RISK, INSTABILITY AND PROPENSITIES: A HYBRID MODEL OF FINANCIAL DISRUPTION

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ABSTRACT

Because of its inherent complexity, terrorist attacks that attempt to disrupt the international financial system are challenging to model. The present project integrates three scales of interaction, global, national and regional, each with the distinct dynamics, in order to explore the types of composite risks the financial sector faces. The model that connects the three layers is hybrid, with the first two mechanisms being in the form of systems dynamics mechanisms, and the third being a fine-grained agent simulation. These distinct components are integrated using Popper propensity fields.

INTRODUCTION

Financial instability can be caused by endogenous or exogenous factors, or a combination of the two (Johansen and Sornette 2002). While exogenous factors can be highly disruptive, they can be further exacerbated by endogenous weaknesses (Horwich 2000). A particular kind of exogenous threat to financial stability is posed by substate actors (cf., van Creveld 1991). Unlike conventional exogenous dangers, the terrorist threat is intentional and, thus, specifically designed to exacerbate and amplify natural weaknesses of the market.

Days before the 2004 U.S. presidential election, for example, Osama bin Laden (2004) released a speech to *Al Jazeera* in which he took satisfaction in putatively causing a million dollars of economic disruption for each dollar that Al Qaeda had 'invested'. He indicated that he and his co-conspirators will continue a policy of "bleeding America to the point of bankruptcy."

Economic and financial attacks can be used to complement and/or intensify more comprehensive terrorist disruption objectives. An attack on financial institutions might have multiple effects within a coordinated attack, including:

- Intensification of a complementary physical attack
- Undermining confidence in financial and/or government institutions
- Prevention of the provision of liquidity or other financial resources
- Penetration of banking institutions to conduct proscribed transactions
- Generation of revenue for terrorist networks

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- Disruption of global financial stability

However, the consequences of an attack, or series of attacks is a vast, unwieldy process to model in-depth.

The financial system is global, dynamic and immersed in the much larger economic system. There is extensive data on financial transactions, but most pertains to endogenous economic and financial concerns that might mask the effects of an adversarial perturbation. Complexities notwithstanding, a critical part of mitigation requires recognizing vulnerabilities and assessing the potential mitigation effects of various possible policy alternatives.

A model designed for these purposes will necessarily be partial. It must be notional in a way that seeks to decenter endogenous economic and financial interactions, while focusing upon perturbative effects, and the conditions which heighten them. Such notionality will need to be multilevel, recognizing that financial processes interleave global, national and local aspects. And, of course, the threat itself must be represented in order to trace its consequences.

The present paper reports on a project which undertakes to address these objectives. A Systemic Adversarial Financial Risk (**SAFR**) model is presented which accepts a particular attack scenario, and explores how the effects of the disruption spread through national, international and regional financial and economic institutions.

THE FINANCIAL DOMAIN

The global financial system can be conceived as having three interacting levels. First is the *national* system which includes exchanges and their regulation, payment and clearance system infrastructures, and a central bank and its policy capabilities.

There are multiple national systems, so their markets, payment systems, central banks, etc., influence each other internationally, thus, the second level is global. One of its major processes, and the one addressed in the present model is international capital flows. Investments of various types move from one currency to another, from one market to another, etc. Of course, the flow of investments influences the financial well-being of the impacted economies. The secure communications infrastructure has both national and international components, and some online markets (e.g., NASDAQ) can best be regarded as global as well.

The third level concerns firms and, especially, their operations that initiate and respond to orders and payments. These actors utilize financial infrastructures and are impacted by international capital flows. Their decisions, in turn, greatly impact national and global liquidity. Taken together, these three levels provide a complex target for terrorists, subtle policy considerations to the Federal Reserve Board, and a complex working environment for all financial participants.

Exchanges and the Economy

Stock markets impact and, in some ways, represent the larger economy with its diverse and intertwined industries. From the standpoint of disruption, there are two major categories of events: 1) major market shifts, most of which are entirely endogenous, and 2) material and operational disruptions.

The Infrastructure component represents flows of transactions through the payment, execution, clearance and settlement phases. Trading activities are processed only during normal (user-specified) operating hours on normal operating days subject to the exchange being available. The availability of the exchange can be limited by infrastructure and workforce availability as well as automatic shutdown due to market conditions.

Global Capital Flows

The capital flow mechanism is drawn from Tirole's model (2002) of instability in emerging economies and is global in nature. Its focus is the tendency for capital to flee during disruptive crises. This pattern can be observed as arising in endogenous financial dynamics, and has the potential to be exacerbated during adversarial attacks. More particularly, a massive and sustained withdraw of capital is potentially source of deep economic disruption and, accordingly, one of the fervent goals of terrorist movements. Figure 1 summarizes the structure of the model.

