

Modeling approaches and New Realities on Ground in Central Asia

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Nazli Choucri set the tone of the workshop by stating in her opening remarks the expectation of finding connectivity and synergy between the various modeling approaches rather than selecting a best fit method to understand security threats to the region and develop an intervention strategy that avoids/diffuses such threats. The discussion in my observation was cooperative, but perhaps did not fully meet Nazli's expectation. I'd like to begin by sharing my understanding of the three key methodological approaches to modeling brought to the table – namely, agent based modeling (ABM), dynamical systems modeling and system dynamics.

Agent based modeling (ABM)

Agent-based modeling can portray scenarios arising out of interaction of role players responding to rules and information contained in the outcomes of interaction. The programming process involves specification of rules of interaction for each designated agent. As an example, if population growth process is being modeled, the population agents in various age cohorts and gender groups may be assigned different rules of interaction such as:

If age= y , then exit with p probability (death event)

If woman, then find age (cohort identity)

If age within fertility period, then find if married (child bearing identity)

If no. of existing children= n , then give birth with q probability (birth event)

Etc.

This type of modeling will create interesting scenarios with much detail, once a model with a valid boundary and verifiable behavior is known, although getting to that starting point might have to be achieved through other methods. The rules and parameters can be varied with ease to test their impact. There is no designated explanatory process leading to the understanding of a realized scenario, and perhaps knowledge of the system (captured by the model and outside of it), would naturally be used to explain the scenarios created.

Dynamical systems modeling (DSM)

Dynamical systems modeling is based on differential equations. The model discussed above may be specified as follows:

$$d(P)/dt = P*(\text{birth fr.} - \text{death fr.})$$

where, birth fr. = (fr. Adults*fr. child bearing women*no. of live births over fertility period)/ fertility period);
death fr.= 1/av. Life expectancy

The model boundary is based on a specific complex pattern of deterministic behavior, such as bifurcation, chaos, oscillation. Explanatory process resides in the solution expressed in terms of initial conditions, parameters, mathematical functions and time. The solution of the above model will be:

$$P_t = P_0 * e^{(\text{birth fr.} - \text{death fr.}) * t}$$

which will be valid for all values of P_0 , birth fr. ,death fr. and t

Complete solutions in such a form can be found for simple models with linear relationships. Solutions to more complex (higher order and nonlinear) models are found through repetitive computer simulations that can identify the parameter ranges over which certain behavioral characteristics may appear. The solution process in both cases attempts to cover behavioral implications for all possible parameter sets, but does not provide a causal explanation of the behavior.

System dynamics modeling (SDM)

System dynamics modeling is based on developing the system structure on the basis of a pattern of behavior such as bifurcation, oscillation, s-shaped growth, overshoot, decline, etc. (called a reference mode). Behavioral patterns such as chaos have been modeled, but their policy implications are not well understood. The system structure is initially represented in the form of aggregate feedback loops postulated to exist between major subsystems, each of which is modeled in terms of stocks, flows and nonlinear relationships connecting them. Delays in information and material channels are explicitly represented. Feedback loops formed between the subsystems while constructing the model are compared with the postulated aggregate feedback structure initially posited as a first reality check. The ability of the model to produce the reference mode serves as a further reality check. Solution manifests in explaining the dynamic behavior of the model in terms of the changing dominance of its underlying feedback loops, although behavioral implications for all possible combinations of parameter sets may not be known. Computer simulation experiments are the means to getting to the understanding, but there is no prescribed way to conduct simulation experiments and represent their results, hence modeler skill is the key to arriving at meaningful results.

