Simulating Synthetic Economies and Global Economic Interdependence within the EBO-DIME-PMESII Framework

Alok Chaturvedi
Purdue University
West Lafayette, Indiana
alok@purdue.edu

M. Mulpuri, G. Pinczuk
Simulex, Inc
West Lafayette, Indiana
{ mmulpuri, gpinczuk }@simulexinc.com

ABSTRACT

Within the context of Effects Based Operations (EBO), intervention strategies consist of DIME actions (Diplomatic, Information, Military and Economic) that are taken on PMESII nodes (Political, Military, Economic, Social, Information and Infrastructure) to achieve desired effects. This paper presents multi-agent simulation as a technique to explore and investigate the economic component of this holistic framework at multiple levels of analysis. Increasingly, creating an all-inclusive global economy is becoming necessary to develop strategies for ensuring international stability and security. It has hence become critical to better comprehend the shifting econopolitical paradigm in today's flattened world and its implications for national sovereignty and operational strategy.

The simulation model uses micro-foundations that draw from both neoclassical and behavioral economics to build an emergent 'Synthetic Economy (SE)' within a 'Virtual Province (VP).' Provincial economies together give rise to a national economy within a 'Virtual State (VS),' and subsequently, to the global economy within an emergent 'Virtual International System (VIS).' This system, built on the SEAS platform (Synthetic Environment for Analysis and Simulation), facilitates the design of effective economic strategies by providing insight into the impact of various courses of actions conducted at various times. It hence enables the exploration of:

- Critical infrastructure interdependencies within an economy
- Global economic interdependencies through trade and financial networks
- Global impact of domestic and international institutional economic regulation

Keywords: agent-based simulation, global economy, trade network, SEAS

ABOUT THE AUTHORS

Dr. Alok Chaturvedi is a Professor of Management Information Systems at the Krannert Graduate School of Management, Purdue University; the Director of Purdue Homeland Security Institute; and the founder and CEO of Simulex, Inc. He received his Ph.D. in Management Information Systems and Computer Science from the University of Wisconsin-Milwaukee. Dr. Chaturvedi has been working on multi-agent synthetic environments for over fifteen years.

Midh Mulpuri is the Technology Lead for SEAS-VIS at Simulex, Inc. and has helped pioneer its development for almost three years.

Guillermo Pinczuk is an Analyst at Simulex, Inc.

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PROBLEMATIQUE

Since the fall of Baghdad in April 2003, the United States has been unable to fully achieve its goal of establishing a stable, legitimate government in Iraq that is friendly to U.S. interests. This raises challenging issues for U.S. military and civilian planners. While Iraqi and Islamist insurgents have waged a steady unconventional military campaign against U.S. forces, they have been successful in impeding U.S. strategic objectives primarily through attacks and activities that generate second- and third-order political, economic and social effects detrimental to U.S. objectives in Iraq and the larger Middle East. For instance, insurgent attacks on oil and natural gas pipelines reduce the Iraqi government's capacity to generate much-needed revenues and provide basic services like power and water. Combined, these two effects increase Iraqi citizens' frustration with their government and erode the latter's capability to effectively exert its authority throughout the entire country. These results, in turn, erode the legitimacy of the Iraqi central government and the political system itself, thereby calling into question the ability of the United States to achieve its strategic objectives. Unfortunately, these effects are compounded by the revolutionary violence initiated by Sunni fundamentalists intent on fostering social unrest and sectarian strife in an effort to overthrow the new order in Iraq. If the United States is to succeed in Iraq, it will have to expand and enhance its repertoire of Effects Based Operations (EBO) by developing a subtle understanding of the strategic implications of various non-military effects.

Unfortunately, disentangling the multiple social, political and economic effects of different actions and locating them within time and space is fraught with difficulties. Numerous and complex interrelationships exist within and among social, political and economic systems, and there does not exist a unifying approach that can provide a precise, holistic and complete understanding of complex socio-economic phenomena.

BENEFITS OF AGENT-BASED MODELS

Nonetheless, while perfect prediction is unattainable, the use of diverse academic theories in combination with agent-based computational techniques can greatly improve our understanding of social complexity and thereby assist planners in determining various courses of action – Diplomatic, Information, Military, and Economic (DIME) across all elements of a state's power – Political, Military, Economic, Social, Information, and Infrastructure – (PMESII) to understand which actions achieve the desired result.

