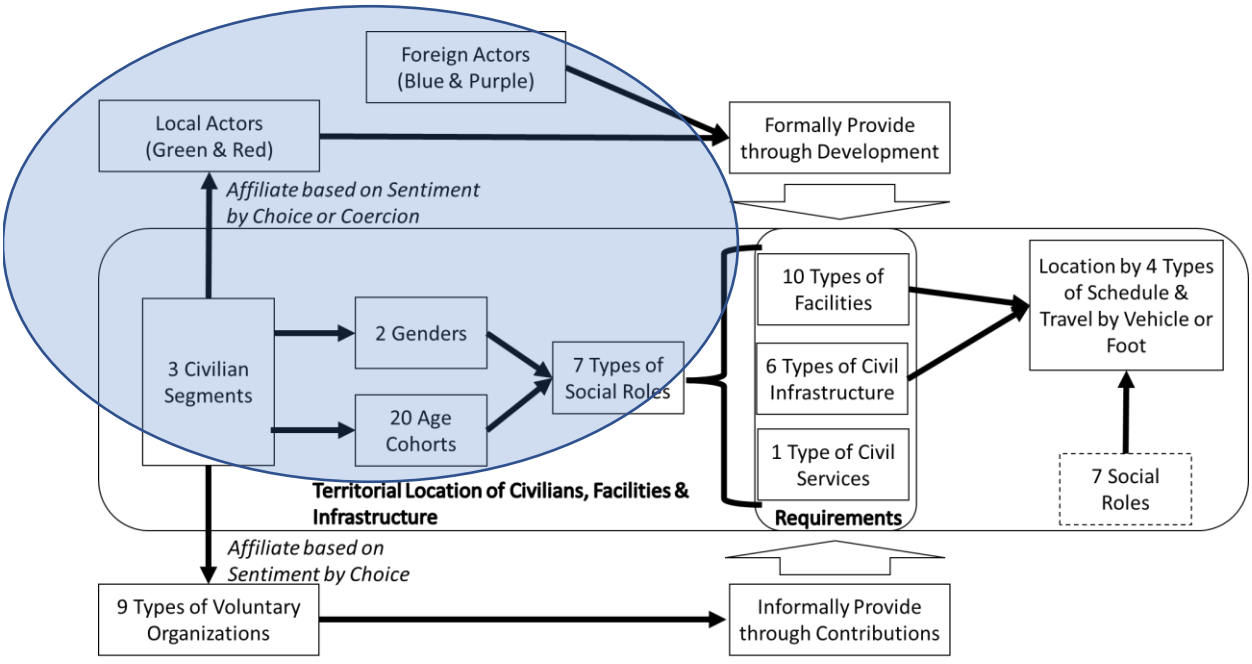

Figure 1: Concept Civilian Pattern of Life

This paper is focused on the enhancements indicated by the shaded areas in Figure 1. These enhancements include more detailed statistical demographics, the social identity of those segmented demographics, and how that informs and reacts to sentiment towards local and foreign actors. In addition, we review data sources to aid in parameterizing those values. As explained in our methods, enhancements in other areas were present in the experiments we conducted, but are beyond the scope of this paper.

In the following sections, we provide first a background on sociotechnical system modeling in systems engineering, and how the update to the E-SAM model provides a methodological contribution to advance systems engineering practice towards achieving INCOSE Vision 2035. We then provide the E-SAM model design update to include statistical demographics, social identity, and sentiment, three key elements of sociotechnical system modeling and simulation that can be adapted to other systems engineering applications. Lastly, we provide concluding remarks that outline possibilities of future research for the E-SAM model and how the results of this paper can be used in a generalized context.

1.1 Background of E-SAM

In military modeling and simulation (M&S), a category of simulations known as DIME-PMESII are considered well suited for "modeling diplomatic, information, military, and economic (DIME) actions, and political, military, economic, social, information, and infrastructure (PMESII) interactions[6, p. 130]." E-SAM is a system dynamics simulation in the DIME-PMESII category designed to meet Department of Defense and National Research Council aims of simulations to support military planners or researchers, to simulate policies or courses of action (COA) and analyze the results, to understand and forecast both adversary and social behaviors, and to give detailed structure of enemy command and control[6, pp. 34–44]. E-SAM considers how local and foreign state and non-state actors compete within both a physical and human terrain. Aggregation was set to an operational level of a large theatre or region. Four playable sides took the perspective of theatre commanders over this region including local state actor (Green), non-state actor (Red), foreign support for local state (Blue) and foreign support for local non-state actor (Purple) in a variety of less-than-conventional conflicts. The policy choices available for analysis and evaluation are the allocation of resources among a variety of operational orders of military, civil and political nature but not the tactical execution of those orders that follows. Within the DIME-PMESII framework, the original E-SAM incorporated information, military, economic, political, and broad social aspects; but did not include diplomacy or infrastructure to any detail. The original E-SAM was completely documented, including extensive supplementary materials, in our prior work[3], [4]. In its updated form, E-SAM is organized into 16 sectors as indicated in Figure 2.

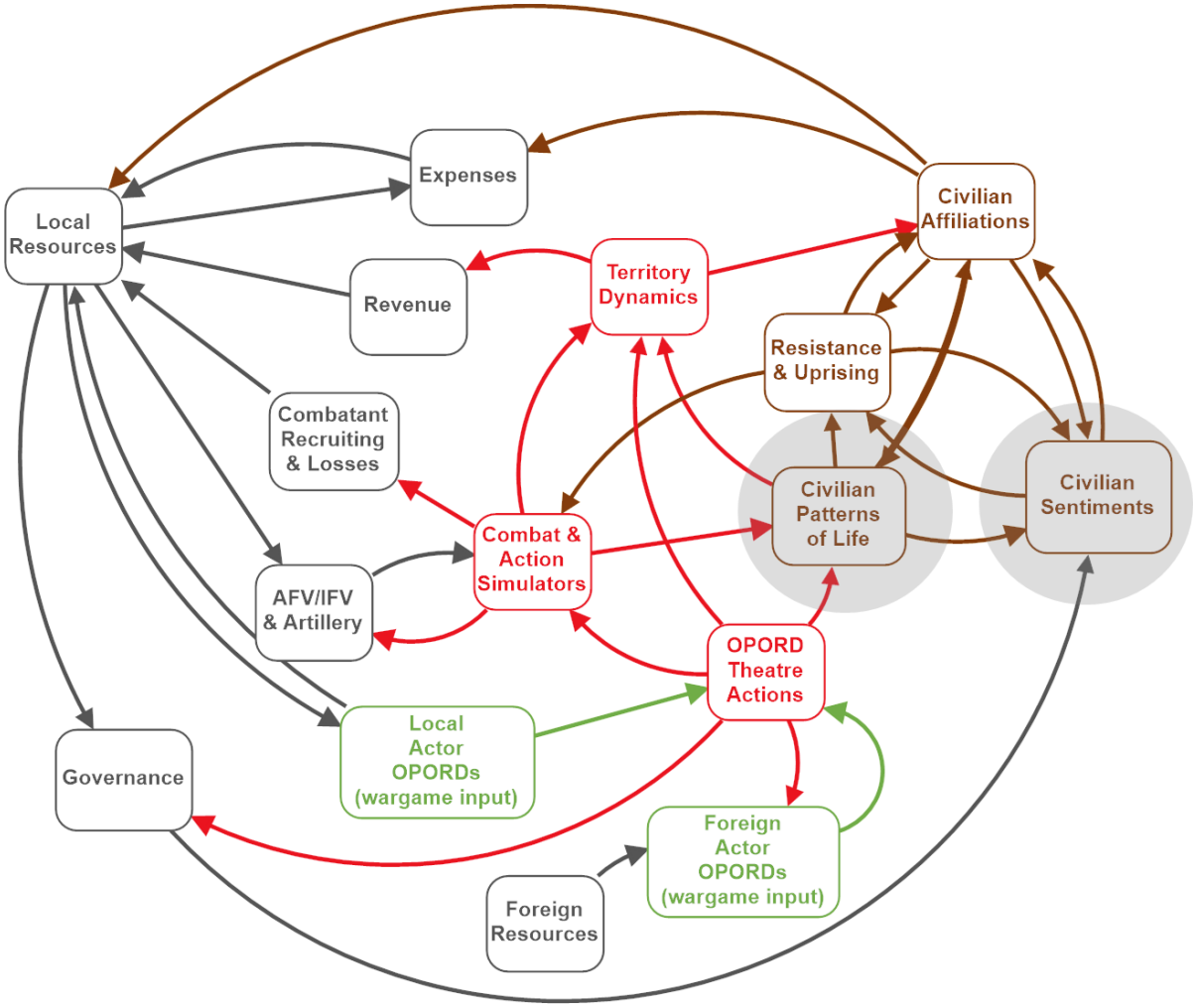

Figure 2: The 16 sectors of E-SAM color-coded to purpose. Gray to actor dynamics, brown for civilian dynamics, red for theatre dynamics, and green for wargaming inputs.