The model structure for the population growth problem would be graphically represented as in Figure 1 below:

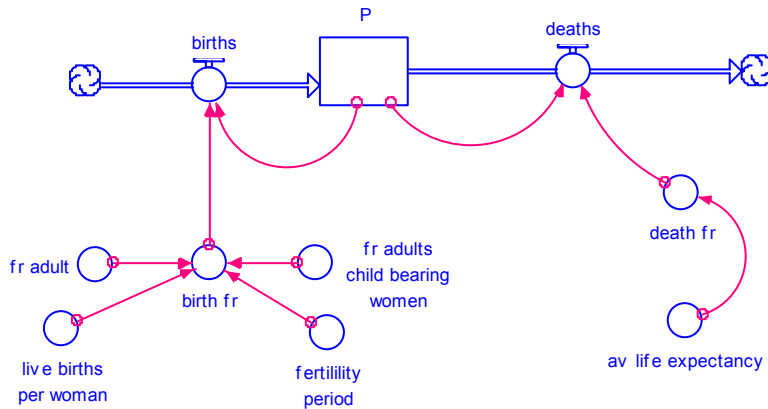


Figure 1: Structure of the population growth model

Model logic is expressed as integral equations as follows:

$$P(t) = P(t - dt) + (\text{births} - \text{deaths}) * dt$$

INIT P = 100

INFLOWS:

$$\text{births} = P * \text{birth_fr}$$

OUTFLOWS:

$$\text{deaths} = P * \text{death_fr}$$

PARAMETERS

$$\text{av_life_expectancy} = 70$$

$$\text{birth_fr} =$$

$$(\text{fr_adult} * \text{fr_adults_child_bearing_women} * \text{live_births_per_woman}) / \text{fertility_period}$$

$$\text{death_fr} = 1 / \text{av_life_expectancy}$$

$$\text{fertility_period} = 15$$

$$\text{fr_adult} = .3$$

$$\text{fr_adults_child_bearing_women} = .2$$

$$\text{live_births_per_woman} = 4$$

The explanatory process

The explanatory process involves reviewing both model behavior and model feedback structure and attempting to explain behavior in terms of the feedback structure. The behavior of the above model can be represented by at least three simulations shown in

Figure 2. These must be explained by referring to the feedback structure of the system represented in Figure 3.