Through a computational experimentation methodology (Chaturvedi, et al 2005), one can re-create the social environment on the basis of theoretical models of behavior and calibrate them to fit idiosyncratic situations. If theoretical models are sufficiently robust, then the re-created situations can provide revealing insights into the phenomena under investigation. Of course, even after developing an ontology that reflects many of the accepted models from various disciplines, there will still be a lack of deep understanding of the flow of information, the interaction between key actors, and the cascading effects of events within a "system of systems" under which various phenomena are observed. An agent-based environment allows us to fill the gap through experimentation by modifying the solitary and collective behaviors of individuals, groups, organizations and institutions.

Specifically, agent-based models can provide useful insights into determining how macro-level phenomena emerge from micro-level behavior. Within a "virtual" environment autonomous agents mimic the behavior of their real world counterparts. They are able to communicate, negotiate and cooperate with each other; choose from multiple (rational and irrational) decision strategies; and employ processes of learning to modify their behavior during the simulation (Chaturvedi, et al. 2005).

This paper is organized into three parts. In the first section we describe the development of a large scale, agent-based virtual international system (VIS). We then provide a more detailed description and configuration of a 'synthetic economy' within the VIS. We then briefly describe how SEAS-VIS is used to model Iraq's economy.

SEAS-VIS MODEL DESCRIPTION

We use the Synthetic Environment for Analysis and Simulation (SEAS) to construct a VIS consisting of fully functioning synthetic societies, organizations, economies, nations, and sub-state units each mirroring their real-world counterparts in all their key aspects (see Figure 1). A virtual state is represented by five primitive constructs: Individuals, Organizations, Institutions, Infrastructures, and Geographies (IOIIG). These five primitives are used to model higher-order constructs such as geographical entities (nations, provinces, cities), political systems (type of government, political parties/factions), military organizations (soldiers, institutions), economic systems (formal and informal structures), social systems (institutions, groups), information systems (print, broadcast, internet), and critical infrastructure networks (banking, oil and gas, electricity, telecommunications, transportation).

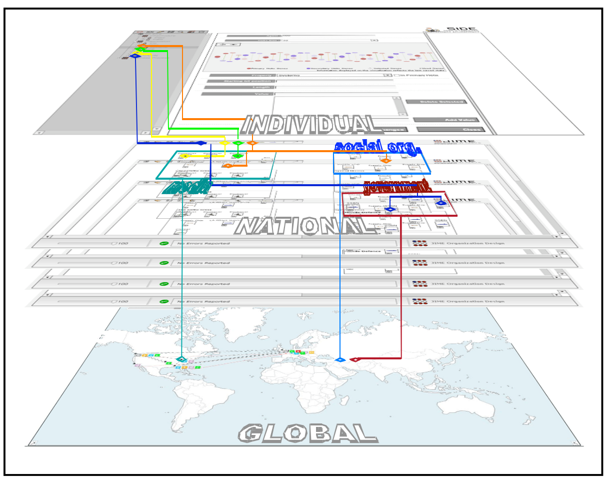


Figure 1: Multi-scale representation of Individual, Organization, Institution, and Infrastructure in SEAS-VIS.

The virtual environment also provides the rules that govern and guide the actions of agents and the interactions between them. These rules are based on theoretical paradigms from various fields (economics, sociology, psychology, comparative politics, international relations, etc.) that are integrated into SEAS to model the behavior of agents and the interactions between them.

Unlike traditional systems of systems simulations, SEAS uses an agent-based paradigm with emergence to capture dynamic relationships between individuals, members joining or leaving organizations, institutional access to resources, international alliances, subscriptions to various sources of media, and financial collaborations. Linkages between agents emerge due to their actions. Interactions between agents can occur at a fine detailed level, capturing transactions, as well as at a coarser level, such as organizations acquiring access to resources.

To represent a synthetic nation, individual citizen agents are constructed as a proportional representation of the societal makeup of the real nation. Each citizen agent is encoded with static traits, such as gender, nationalism, ethnicity, race, income, education and religion, as well as dynamic traits, such as their political, societal and religious orientation, and their will to fight.

We use Kahneman's (1999) concept of **subjective well-being**, which refers to a person's assessment of their perceived state of happiness. An agent's well-being consists of eight fundamental needs: basic, political, financial, security, religious, educational, health, and freedom of movement. Both traits and well-being together determine the basic goals for a class of agents. An agent uses its "**sensors**" to sense the environment, listen to messages from his/her leader(s), the media, organizations, and other members of the society. Based on the sensed information, each agent can autonomously choose from its configurable action set or adjust its goals. Traits, well-being and goals determine the available actions each agent can take. For example, an agent can **migrate** to a different location (geography) to **seek** a better job to satisfy its **financial well-being.** Traits, well-being, sensors, and actions together determine the **behavior** of an agent.