Each sector is color coded to the nature of the modules within it: gray for actor dynamics, brown for civilian dynamics, red for theatre dynamics, and green for wargaming inputs. Each module holds the specific model equations relevant to that function. We have highlighted with gray circles the two sectors of interest in this paper: Civilian Patterns of Life and Civilian Sentiments.

To instantiate these new portions of the E-SAM model, we incorporated three data sources. First, the Gridded Population of the Worldv4 (GPW) provided by NASA's Socioeconomic Data and Applications Center NASA for statistical demography. Second, the World Values Survey (WVS) for all but one social role and sentiment. Third, a Sustainable Development Goals (SDG) Indicator 4.1.1 "Completion Rate of Lower Primary and Secondary schooling" for a final social role. These sources are described in more detail below in Section 3.2.

2 Theoretical Foundations

2.1 How do we approach social identity?

Our conception of a civilian's perception of their identity, in both a civilian segment and social role, is grounded in Social Identity Theory (SIT). SIT provides a well-established academic process for understanding how individuals generate their discrete idea of self, or identity[7], [8]. In the context of Statistical Demographics within the Civilian Patterns of Life sector, we rely on SIT to assist in categorizing how individual civilians view themselves as parts of civilian segments and as members of specific social role. In the Civilian Sentiment sector below, we combine SIT with legitimacy theory[9],[10] to understand how civilians create an identity and its related sentiment or affiliation with both local and foreign state and non-state actors.

Relevant to civilian segments and social roles, SIT consists of three key concepts: self-categorization, prototyping, and depersonalization[8]. These three concepts provide our structural approach to modeling a person as identifying within a given civilian segment, which will not change over the course of the simulation, and a slightly more permeable social role, largely influenced by their gender and age-cohort and changeable over time. However, we are not modeling the changes in social roles based on a discrete, agent-based view of a person identifying themselves, but rather in keeping with the operational scope of the simulation from a societal influenced set of roles which, in general, an individual will find themselves moving between over the course of their life.

2.1.1 Self-Categorization

The first step of the adoption of a civilian segment and social role is where the person begins to categorize themself with the group[8]. Self-categorization can happen as one finds the group voluntarily, but it can also happen as a person is ascribed into the group or told by outside pressure they are the group. Using Ukraine as an example, we demonstrate in a simplified way how levels of identity connection within a civilian segment and a social role can arise between this interplay of voluntary and ascribed identities:

- I was born in Ukraine and raised speaking Russian. These are facts based on my birth or circumstance, I cannot choose differently from them, and they may affect how others perceive or treat me.
- Being a Ukrainian woman, my role as a woman is written into my social being. I cannot easily leave womanhood when I choose, and it may affect how others perceive or treat me.
- As an adult Ukrainian woman, I can choose to speak Ukrainian or Russian within the limitations of my circumstances, but my choice as an adult cannot overwrite or overcome my experiences growing up as a Russian speaking Ukrainian, or how others perceive me. Primary language, then, is a semi-voluntary aspect of identity but limited by the constraints of my upbringing.
- As an adult Ukrainian woman raised speaking Russian, I can choose between several social roles, but the options available to me or the success I may have in their pursuit may not be equal to my male counterparts, or to those who were both born in Ukraine and raised speaking Ukrainian. I have some degree of voluntary choice within this limited set of options, but the distribution of choices available to all adult Ukrainian women raised speaking Russian compared to those available to the

larger population of all adult Ukrainian woman raised speaking Ukrainian, or even all adult Ukrainian people raised speaking Ukrainian, is not the same.

2.1.2 Prototyping

Social roles, once adopted, can serve as an inducement toward changes in an individual's behaviors to better fit perceived social role identities through a process called prototyping. This process, involving both the group's perception of itself and its perceptions of others, generates through informal consensus ideas about how ideal members of the in-group thinks and behaves as well as beliefs about who those outside the group, or the out-group, are. Prototyping in either form involves a degree of depersonalization (defined below), or the flattening of a person or people into short-hand stereotypes. In the example of the Ukrainian civilian segment of Russian speaking Russians living in Ukraine, out-group model formation may arise within Russia based on Putin's propaganda that all Russian speaking Russians are a "part" of Russia, as well as from the reaction of Ukrainian speaking Ukrainians to Putin's messaging. This is an example of out-group modeling. But, even within the in-group, prototyping processes occur. For example, in the social role of "caregiver" there will be in-group prototyping among a network of caregivers. Key to remember, though, is that prototyping is not fixed to the external outgroup and should be separated from the concept of sentiment to an actor. In the example of Russian speaking Russians in Ukraine, Putin may believe and try to influence the generation of a prototypical view all Russian speaking Russians in Ukraine are a part of the larger Russian empire. However, the individual members of that civilian segment within Ukraine may disagree strongly, especially after experiencing Russian military instigated violence, and reject Putin's attempted influence on their in-group prototype. As sentiment shifts against the Russian military, a new Russian speaking Russian living in Ukraine prototype may take hold. However, as our simulations only last 10 years, we model changes in sentiment as the dynamic while membership in the civilian segment is fixed. On a longer perspective over decades or generations, this contest of prototyping may give rise to new conceptions of civilian segments – for example based on which side of the war a group is perceived to have fought.

2.1.3 Depersonalization

We operate under the premise these identities are sticky. One will not change out of their civilian segment within the 10 years of the simulation, and social role distributions only change every five years. This is because of depersonalization, which is the process of "becoming one" with the group, whereby a person allows the group to change how they think or conforms to the group's ideas as they personally perceive them. In the group sense, this allows the individual to de-emphasize being an individual in favor of emphasizing being a good member of the group [11],[8].

Depersonalization is also why we model the population in larger groups, such as civilian segments and social roles, rather than as discrete individuals. According to SIT, certain situations will encourage in the moment group identification more than others (i.e., being the group versus being an individual)[8], [11], including crisis situations of the kind typically designed to be modeled in wargames or natural disaster

scenarios. Self-reinforcement through prototyping figures into this as people use prototypicalness, and membership who display the best prototypicality, to determine how they should act[8]. Curation of membership within the group serves to strengthen this group tie. A degree of anti-prototypicality is also involved, wherein the individual does not express enough prototypicality for the group, and thereby gets pushed toward its fringes, and even viewed with suspicion as a potential threat to the group identity [8]. Again, we do not model this directly within the civilian segments; but we can approximate it with the changes in social role over the lifespan of an individual. To be clear, we do not account why, for example, a Ukrainian speaking Ukrainian woman shifts from College Student at age 22 to Worker at age 25 and caregiver at Age 30, but those reasons can happen either because of changing circumstances or because of anti-prototypicality with the group they were in, encouraging them to seek other social roles.

Depersonalization works in the direction of outgroups as well. Ingroup depersonalization helps create cohesion and intragroup value/ranking. This effect is amplified in situations of radicalization[12, pp. 31–65] but exists even in non-radical scenarios according to SIT. Outgroup depersonalization creates the circumstances by which quick, snap judgements about outgroups can be made[8]. From our Myanmar experiment, for example:

- Women should be caregivers at home rather than aspire to professional careers.
- Ethnic minorities are inferior to the Bamar majority.
- Anti-Junta Bamar are not trustworthy to put ethnic minority concerns first.

2.2 How do we approach Sentiment?

The theoretical foundation of how civilians affiliate with actors and their sentiment to them builds upon the SIT theory described above and ties it with legitimacy theory. Affiliation is the distribution of a civilian segment controlled by an actor between three stocks representing a continuum of legitimacy: Unaligned, Coerced, Calculated Legitimacy (Best Choice for Now) and Governed. The distribution of population between these stocks has implications in the simulation for the resources or support the actor can expect from the civilian in that stock. Sentiment is the driver of change between affiliation stocks based on perceived legitimacy.

Sentiment is how a population views the legitimacy of an actor in relation to how that actor exercises power. Coercive power results from the exercise of "coercion and reward" and is "particularistic as it is support for a specific action or specific person, not for an institution or a system of government." Coercive power is more resource intensive as it "requires the investment… to induce compliance whenever necessary" [9, p. 37]. Legitimacy is a form of power relying on the populace having a sentiment where they consider the power credible, even if not just. Unlike coercive power used to ensure compliance, control by others is replaced by self-control in legitimacy, which socially is a much cheaper way to ensure social order" [9, pp. 38–40]. Calculated legitimacy is a middle-stage, lying between coercion and legitimacy a stage of "self-interest." The difference between coercion and calculated legitimacy "is that an application of coercion leaves the coerced actor worse off than it was beforehand…whereas a self-interest perspective sees the actor as better off than it would be taking any other available path[10, p. 386]."