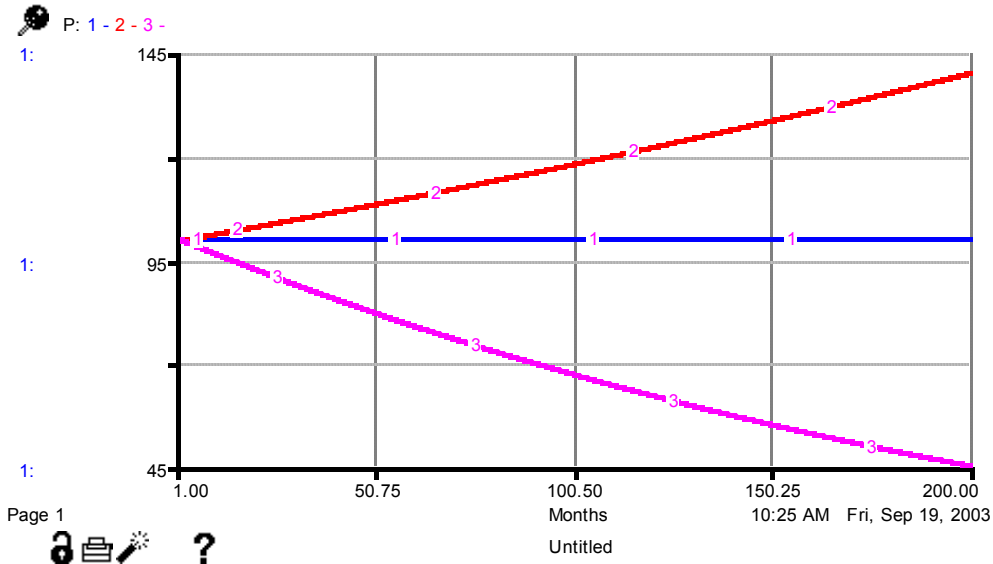


Figure 2: Minimum simulation paths needed to explain behavior

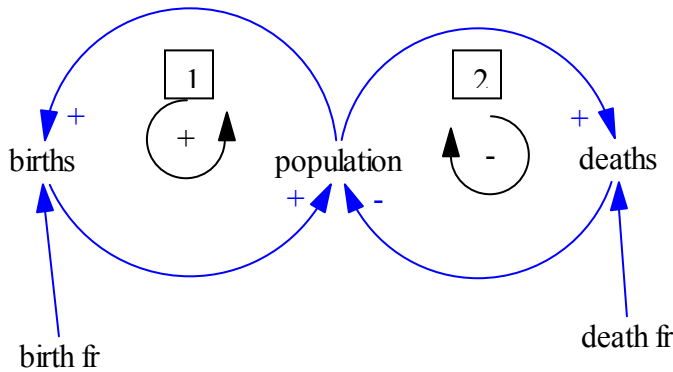


Figure 3: Feedback loops needed to explain behavior

The parameters birth fr and death fr control respectively the strength of the feedback loops 1 (reinforcing) and 2 (Balancing) shown. When birth and death fractions equal, the population is in a dynamic equilibrium shown by graph 1 in Figure 2. When birth fr > death fr, feedback loop 1 will dominate behavior and the system will exhibit exponential growth which is a characteristic of feedback loop 1. When, death fr < birth fr, feedback loops 2 will dominate behavior and the system will exhibit asymptotic decline to a goal of zero, which is a characteristic of feedback loop 2.

If a specific behavioral path is considered desirable, the policy issued by above analysis is to affect the parameters influencing birth fr and death fr. that control the growth and control feedback loops. Operational plans to do so and their implementation often require additional modeling effort.

I have gone into a rather pedantic detail to explain a simple system to assure that the spirit underlying the modeling process, which is to understand an observed dynamic behavioral pattern and identify entry points to change it to a more desirable pattern rather than obtaining a complete solution in terms of the behavioral patterns for all possible combinations of the parameter sets. This process can be applied to a more complex system, with varying degrees of effectiveness that continues to depend on modeler skill since all steps in the process, including the delineation of a pattern of behavior to be modeled, the architecture of the model, and the design of an experimental process that would deliver a clear understanding of the system and also identify operational entry points, require subjective judgments that cannot be obtained from a well laid out procedure.

Solutions to models or solutions to problems?

Let me first say, that I am defining solution in a mathematical sense, meaning understanding logic of the system in some form. All three modeling approaches described above provide some form of solution to the respective models they construct. An important question to be asked would be whether these solutions also provide an understanding of logic of the problems the models are built to address.

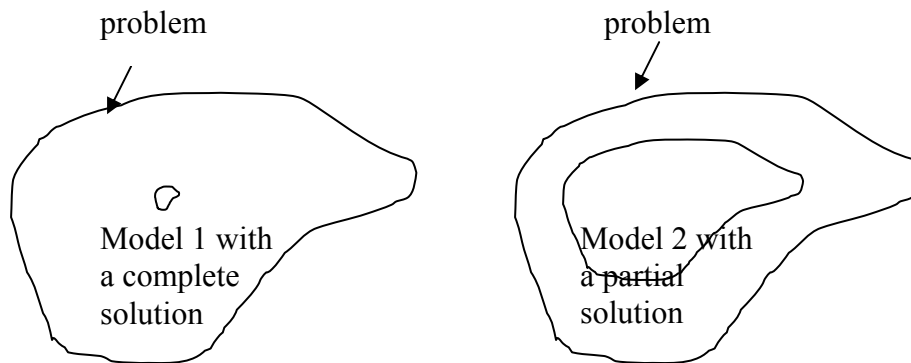


Figure 4: models and reality

Given that all models are wrong, a solution to a model has to be interpreted to become the solution to a problem. The more abstract is this model, the more complete and precise is the solution to the model, but the less precise is its interpretation for the solution to the problem at hand. Thus, as illustrated in Figure 4, an abstract model with a complete

solution may be less useful than a more realistic model with a partial solution when the solution to a problem is considered.

The way a solution is articulated also affects its usefulness. Thus a complete solution giving the outcomes for all parameter sets, might be irrelevant from a policy perspective when the parameters can neither be measured nor controlled. On the other hand, a solution outlining cause and effect relationships might be able to provide a clue to the design of corrective roles or remedial institutions counterbalancing malignant outcomes of existing causes and effects without carrying out any precise measurements.