An agent can be an ordinary citizen or a leader. The leader agent is encoded with influence levels that reflect his/her power within the group, organization, or institution. A leader agent is categorized as social, religious, and/or political and has a repertoire of actions that is larger than that of citizen agents. Also, it possesses additional traits such as power base, ideology, and his/her stance on economic, political and social policies. These agents are able to affect the political and social climate of their synthetic environment and impose their views upon citizens and organizations to promote their respective goals. The goal of a leader agent is to set the agenda of the organization or institution in which they reside and persuade the citizen/member agents to make decisions that favor those positions.

Clusters of agents form larger entities such as groups, organizations and institutions. They differ from individuals with regard to the rules that govern their behavior and intent. Groups are either informal or formal. Formal groups' rules of engagement are published and are relatively static, while those of informal groups essentially represent private information known only to its members and which continuously evolve based on interactions within the environment.

Institutions are modeled as "governmental entities," such as the army, police, legislature, courts, executive, bureaucracy, and political parties – entities that have discretionary resources and that are able to formulate legally binding policies. We also consider institutions as structures that are products of individual choices or preferences, with the latter, in turn, constrained by the institutional structures in an interactive and iterative process. The government institution agents represent the leadership and various branches of government. Institutions resemble formal organizations but with an additional power to influence the behaviors of members and nonmembers.

THE SYNTHETIC ECONOMY WITHIN SEAS-VIS

A synthetic economy provides a model of a domestic economic system and of an international economy within SEAS-VIS. A synthetic economy is represented by fifteen sector agents, thirteen of which are **production** sectors (see Figure 2). These include oil, power, natural gas, water, telecommunications, transportation, manufacturing, agriculture, finance, education, military-industrial, labor and capital, and all but the last two are also modeled as infrastructure. The final two sectors, consumers and government services, represent **consumption** sectors. A macro-economy emerges from the interactions of these fifteen sectors. A synthetic economy can represent either a country or a province within a country. In addition, synthetic economies can engage in bilateral trade with other economies.

Each sector is interdependent with the other sectors via several propagation mechanisms through which effects percolate throughout the system. First-order dependencies are present whenever one sector uses the output from another sector as an input into its own production process. Second- and third-order effects emerge once time is explicitly included as a variable, thereby permitting delayed and indirect cause-effect relationships to emerge.

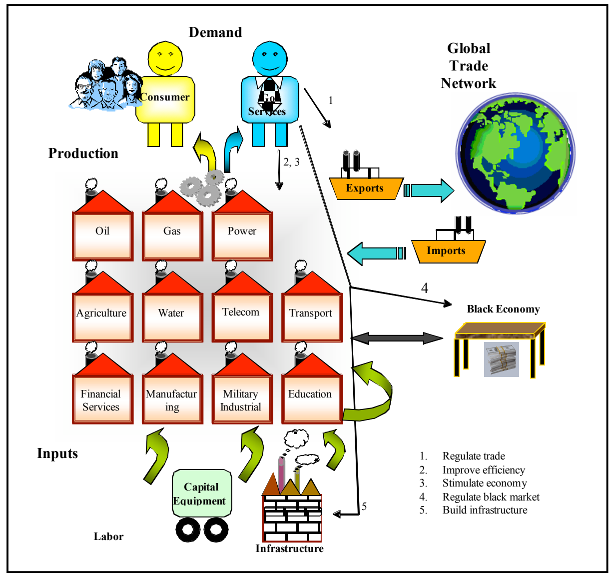


Figure 2: Schematic of Synthetic Economy in SEAS-VIS

Traits, Goals, Sensors, and Actions

Like other agents within SEAS-VIS, sector agents themselves are characterized by traits, goals, sensors and actions, with the first three combining to generate the latter. Each of the production sectors possess twelve traits, among which include maximum production, maximum exports, imports, local inventory target, and unit production requirements. The latter trait specifies the quantity of goods needed from the other sectors in the form of intermediate goods to produce one unit of output, and it is partially determined by the level of technological development within an economy. The consumption sector possesses three traits: initial demand, unmet demand and total consumption. The goal of each production sector is to maintain its inventory at target levels, while the consumption sectors seek to satisfy all of their demand.

Sector agents use their **"sensors"** to receive messages from the environment and from other agents. Examples of the former include "current availability," where each sector senses the availability of goods in the other sectors of the domestic economy; "global imports and exports," where each sector can sense the global demand for the goods of its trading partners as well as their inventory levels; "trade blockade," where a sector can sense a blockade being applied to its geographical region; and "capital flight," where sectors sense the level of capital exiting a region. Incoming messages from other agents include "trade embargo," "boycott," and "freeze assets."