We tie this understanding of legitimacy to sentiment through SIT theory which describes the processes by which members move into and out of group identities. In the SIT perspective, membership in groups is referential to various things that support a person's identity. There is no reason to leave a group unless the group stops supporting the identity to that identity's best position. However, there are various things impacting that support or one's ability to shift into or out of an affiliation. Some of these elements include:

1. How one's group is positioned, or privileged, hierarchically, compared to others; where this group is positioned in a hierarchy of social groups[11], [13].
2. How legitimate the hierarchy is[13].
3. How stable the hierarchy is[13].
4. How permeable the boundaries between groups are [13].

SIT helps inform the out-process of leaving affiliation or, if Coerced, adapting to circumstances and seeking change from within [11, p. 207], [13, p. 134]. In

3 Data Sourcing and Model Design

We present our data sourcing and model design for three sections. First we describe the primary data sources used across statistical demographics, social identity, and sentiment. Next we represent the model structure for statistical demographics and social identity. Finally, we represent the model structure for sentiment. Specific details on data ingestion from the sources into the model is included with each relevant section on that structure.

Our criteria for data sourcing was to identify established, academically respected, international efforts with global coverage. The data providers should use transparent research methods including supporting documentations of codebooks was also important. Governing mechanisms for the oversight of data collection should likewise be transparent and clear. Finally, data should be freely available allowing other researchers to access data for their own uses of E-SAM or other sociotechnical modeling. Although the choice of data selection will vary with any project, we recommend the above criteria or similar as a useful standard for selection.

Out first data source, for statistical demographics, was the "Gridded Population of the Worldv4" (GPW) provided by NASA's Socioeconomic Data and Applications Center (SEDAC[4].) This data set identifies the number of people, age by 5-year cohort, gender, and location by subnational unit or major city. The data set covers 241 countries and is updated every 5 years with historical data covering 2000-2020. The GPW approach is to model human populations on a continuous global raster. Population counts are drawn from estimates based on United Nations World Population Prospects derived from nearly 3,000 representative national samples. Sampling method varies by country and are documented on the UN website[14]. GPW is released under Creative Commons Attribution 4.0 license.

The second data source, used for social identity and sentiment, is the "World Values Survey Wave 7" provided by the non-profit World Values Survey Association[5]. This data set surveys a population of a country with 291 questions and up to 30 supplemental questions based on the region. The current wave covers 80 countries, and a new survey, is conducted every 5 years with historical data from 1981-2022. The next survey is scheduled to begin in 2024 and last through 2026. It is provided publicly for free.

WVS cooperative method results in informationally consistent datasets from one country to the next – by surveying the same questions. Individual questions, when possible, offer the same series of potential answers. Where appropriate, local context is added, such as in the names of regionally prevalent political parties. Survey interviewers distribute their questioning cross-country, noting the regional, state (where applicable), city or town location for each individual interviewed. They also note ethnicity of the respondent, language spoken at home, and an array of nominal information useful in the process of sorting a population into socially and politically significant groups. Their method does not rely on inconsistent or potentially flawed census data. Though it cannot tell us the exact number of a particular ethnicity in a region, for example, its sample sizes are large enough (generally n=1200) to allow us to generalize by percentage distributions into population data taken from traditional demographic sources. Thus, the sentiment data we draw from the WVS comes responsibly close to being unbiased and can be consistently imported into the E-SAM simulation for the widest array of countries to be studied.
In the E-SAM statistical demographics module, this data is used to identify the civilian segments and social roles of the population aside from "student", which is handled below.

The third data source, for "student" social roles only, is the Sustainable Development Goals (SDG) Indicator 4.1.1 "Completion Rate of Lower Primary and Secondary schooling" provided by the United Nations[6]. The UN SDG cover all 193 countries of the United Nations and data is collected every four years, beginning in 2017. Samples are collected from at least 4,000 students per nation but clustered into school-samples of roughly 400 per sample. The latest data collection is 2022 and the next is scheduled for 2026.

We combined these three data sources to create 'civilian segments', located within the territory by subnational unit or major city. Each civilian segment tracks the age cohort, gender, and social role of every person within it. The specific methods of this approach are described below.

3.1 Representing statistical demographics and social identity of civilian segments

Statistical demographics is a module within the Civilian Pattern of Life sector of E-SAM as indicated above in Figure 2. The Civilian Pattern of Life sector as depicted in Figure 3 tracks multiple aspects of civilian populations. The statistical demographics of civilian segments sector within the daily patterns of life module, highlighted in Figure 3is the key engine of civilian populations in our effort. For each of the three main civilian segments of interest, it tracks the dynamic changes in births, deaths and losses while also tracking the aging of the population and gender characteristics. This sector also assigns

population to social roles based on the intersection of their age cohort and gender. This makes statistical demographics of civilian segments the "heartbeat" of which many other simulation sectors and modules pull their information from.

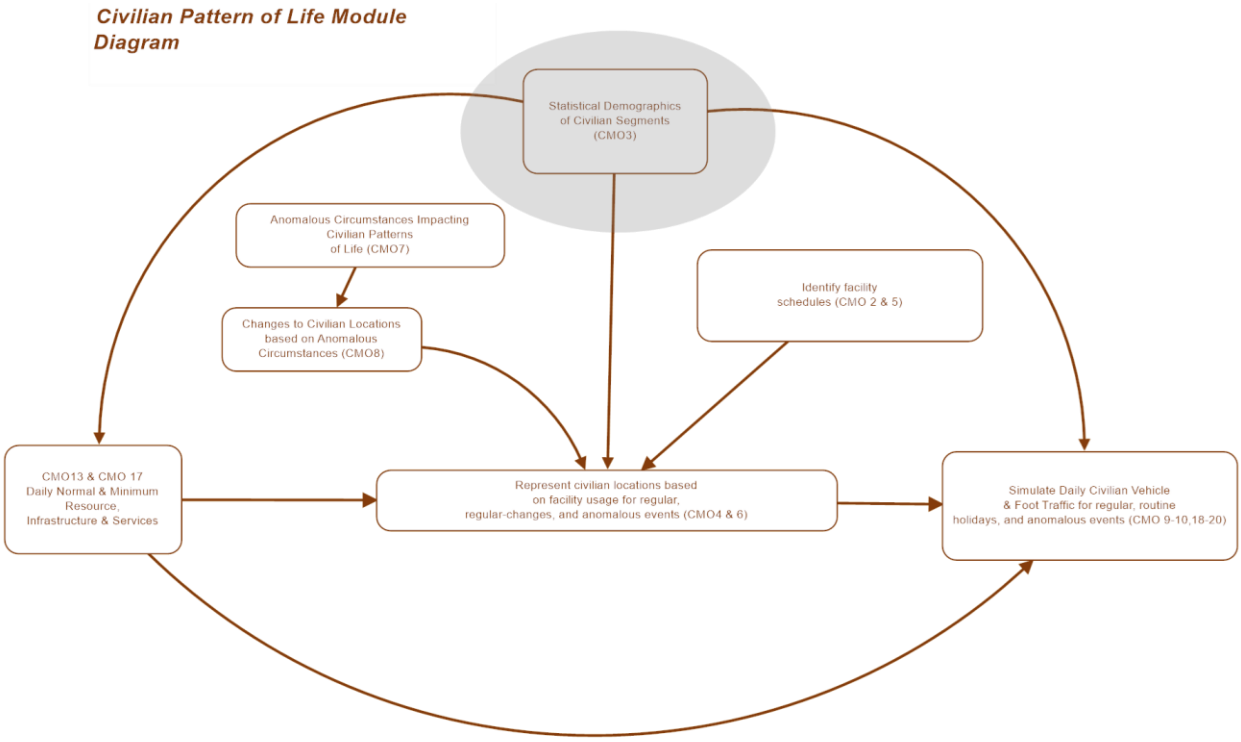

Figure 3: Statistical Demographics located in Module Diagram for Civilian Patterns of Life Sector

Statistical demographics of civilian segments uses a single structure and subscripts to manage important information about each of the three civilian segments represented in E-SAM. The three civilian segments, when combined, represent the entire civilian population of interest in the model. The statistical demographics module is the ground-truth basis of civilian counts for the entire simulation. All adjustments to civilian populations: births, deaths to natural causes, deaths to anomalous events, are reflected. Other dynamics including sentiment adjustment and affiliations with actors relies on the demographic information. (For more on Sentiment and Affiliations see below their respective sections.) Daily needs and daily schedules across infrastructure, facilities, and services are determine by the social roles in this sector. Also, reporting of data by age, gender, social role, or civilian segment relies upon statistical demographic data .