Thus the choice of a modeling method selected for addressing a problem must depend on the purpose of the modeling effort, the nature of the data available and the available entry points into the system. If the purpose is intervention, a model that helps understand the system, and design a feasible intervention is obviously of value. Additionally, when numerical data is imprecise or unavailable, a model that provides a causal rather than a quantitative solution and intervention mechanisms would be of value.

Modeling agenda for Security of Central Asian States

I have outlined following modeling agendas in my presentation in workshop II. I should add that this is a *a priori* system dynamics modeling (SDM) agenda, since I am a system dynamics modeler. I will attempt to assess how DSM and ABM can add value to the process.

1. Understanding the system relationships underlying political patterns in CAS
 - Development of a valid model
 - Design and performance of experiments for understanding model behavior
2. Identifying agents of change and defining their roles
 - Design of a policy framework
 - Design and performance of experiments to articulate policy
3. Designing a policy implementation strategy to assure reliable performance of roles
 - Design of an implementation process
 - Design of experiments to outline a robust implementation strategy

Item 1 above is of immediate concern and items 2 and 3 are contingent upon satisfactory treatment of item 1. The first step in the modeling effort has to be delineation of a pattern of behavior that the modeling effort would explain. This step would normally involve following steps as suggested in Saeed (2003):

- 1) Collection of historical information related to the known dysfunctions to be addressed by policy so a ***problem domain*** is identified.
- 2) Decomposition of complex historical patterns in available historical data into simpler components and selection of a pattern of interest for modeling so a

preliminary boundary of an abstract system underlying the dysfunctional conditions is identified.

- 3) Aggregation of variables in the preliminary system boundary to eliminate unneeded detail and selection of a subset of these to determine a *preliminary model boundary*.
- 4) Identification of limiting factors not apparent in data and insertion of missing variables (usually stocks) representing them in the preliminary model boundary to obtain a *modified model boundary* that is also internally consistent.
- 5) Identification of phase relationships in the behavior constructed so far and intelligently inferring its future course to obtain an archetypal pattern comprehensively illustrating the *inter-related dynamic trends* internally created in the problem domain.

Unfortunately, there is little historical data expected to be available to allow construction of a problem patterns following above procedure. There, however, exists a variety of snapshots describing existing and projected conditions, both in terms of the state of economy and the state of governance in the Central Asian states. Hence the only way to construct a basis for the model would be to view the variety of available snapshots as multiple manifestation of system behavior and carefully examine stability characteristics of each snapshot. Policy frameworks can then be outlined for achieving designated paths.

The multiple manifestations can be represented in a carefully constructed state space. When dealing with several variables, several state space maps would have to be constructed to represent a given snapshot. Figure 5 shows a state space subsuming four key variables concerning the economy and the governance of the CA states discussed in Workshop I. These include the relative magnitudes of the legitimate and non-legitimate economic sectors and the nature of the government authority. The legitimate economic sector includes production of goods and services and payments to production factors as legitimately sanctioned by law of the land, the non-legitimate economy subsumes all goods, services and payments not allowed. These would include gains from bribery/influence or nepotism, drug and illegal weapon production and distribution, protection fees charged by warlords, income earned by people working for terrorists, drug producers and gun runners, etc. The government can exercise its control in two ways: through its ability to impose rules and regulations on public, which is termed manifest authority, and through its ability to elicit voluntary cooperation from public, which is termed moral authority.

In this state space, a country with a predominantly legitimate economy governed by a political institution that has moral authority over public will be placed at the top left hand corner. Examples of such countries would include the developed country economies governed through a democratic process. Perhaps none of the CA states would qualify to be in that category. In fact, most would tend to cluster somewhere in the lower left hand quadrant in Figure 5. It would be instructive to know why such a cluster occurs and what can be done to move this cluster to the top left hand quadrant and prevent it from moving to the two right hand clusters.