Producing goods and services is the key action taken by the production sectors. Production in each sector is driven by demand. As a sector's inventory gets depleted due to domestic consumption or export, it attempts to restore its inventory target level by producing locally. To do so, it senses the availability of the intermediate goods and services it needs from the other (domestic) sectors. If the latter are not available, it engages in international trade with sectors outside of its geographical area. Within SEAS, the oil, power, gas, manufacturing, agriculture, military-industrial, and capital sectors are currently enabled to engage in international trade.

The two consumption sectors demand goods and services from the production sectors. Consumers spend a portion of their income on consumption according to the following equation:

$$C = C_0 + mpc * Y_d \qquad (1)$$

Within equation (1), Y_d represents disposable income (total income less taxes), and *mpc* represents the marginal propensity to consume – the fraction of disposable income that is spent on consumption. The remainder is saved. As equation (1) indicates, consumers would still consume even if disposable income were zero, with consumption under these circumstances equal to C_0 and financed by savings from past periods.

Besides macroeconomics, SEAS-VIS also employs psychology to explain consumer consumption. As already mentioned, financial well-being is one component of overall subjective well-being. Consumers, therefore, will adjust their consumption patterns according to whether their actual financial and overall well-being are at desired levels.

The government services sector also consumes goods and services from the thirteen production sectors, and it obtains its revenues from taxes and budget deficits. A percentage of its total budget is spent on performing various policy actions, including rebuilding infrastructure, improving productive efficiency, negotiating trade contracts, regulating the black market, and stimulating the economy by increasing its expenditures. Government agents can also change tax rates to gather more resources and to influence other macro-economic conditions.

Black market effects are incorporated within SEAS-VIS in terms of their impact on government revenue. Black market activity arises out of two causes: trade in prohibited goods and services, and trade in legal goods and services for the purpose of tax evasion (Quenum, B.M., 2004; Dabla-Norris, E. and Feltenstein, A., 2003).

Production and Gross Domestic Product (GDP)

Within SEAS-VIS, sector-agent production follows a basic Cobb-Douglas production function:

$$Y = AL^{\alpha} K^{\beta} \qquad (2)$$

In equation (2), Y represents output, A represents the technological capacity within an economy, L and K represent labor and capital, respectively, and α and β are parameters representing the productive capabilities of labor and capital.

Within SEAS-VIS, labor represents an economy's labor force, and capital has three components: (1) infrastructure; (2) intermediate goods and services; and (3) equipment such as plant and machines needed to produce output. Developing countries tend to be less capital intensive, and that capital which is present will have a higher productivity (larger β). In developed countries labor is generally is more efficient than in developing countries (higher α).

A is determined partly by the unit productions requirement trait and partly by a calculated technology factor. We assume that technological capacity is correlated with GDP per-capita. Therefore, the technology factor is calculated by dividing each country's GDP per-capita by the GDP per-capita of the country within SEAS-VIS possessing the highest level of that variable.

Within SEAS-VIS, this production function has several defining properties. First, it is characterized by constant returns to scale. Thus, if both capital and labor are increased by the same proportion, output also increases by the same proportion. This restraint forces both α and β to sum to one. Second, production exhibits diminishing returns, which means that, while holding other inputs constant, increasing only one input contributes progressively less and less to output. This can occur only if both α and β are less than one, which is true in SEAS-VIS by virtue of the fact that their sum equals one and that both are used within the production process. Third, labor and capital can be substituted for one another depending upon availability.

GDP for a sector-agent is defined by the following equation:

$$Y = C + I + G + EX - IM \qquad (3)$$

In equation (3), Y represents the market value of all **final** goods and services produced within an economy during a time period. C is total consumer consumption (both local and foreign goods), I is investment in capital equipment and inventory increases, G is government spending, EX is exports and IM is imports.

Within SEAS-VIS, production in the short run changes in response to aggregate expenditures (i.e. the sum of consumption, investment, government spending and net exports). In the long run, demand is limited by the level of potential output, which is determined by the level of technology and the quantities of capital and labor operating through the production function.

International Trade

As mentioned, various sectors in SEAS-VIS can engage in bilateral trade. Each trading sector has an "import vector" that contains the quantity it wants to import from each of its trading partners. Exporting sectors, though, limit their total maximum exports, and therefore importing sectors may not be able to import all that they desire.