Our structure of statistical demographics consists of a standard population aging model as shown in Figure 4 combined with a social role assignment. The outflow of population due to anomalous circumstances is handled by existing structure described more fully in our previous work [3] and [4].

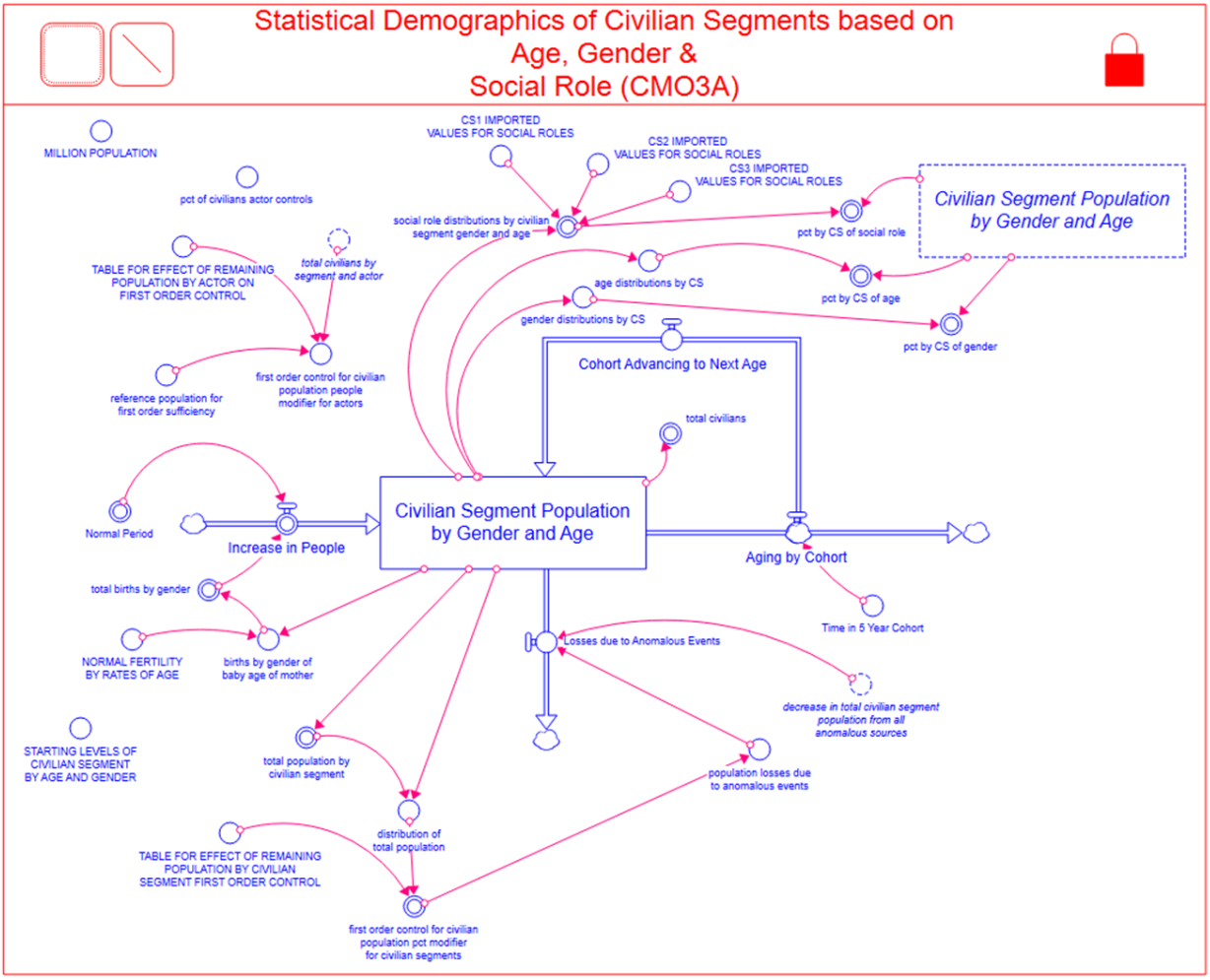

Figure 4: Stock & Flow Diagram for Statistical Demographics for Civilian Segment

Although E-SAM did not previously use subscripts for the civilian segment more in-depth than the civilian segment itself, we expanded the subscripts to represent the detailed micro social identities and these are displayed in Table 1.

Table 1: Subscripts for Statistical Demographics

Civilian Segments	Actors	Gender	Age	Social Role
CS1	Green	Male	A5, A10, A15	Students
CS2	Red	Female	A20, A25, A30	CollegeStudents
CS3	Blue		A35, A40, A45	Workers
	Purple		A50, A55, A60	Caregivers
			A65, A70, A75	Activists
			A80	Unemployed

				Retired

The next step is to identify within this population the civilian segments of interest and identify their percentages as indicated by CS1%-CS3% in Table 1. What constitutes a civilian segment can vary based on the scenario and wargame envisioned, but should represent a significant ethnographic, demographic, or cultural segment of the population which has a strong identity of itself as well as its place in relation to other civilian segments. To demonstrate the flexibility of our approach and data sources, we used three different "concepts" of civilian segment across our four experiments as outlined in Table 2.

Table 2: Example Civilian Segment Configurations by Experiment

Experiment	Concept of Civilian Segment	Resulting Civilian Segments
Myanmar	Affiliation to or against the Junta by majority Bamar population and coalition of ethnic minorities.	Anti-Juna Bamar Pro-Junta Bamar Coalition of Ethnic Minorities
ISIS (Syria & Iraq)	Primary language spoken and religion.	Arab Sunni Arab Shia Kurdish Sunni
Ukraine	Primary language spoken and self-identified ethnicity.	Ukrainian speaking Ukrainians Russian speaking Ukrainians Russian speaking Russians

3.2 Data Ingestion for Statistical Demographics of Civilian Segments

Once the definition of a civilian segment is established, the WSV can be used to establish the percentage of the population representing that civilian segment, and the next step is to identify the social roles. WVS can cross reference data three layers deep, so while holding constant civilian segment, age and gender, the analyst retrieves data on the identity of respondents within that slice and associates them to a social identity mapped to WSV.

Once civilian segments are determined, the next step is to determine the distribution of social roles to every slice crated by age-cohort, gender, and civilian segment. As depicted in Table 3, there are 576 resulting permutations of an age, gender, civilian segment combination across all social roles.

Table 3: Permutations of Social Role Slices

Subscript	Number of Elements in Subscript	Resulting Social Role "Slices"
Civilian Segment	3	576
Age Cohort	16	
Gender	2	
Social Role	6 (Note the social role of "Students" are handled separately.)	

We map these permutations using WSV Questions 99,101, 103, and 104 as indicated in Table 4. This involves a worksheet considerably larger than can be displayed in this report but notionally identifies the percentage of every age-gender-civilian-segment slice to one of the social roles of CollegeStudent,

Worker, CareGiver, Activist, Unemployed, and Retired. Since WSV does not survey minors, there is no data on people beneath the age of 20[15] and thus no data on students who attend K12. We obtained student social role data from the UN SDG indicator 4.1.1[16] and input the corresponding percentages in the same worksheet as the other social roles.

Table 4: Map of WSV Questions to Model Element in Statistical Demographics

WSV Question	Question	Provides Data On Model Element
Q290	Respondent's ethnic group	Civilian segment identity in some scenarios.
Q223	If there were a national election tomorrow, for which party on this list would you vote? Just call out the number on this card. If DON'T KNOW: Which party appeals to you most? (list of country specific political parties)	Civilian segment identity in some scenarios.
Q272	What language do you normally speak at home?	Civilian segment identity in some scenarios.
Q279, Q280	For respondent and spouse are they employed? If not are they unemployed, student, Housewife or otherwise not employed, or retired?	A20+ Social Role: College Student, Worker, Caregiver, Retired by Civilian Segment
Q99, Q101,Q103, Q104	Active member in environmental organization, charitable/humanitarian group, self-help/mutual-aid group, women's group	A20+ Social Role: Activist by Civilian Segment

Because the definition of civilian segment is scenario specific, not every question will always be used. For example, Q223 in Table 4 on political parties was used in Myanmar to identify Junta and anti-Junta political positions within the single majority ethnographic group of Bamar. However, we did not use this question in the other experiments, because the civilian segment definitions in those circumstances did not require it.