GOVERNMENT AUTHORITY	ECONOMY	
	<i>Predominantly Legitimate</i> ←	→ <i>Predominantly Non-legitimate</i>
<i>Predominantly Moral</i> ↑	Representative Democracy	
<i>Predominantly Manifest</i>	Oppressive Dictatorship	Anarchy, Lawlessness Warlordism, Extremist orders

Figure 5 State space representation of the economy- and governance- related variables

State space representations would have to be developed for other variables related to economy and polity and forming part of the scenarios articulated in Workshop 1. These would include the power of moderate and extremist dissidents, the civil rights and freedoms enjoyed by the public, the material and psychological welfare of the public etc. as discussed in simpler models in Saeed (1986) and Saeed (1990).

Once, a satisfactory placement of countries in the state space plots has been developed, it would be important to identify the actors and their respective roles that affect each delineated state as well as their goals and motivation. I suggest Table 1 as an example of how this step might be carried out.

Table 1: Internal actors, their motivations and actions.

Internal actors	Objective	Motivation to act	Actions
Public	Welfare/Civil liberties/Safety	Satisfaction	Support of govt. or dissidents
Government	Control	Threat to power	Resource allocation, change in civil liberties, armed action
Moderate dissidents	Reform	Support from public/civil society/external institutions	Censure of govt.
Extremist dissidents	Power	Govt. Failure, support of extremist orders and external institutions, opportunity	Insurgence, government overthrow
Legitimate producers	Profit	Demand	Investment
Non-legitimate producers	Profit	Failure of legitimate economy	Engage unemployed, seek facilitation from dissidents

The public seeks economic welfare, civil liberties and safety. Depending on its degree of satisfaction in those contexts, it would either support the government or the opposing groups.

The government seeks to keep its control. Depending on the degree of threat it faces to its control, it will take actions to allocate public resources to welfare and control activities, make changes in institutions providing civil liberties and in instances wage armed action against threatening groups.

Moderate dissident groups often seek reform. They are motivated by support from public, civil society and, sometimes, external institutions. Their actions mostly manifest in censure within the limits of the control order imposed by the government. Extremist dissidents, on the other hand seek to overthrow government and take control of power. They are motivated by the failure of government control, support of extremist orders (both religious and cultist) and external institutions. Their actions manifest in insurgency, and forced overthrow of the government.

As for the economy, both legitimate and non-legitimate producers might be seeking profit. The former attempt to meet the demand created from household income through investing in the legitimate sectors of the economy. The later profit from an economic failure through attracting the unemployed into illicit activity and facilitating this activity by seeking support of the dissidents. This would create a coalition of extremist dissidents and an underground economy manifesting in a culture of bribery, gun running, mercenaries, drugs and illicit protection taxation.

If I were to suggest a project, it would be to develop a model on above lines and experiment with it to determine the causes for existing behavior and to explore future paths of development and how they can be influenced.

Connectivity and Synergy between agent-based modeling, dynamical systems modeling and system dynamics modeling

It seems to me that system dynamics modeling (SDM) can provide the causal explanations, dynamic systems modeling (DSM) a detailed analysis of possible paths and the parameter sets that determine them, and agent based modeling (ABM) a variety of scenarios. SDM would be valuable if a causal explanation is needed and the data available to determine model parameters is rough. DSM would be useful if the system is precisely known and a model representing it can be applied to the system with confidence. DSM does not provide a causal explanation, but can give complete detail about the nature of the behavior as it would be affected by the various parameter sets. If we are dealing with a system where measurements are difficult and the magnitude of policy influence unquantifiable, the detail provided by DSM may not be helpful. ABM seems to provide neither a causal explanation, nor a complete detail about the behavior domains, but can create remarkably detailed scenarios for visual interpretation.

Given above strengths and weaknesses of the three approaches, I'd suggest use of SDM for the causal interpretation of the system, and identifying points of entry for change. ABM can then be used for developing detailed scenarios for variations in policies identified by SDM. DSM can be valuable in creating detailed analysis of simplified models subsuming the dominant structure once its causal interpretation has been understood using SDM.

References

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