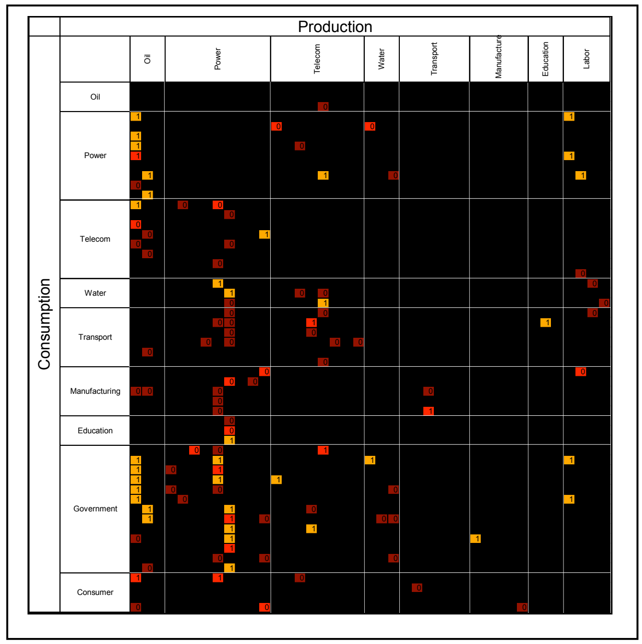
Levels of trade can change due to trade blockages and embargoes. If trade with one or more partners is hampered due to an embargo, a sector tries to make up the difference by increasing trade with other partners. Also, as a simulation proceeds, sectors change their export and import targets with all partners based on varying international and domestic conditions. For instance, a sector will increase exports if local demand is met, production capacity is available, and export inventory is almost depleted (which signals increased global demand).

Emergent Phenomena

SEAS-VIS presents a mechanism for exploring the micro-foundations of macro-level economic phenomena (which themselves proceed to influence microeconomic behavior). Once consumer, government and business infrastructure agents begin to stimulate demand within an economy, the production sectors begin to produce output according to their production functions. Economic agents within an economy engage in international trade if they cannot satisfy their demand and sell all of their supply domestically. International trade patterns change as domestic and international conditions fluctuate, and macro-level variables (such as GDP) emerge from micro-behavior while also influencing the latter in an iterative process.

Figure 3: Snapshot of emergent infrastructure interdependence, production, and consumption in Iraqi economy.

MODELING THE IRAQI ECONOMY



We use SEAS-VIS to model the Iraqi economy as a whole as well as its important components, and we also account for its interactions with other economies. Figure 3 is a snapshot of emergent infrastructure interdependence, production, and consumption within the Iraqi economy. Specifically, we model all of Iraq's eighteen provinces, 2,500 infrastructure nodes within the country, and its economic interactions with 48 other countries. Initial conditions include high domestic demand for goods and services and a decayed infrastructure, and we use SEAS-VIS to examine the social, political and economic impacts in Iraq and abroad resulting from various exogenous shocks, such as insurgent attacks on different critical infrastructure nodes.

Within this synthetic economy, the examples of major policy actions within DIME that can be taken are:

1. *Rebuild infrastructure*: Sectors that become a bottleneck for the economy may be given priority for infrastructure improvement.
2. *Improve efficiency*: The government negotiates importation of technology so as to increase its production efficiency. The "technology factor" increases as a result, requiring fewer intermediary

goods and labor for production (i.e. lowering "unit production requirements" for the country's production sectors).

3. *Negotiate trade contracts*: The list of trade partners may be expanded, and export targets may be increased.
4. *Regulate black market*: Government increases crackdown on the black market which may reduce its activity level, boosting the government's tax revenue for the next time period.
5. *Stimulate economy*: Government increases its expenditures budget, which results in more being spent on other actions and on the consumption of goods, services and labor. This increase can be funded by a budget deficit or/and foreign assistance. This in turn increases the demand for goods and services by consumers due to the multiplier effect.

Conclusion

SEAS-VIS can be used to create a synthetic economy that, once appropriately scaled and modified, can serve as a model for provincial, national and international economies. A synthetic economy is represented by thirteen production sectors and two consumption sectors, with each sector interdependent with the rest. A macro-economy emerges from the micro-level interactions of these fifteen sectors, and emergent macro-level phenomena in turn impact micro-level behavior within an ongoing and iterative process.

Synthetic economies within SEAS-VIS are only one portion of a larger ontological framework that also incorporates models of various social and political phenomena. As such, SEAS-VIS offers military and civilian planners a powerful tool for understanding social complexity. Perfect prediction is unattainable. But by marrying diverse social science theories with agent-based computational techniques, SEAS-VIS offers planners a powerful tool for understanding the strategic implications of various non-military effects.

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