3.3 Representing Starting Sentiments & Changes

Civilian Starting Sentiments and change is a module within the Civilian Sentiments sector of E-SAM as indicated above in Figure 2. This sector, as depicted in Figure 5, tracks multiple aspects of civilian sentiments towards both actors and "VolOrgs." VolOrgs represent non-state actors who can exercise no coercive control over a population (e.g. non-profits, volunteer or community organizations, celebrity influencers etc.) In this section we only focus on the sentiment of civilians to state and non-state actors who can exert coercive control over a population, though the mechanisms are similar.

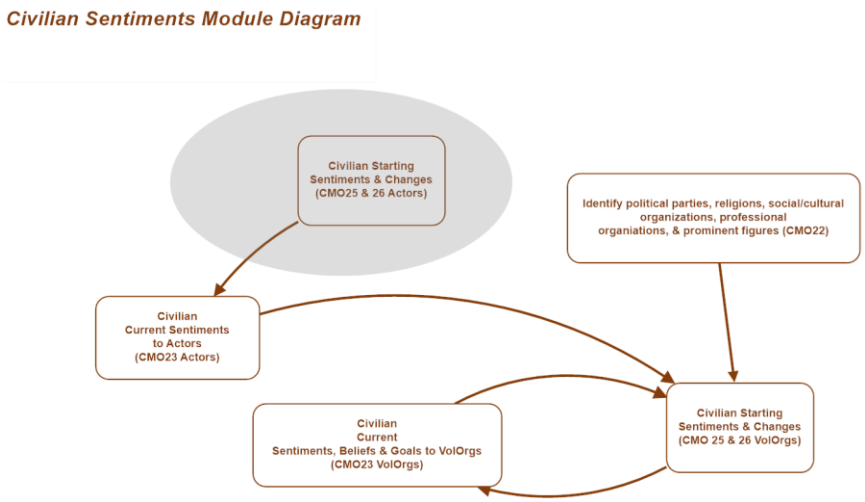

Figure 5: Civilian Starting Sentiments & Changes for Actors located in Module Diagram for Civilian Sentiments Sector

The structural basis for adjusting civilian segment sentiment reflects a common judgmental heuristic known as "anchoring and adjustment." Anchoring and adjustment reflects how individuals and even groups of people: "make a judgment by anchoring or beginning with a known reference point, then adjusting their judgment to account for factors specific to the case at hand.[17, p. 534]" This sentiment formation structure adjusts current short and long-term sentiments. These two reflect a civilian populations sentiment towards state and non-state actor based on past experiences. These sentiments are retrospective based on past experiences. The long-term sentiment is the "generational anchor" and represents cultural and sociological norms. The short-term sentiment reflects more recent information. Under normal conditions, without influence the long-term and short-term sentiment will converge on the same value; representing a bias of current sentiment that reflects long term experiences formed over many years. However, continued information adjusting the short-term sentiment will, over time, drag the anchored long-term sentiment to a "new normal."

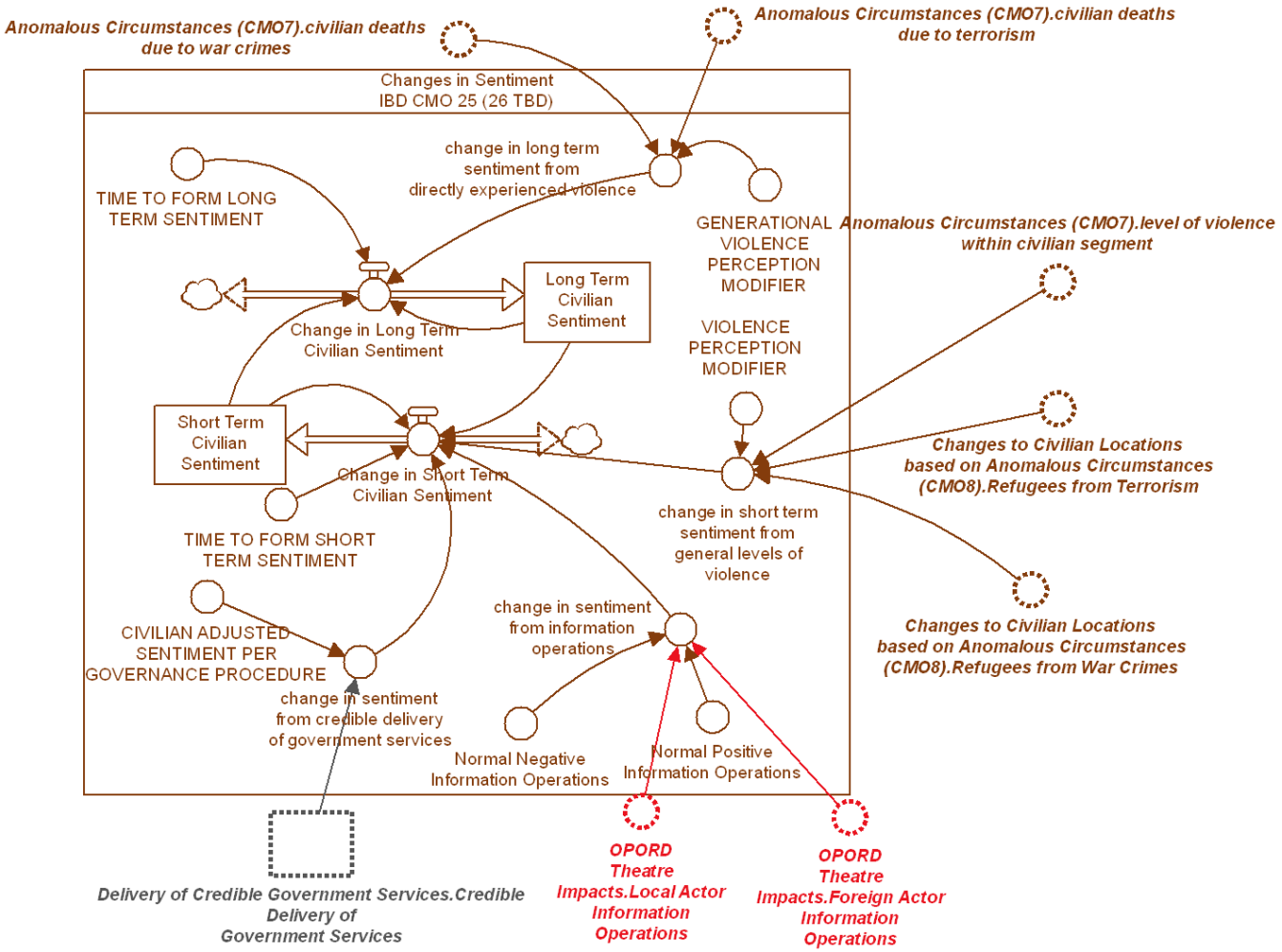

Figure 6: Stock & Flow Diagram for Starting Sentiment & Changes to Actors

The structure can be thought of as having a fast and slow gear driving Affiliation via Sentiment. In generalizable terms, the short-term sentiment rapidly reacts to 'now' circumstances including changes in hierarchy and provision of "credible institutional" procedures, infrastructures, and services provided by the actor [9]. Short term sentiment is also subject to information operations by local or foreign actors and VolOrg advocacy. The anchored, long-term sentiment, is driven by the short-term sentiment at a slower averaging time of sentiment-formation and represents a generational perspective, or anchor. This anchor serves to slow sharp changes based on short term circumstances while still allowing for long-term shifts in sentiment. A short, sharp episode of instability registering as negative short-term sentiment will average out over time if it is isolated with the long-term sentiment. However, continued violence can adjust what the population considers "normal," adjusting the long-term sentiment.

Short- and long-term sentiments are also influenced by surface anxieties and deep anxieties respectively. In our modeling of conflict scenarios surface anxieties include an overall perception of instability based on general levels of violence in the region while a deep anxiety might be particularly experienced violence within a local community or kin network. In rough analogy to a business context, surface

anxiety may be over instability in some other part of the enterprise or even a deteriorating marketing condition, while deep anxieties are experienced when layoffs occur directly impacting a worker or their coworkers.

Note that in this structure, both short term and long-term sentiment are calculated as total individuals within a civilian segment. This allows easy conversion by dividing into the total population controlled by actor to determine a percentage of the controlled population to locate in each of the affiliated stocks of unaligned, coerced, best choice for now, and governed.

3.4 Data Ingestion for Starting Sentiments to Local and Foreign Actors

In Table 5, we map 14 WVS questions that focus on perceived legitimacy of an actor to determine starting sentiment. Using WVS, we can see the responses to these questions within each civilian segment we have identified. This gives us three different perspectives on state power.

Table 5: Map of WSV Questions to Model Element in Civilian Sentiment for Actors Module

WSV Question	Question	Provides Data On Model Element
Q69	Confidence in: Police	Starting Sentiment to Actor by Civilian Segment
Q70	Confidence in: Courts	Starting Sentiment to Actor by Civilian Segment
Q71	Confidence in: Government	Starting Sentiment to Actor by Civilian Segment
Q73	Confidence in: Parliament	Starting Sentiment to Actor by Civilian Segment
Q74	Confidence in: Civil Service	Starting Sentiment to Actor by Civilian Segment
Q76	Confidence in: Elections	Starting Sentiment to Actor by Civilian Segment
Q224	Votes are counted fairly	Starting Sentiment to Actor by Civilian Segment
Q225	Opposition candidates are prevented from running	Starting Sentiment to Actor by Civilian Segment
Q227	Voters are bribed	Starting Sentiment to Actor by Civilian Segment
Q229	Election officials are fair	Starting Sentiment to Actor by Civilian Segment
Q230	Rich people buy elections	Starting Sentiment to Actor by Civilian Segment
Q231	Voters threatened with violence at polls	Starting Sentiment to Actor by Civilian Segment
Q234A	Does your country allow people like you to have a say	Starting Sentiment to Actor by Civilian Segment
Q254	How proud are you to be of the nationality of this country.	Starting Sentiment to Actor by Civilian Segment

Transformation of this data involves identifying what percentage of the population begins viewing the actor with legitimacy (governed), as the calculated best choice for now (calculated legitimacy), or without support (coerced.) We map question responses to an assigned sentiment of coerced, calculated legitimacy, or legitimacy as indicated in Table 6.

Table 6: Mapping of WVS Questions to Actor Sentiment Type

Question Set	Respondent Response	Sentiment Type
Q69-Q76 "How confident are you in the following [governmental] organizations…"	A Great Deal	Governed
	Quite a Lot	Calculated Legitimacy
	Not Very Much	Calculated Legitimacy
	None at All	Coerced
Q224-Q231 "In your view how often do the following (indicators of legitimacy) occur in this country's elections?"	Very Often	Governed
	Fairly Often	Calculated Legitimacy
	Not Often	Calculated Legitimacy
	Not at all Often	Coerced
Q254 "How proud are you to be [country's nationality]?"	Very Proud	Governed
	Quite Proud	Calculated Legitimacy
	Not very Proud	Calculated Legitimacy
	Not Proud at All	Coerced
	I am not [country's nationality]	Responses excluded.

When these responses are mapped by civilian segment they are then entered into the worksheet tab "B1) Social Roles, Sent. & Aff." depicted below in Figure 7.

87	***STARTING SENTIMENT TO STATE ACTOR BY CIVILIAN SEGMENT 3***				1	HeaderInfo	% By Cat	Cat 1	Cat 2	Cat 3	Cat 4	Governed	Calc Legit	Coerced	Unaligned	Error Check		
88	WorldValue Sur	Q69	2020	CMO23[Gl	2	data	CS3	0.142191	0.454545	0.223776	0.179487							
89	WorldValue Sur	Q70	2020	CMO23[Gl	3	data	CS3	0.165501	0.424242	0.242424	0.167832							
90	WorldValue Sur	Q71	2020	CMO23[Gl	4	data	CS3	0.32634	0.452214	0.144522	0.076923							
91	WorldValue Sur	Q73	2020	CMO23[Gl	5	data	CS3	0.20979	0.540793	0.16317	0.086247							
92	WorldValue Sur	Q74	2020	CMO23[Gl	6	data	CS3	0.237762	0.498834	0.172494	0.090909							
93	WorldValue Sur	Q76	2020	CMO23[Gl	7	data	CS3	0.240093	0.512821	0.170163	0.076923							
94	WorldValue Sur	Q224	2020	CMO23[Gl	8	data	CS3	0.291375	0.235431	0.18648	0.286713							
95	WorldValue Sur	Q225	2020	CMO23[Gl	9	data	CS3	0.037296	0.156177	0.167832	0.638695							
96	WorldValue Sur	Q227	2020	CMO23[Gl	10	data	CS3	0.058275	0.153846	0.172494	0.615385							
97	WorldValue Sur	Q229	2020	CMO23[Gl	11	data	CS3	0.237762	0.314685	0.18648	0.261072							
98	WorldValue Sur	Q230	2020	CMO23[Gl	12	data	CS3	0.074592	0.170163	0.179487	0.575758							
99	WorldValue Sur	Q231	2020	CMO23[Gl	13	data	CS3	0.013986	0.076923	0.167832	0.741259							
100	WorldValue Sur	Q234a	2020	CMO23[Gl	14	data	CS3	0.079254	0.130536	0.282051	0.508159							
101	WorldValue Sur	Q254	2020	CMO23[Gl	15	data	CS3	0.83683	0.142191	0.013986	0.006993							
102	WorldValue Sur	NA		CMO23[Gl	16	data	CS3	0.22028	0.480575	0.186092	0.113054	Governed	Calc Legit:	Coerced:				
103	WorldValue Sur	NA		CMO23[Gl	17	CS1StateSent	CS3					0.22028	0.666667	0.113054	1	<-- Should = ^<1		

Figure 7: Civilian Segment Sentiment towards Actor (Myanmar Experiment)

The percentages for Cat 1-4 are added by question, and then averaged for an overall allocation to Governed, Calc Legit, and Coerced. These amounts should then account for 100% of the given population in CS3, which is confirmed with an error check. In Figure 7, the data comes from the Civilian Segment 3 of the Myanmar experiment representing the coalition of ethnic minorities generally opposed to the Bamar majority and specifically the Junta. When transformation is done, only 22% view the State actor as legitimate, 66% view them as the best choice for now in calculated legitimacy, and 11% view themselves as being coerced by the state actor. Though we are not saying these numbers are

precise, we do believe they are realistic and plausible given our understanding from past research on how populations usually split among the categories even if they view the state as an oppressor.

The same approach can be used to model sentiment of civilian segments to international organziations. WVS questions Q82-Q86 are to used to ask about regional and global international actors. For example, in the Ukraine experiment Q82 "Confidence in the European Union", Q83 "Confidence in the United Nations", and Q86 "Confidence in NATO" but in the Myanmar experiment Q82 asked about ASEAN.

Across both local and foreign actors future research can involve greater analysis using the entire set of WVS, including historical waves reaching back into the 1980, to correlate findings as useful indicators of trust or distrust in governing institutions.

4 Experimentation to Build Confidence in the Model Design

To build confidence in our design we conducted four broad experiments, demonstrating the feasibility of improved statistical demographics, social identity, and sentiment formulations. These experiments each represent a potential use of E-SAM in a different region, time, and circumstance in the world. The three experiments include the original E-SAM case study of ISIS in Syria-Iraq 2010-2020, summarized Table 7; a hypothetical post-conflict stabilization mission to secure a ceasefire obtained in December 2022 of the Russian-Ukraine war, summarized in **Error! Reference source not found.**, and a two-year humanitarian rescue wargame conducted on a futures scenario of Myanmar in 2029, summarized in Table 9. Experiments were designed to help refine the models and data sourcing, but they also identified limitations, e.g., can the data sources supply data on such widely diverse areas and circumstances? Can the model structure accommodate a high degree of variation in wargame purpose?

Table 7: ISIS Experiment Summary

ISIS Experiment	
Element	**Description**
Purpose	Counter insurgency wargame to evaluate CMO courses of action (COA) against ISIS.
Theatre & Time Period Covered	Theatre: Syria & Iraq over 2010-2020, simulation dt calculates each "calendar day" Period = “3 calendar months or “1 Quarter”; Campaign Turns = 1 “calendar year”
Common Scenario Details	Scenario starts with 2010 Arab Spring, continues through rise of ISIS, and intervention of foreign forces 2015-2020.
Scenarios	Historical = Historical baseline incl ~115k foreign military intervention. Counterfactual = Hypothetical scenario with no foreign intervention. COA2 = Proposed course of action incl both political & military options. COA2 Political Only = As COA2, but only with political options. COA2 Military Only = As COA2, but with only military options.

Table 8: Ukraine Wargame Experiment Summary

Ukraine Post-Conflict Stabilization Experiment	
Element	**Description**

Purpose	Post-conflict stabilization wargame based on a hypothetical ceasefire in the Russian-Ukraine war.
Theatre & Time Period Covered	Theatre: Ukraine, 2022-2032, simulation dt calculates each "calendar day" Period = “3 calendar months or “1 Quarter”; Campaign Turns = 1 “calendar year”
Common Scenario Details	Scenario starts with ceasefire leaving current Russian occupied territory under separatist control secured by 100k Russian troops. Reconstruction efforts begin with promise to withdraw all foreign troops in 3years.
Scenarios	Cease-fire: Frequent DMZ violations but Russia withdraws as promised. Frozen War: Russia fails to withdraw creating a 'frozen war' scenario similar to 2014-2022.

Table 9: Myanmar Experiment Summary

Myanmar Experiment	
Element	**Description**
Purpose	Pre-game development futures wargame simulating Myanmar conflict until natural disaster requires planning for multi-year humanitarian support.
Theatre & Time Period Covered	Theatre: Myanmar, 2022-2032, simulation dt calculates each "calendar day" Period = “3 calendar months or “1 Quarter”; Campaign Turns = 1 “calendar year”
Common Scenario Details	Scenario begins with current Myanmar civil war escalating to intense conflict 2024-2026. A combination earthquake/tsunami hits in 2029 creating widespread death and destruction creating a humanitarian crisis.
Scenarios	Civil War: After escalation, a stalemate settles in while hostilities remain preventing humanitarian missions in 2029 leading to widespread famine. Reconciliation HÀ: The 2026 stalemate prompts reconciliation between pro and anti-Junta Bamar ethnic majority while Junta conducts reprisals against ethnic minorities. US humanitarian mission in 2029 allowed to aid in recovery from natural disaster.

Table 10: Example Civilian Segment Configurations by Experiment

Experiment	**Concept of Civilian Segment**	**Resulting Civilian Segments**
Myanmar	Affiliation to or against the Junta by majority Bamar population and coalition of ethnic minorities.	Anti-Juna Bamar Pro-Junta Bamar Coalition of Ethnic Minorities
ISIS (Syria & Iraq)	Primary language spoken and religion.	Arab Sunni Arab Shia Kurdish Sunni
Ukraine (both experiments)	Primary language spoken and self-identified ethnicity.	Ukrainian speaking Ukrainians Russian speaking Ukrainians Russian speaking Russians

5 Exploration/Design Improvement/Incremental Knowledge Gain

This section briefly demonstrates general capabilities with these enhancements in simulating statistical demographics, social identity, and sentiment within our experiments. These are selected illustrative examples only as the range of dynamics of any simulation in these complex contexts is beyond the scope of this paper. However, we hope they demonstrate how generalizing these structures can improve the range of sociotechnical contexts systems engineering efforts can undertake.

5.1 Example of Statistical Demographics

Our first example is for statistical demography representing a key population of men aged 15-40, known in conflict studies as the population of "Fighting Age Males" (FAM). Figure 8 breaks out this population into 5-year age cohorts across the three civilian segments.

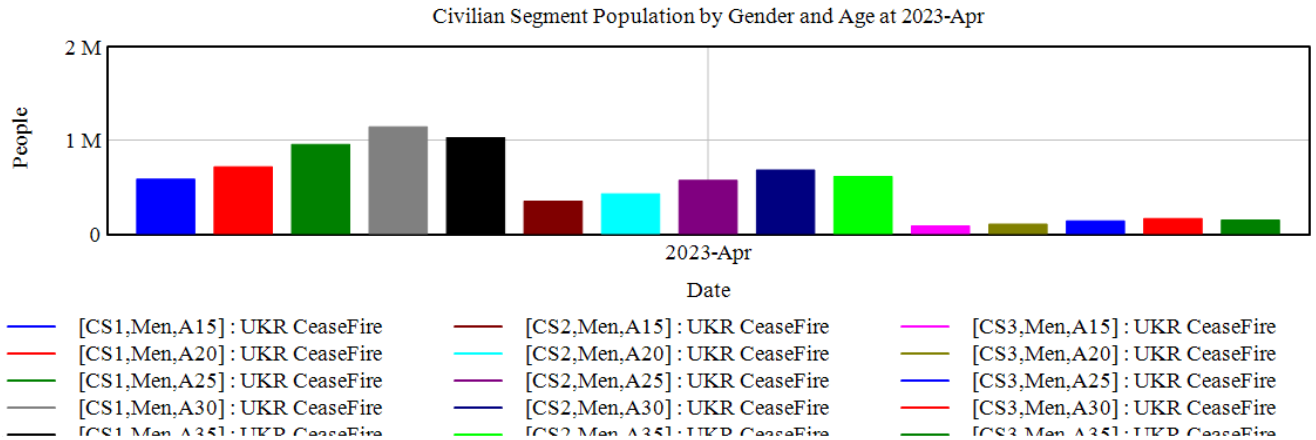

Figure 8: Fighting Age Men (FAM) of three Civilian Segments at the start of CeaseFire; CS1 = Ukrainian-speaking Ukrainians; CS2 = Russian-speaking Ukrainians; CS3 = Russian-speaking Russians.

Although just a snapshot early into the hypothetical ceasefire, it represents the demographic size differences between the three civilian segments. CS1, Ukrainian-speaking Ukrainians, has the largest population of FAM, followed by CS2 Russian-speaking Russians, and finally, CS3 Russian-speaking Russians. Note that this is an aggregated view of the country and does not indicate the affiliation of any of these groups with either the Green (Ukraine State) or Red (Russian-occupied separatist regions) in the hypothetical scenario.

5.2 Example of Social Roles

As an example of simulating social identity, we forecast distribution across social roles for two civilian segments Figure 9. The forecast is of the distribution in 2031 in the Myanmar Civil War scenario, where there is no reconciliation.

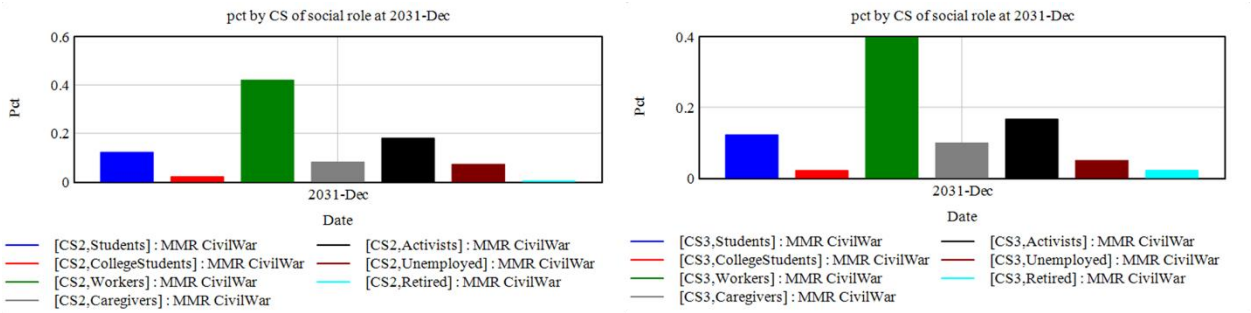

Figure 9: Forecasted Social Role % by Civilian Segment in 2031 Myanmar Civil War Scenario; (Left) CS2 = Anti-Junta Brama; (Right) CS3 = Coalition of Ethnic Minorities.

On the left of Figure 9 is the distribution by a social identity within the Anti-junta portion of the Barma majority (CS2). On the right of Figure 9 is the same distribution by a social identity within the coalition of ethnic minorities (CS3).

5.3 Example of Sentiment Changes

As another example of general capabilities - we simulate changes in sentiment for Ukrainian-speaking Ukrainians (CS1) living in Ukraine after a hypothetical cease-fire with Russia declared along the then-current line of control in December 2022.

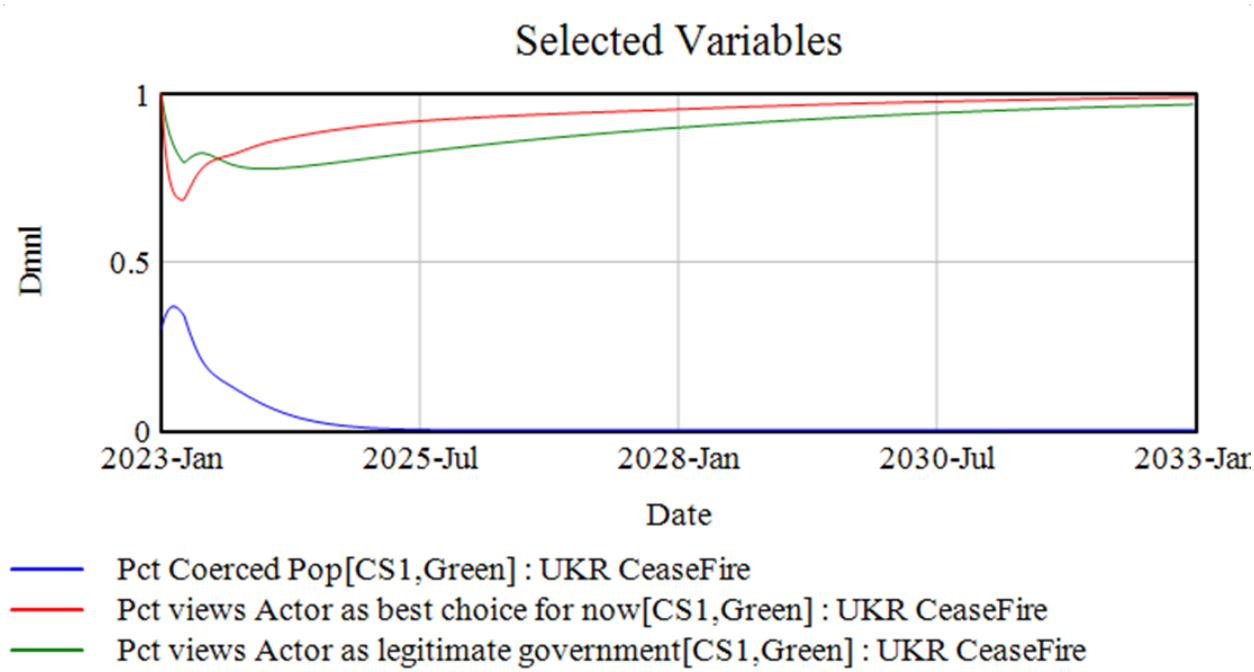

Figure 10: Sentiment changes among Ukrainian-speaking Ukrainians (CS1) living in Ukraine after a hypothetical cease called in DEC 2022.

This seeming counterintuitive pattern of a spike in coerced sentiments matching declines in the perception of legitimacy is not uncommon for populations shifting from wartime to peacetime through an arbitrated solution. Any euphoria of cessation of hostilities balances with frustration at the terms of the ceasefire. Even if briefly, the continuation of war-time measures and the daily struggles to navigate destroyed infrastructure puts an onus on the home government to action. However, with a post-conflict reconstruction plan and easing of war-time conditions, the coerced sentiment eases and improved calculated and governed legitimacy increases.

Our final example depicts short and long-term sentiment changes in the ISIS experiment within the key Arab Sunni population. In Figure 11, we depict two charts, one showing the erosion of sentiment towards the state actors (Green) and the other examining competing sentiments among Arab Sunni between both state and non-state actors (Red).

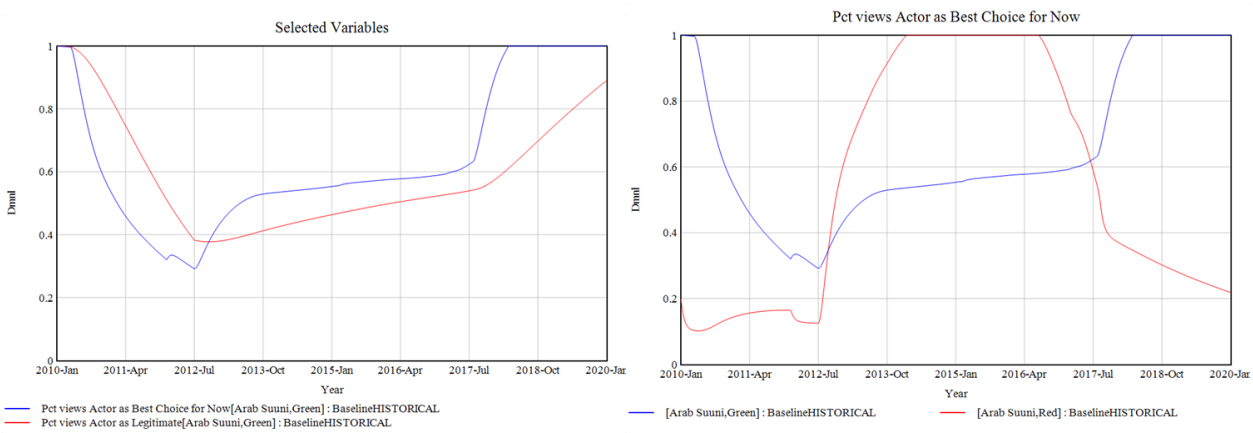

Figure 11: (LEFT) Arab Sunni long and short-term sentiments towards Green state actors. (RIGHT) Pct of Arab Sunni's viewing Green or Red Actor as "Best Choice for Now " ISIS Experiment

In Figure 11, the left chart depicts the erosion legitimacy of Green state actors during the Arab Spring. The short-term sentiment (Best Choice for Now) falls first under oppressive actions by state actors to quell unrest. After time this solidifies into long-term sentiment erosion. On the right, we show the consequences of this erosion of sentiment in a chart depicting the competing views of the Arab Sunni population between Green and Red actors. At first, ISIS (Red Actor) is the "best choice for now", either as an alternative or increasingly as they militarily occupy Arab Sunni populations during their expansion. However, the comparative short-term sentiment towards the Green actor (Syria & Iraq) improves as sentiments towards Red (ISIS) erode.

Although simplified with brief explanations, these examples demonstrate the range of complex dynamics depicted sociotechnical structures can add to systems engineering efforts. System engineers can broaden these general structures beyond the conflict scenarios we present here. Statistical demographic could represent constituents of policy, user base of applications, or even complex workforces. Social roles could be kept in the same context or replaced with other proxies for career path or job occupation in a different context. Changes in sentiment may represent, as here, large population perceptions to state or non-state actor, or they could be adapted to represent segments of transnational companies or large government agencies and their perception of the key initiatives system engineering is modeling.

5.4 Reduction in Time to Instantiate an E-SAM Simulation

In addition to data ingestion and representation of social identity at higher fidelity, one of our goals was to reduce the burden in instantiating an E-SAM scenario and simulation values. As Table 11 indicates, we dramatically improved the time it takes to instantiate a new scenario in E-SAM over the course of the study. Partly this was based on identifying the set of data sources in the first ISIS experience, and then leveraging those data sources and streamlining data ingestion methods through excel and Vensim between the Myanmar and Ukraine experiments.

Table 11: Reduction in Time for Data Sourcing over Phase I

Experiment	Time to Obtain Data & Instantiate Experimental Simulation
ISIS Experiment (Syria & Iraq)	Weeks
Myanmar Experiment	Days
Ukraine Experiment	Hours

These numbers should be taken as notional. We did not conduct rigorous time trials and the process of creating E-SAM scenario remains manual. Additional gains above and beyond what has already been established are unlikely without utilizing API or XML ingestion. However they demonstrate the importance of data ingestion from credible sources with expert oversight to speed model instantiation for different scenarios.

6 Discussion and Conclusion

What we demonstrate in this E-SAM improvement is how to operationalize sentiment and social identity, as connected to demography dynamically over a time horizon, both historical and projected into the future. This offers significant benefits for system engineering, including generalizable approaches to include these elements in other applications. People and their social dynamics are often left out of systems engineering processes, both document-based and in model-based systems engineering (MBSE). The E-SAM example shows how they can be included physically with demography modeling. This is well-established using system dynamics modeling[18], and, even though system dynamics modeling is not foreign in systems engineering practice, the application to demography in systems engineering to include social systems has seen very little traction.

Beyond the physical social systems (i.e., people), the improvement to E-SAM demonstrates how abstract social systems (i.e., social identity) can be modeled as a system. Concepts like gender and other social identity categories are often left out of modeling[19] because there is too little demonstration of how to model it as a system. This often leaves social identity characteristics relegated to the qualitative narrative to support model-based research. The problem with this is that the importance of these factors to outcomes are under-utilized, because they are not modeled or quantified, or because the model-based results are given more weight due to their visual displays in graph form[18].

Likewise, sentiment is relevant for a whole host of systems engineering applications, both how it dynamically changes over time, and its effects on decision-making. This is easily seen when a systems engineer follows any engineering project, product, or service through its lifecycle and identifies how different types of actors (demography) may influence its lifecycle processes depending on the actor's role, how they see that role (social identity), and their operationalized opinion/perception (sentiment). The E-SAM improvement demonstrated in this study provides a methodological contribution to systems engineering literature, allowing other systems engineers to apply this operationalization to their specific domain application. While this study focuses on emergent state actors, modeling demography, social identity and sentiment remains generic.

Social systems are the foundation of systems engineering practice. Without people, there is no engineering, and projects fail more often for the social reasons than the technical[20]. Although this study uses system dynamics modeling, it provides a generalizable outline of how to include demography, social identity, and sentiment as a system, regardless of whether you are using system dynamics modeling. The same principles can relationally be developed (for example) using SYSML or simulated using agent-based modeling. By including social systems as part of the modeling in systems engineering, it strengthens modeling in systems engineering practice and providing another step towards INCOSE's Vision 2035.

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