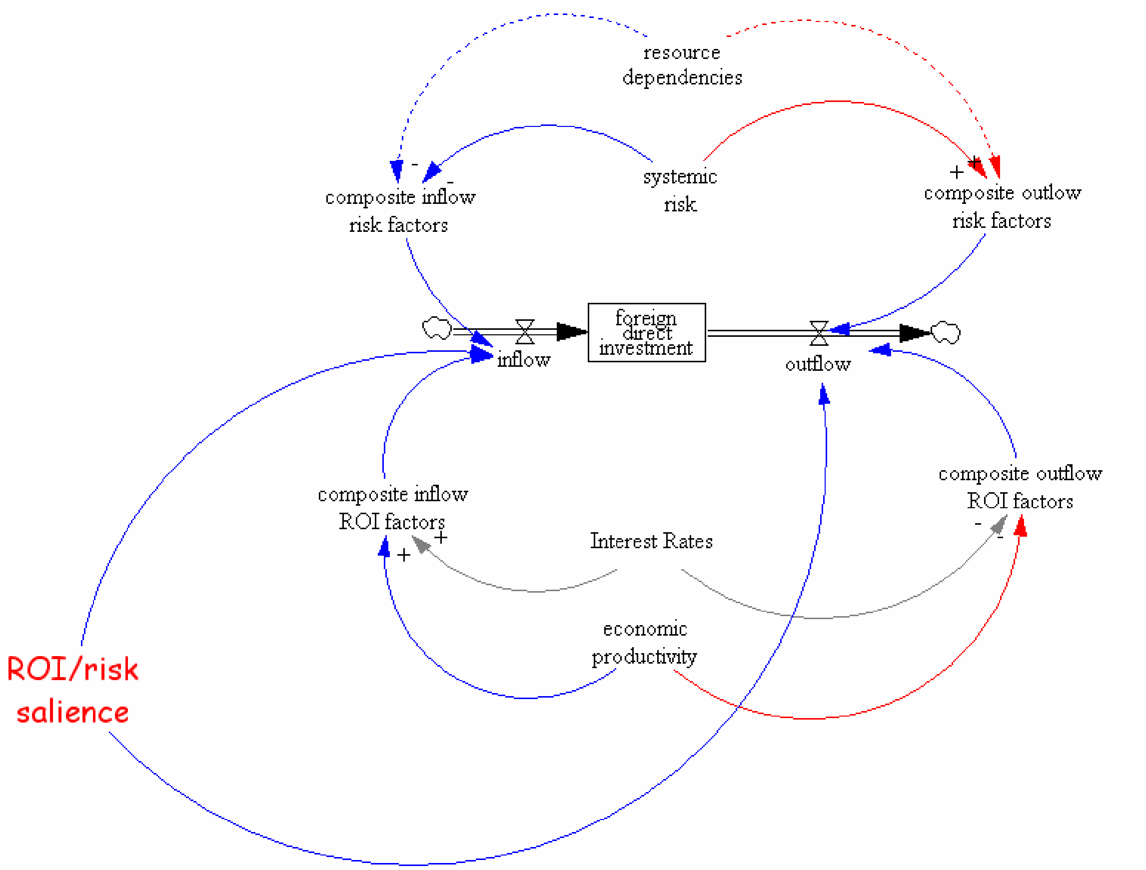

Figure 1. The Structure of Capital Flows

During normal economic periods, the importance of return on investment (i.e., interest rates and economic productivity) cause the lower loops to dominate. However, in a crisis period, risk becomes more salient and the upper loop dominates the flow of capital.

Transaction Practices

In addition to robustness issues related to physical infrastructure and operations, there are robustness issues related to firm responses to disruption as well. As an example of the latter, after an adversarial attack on economically sensitive targets and/or international financial infrastructures, systemic risk can be exacerbated, albeit inadvertently, by a reluctance of firms to resume payments until the flow of payments owed them has resumed. Because there is a densely connected network of financial obligations, each delayed response, measured in hours, has the potential to create, and then intensify, a liquidity crisis, correlatively deepening the danger of national and global systemic risk.

The robustness issues inherent in payment practices can best be captured using a fine grain agent-based model with the potential to clarify the effects of the range of responses of diverse firms to multiple interacting risks. The model differentiates representation of firms as distributed by industry, region and size based upon empirical data from the U.S. Census Bureau (see Figure 2 for an illustration).

	A	B	C	D	F	G	H	I	J
5	Geographic	2002 NAIC	Meaning of 2002 NAICS code	Meaning o	Year	Number of esta	Sls, shps,	Annual pa	Number of e
6	Alabama	211	Oil and gas extraction	Total	2002	45	1,393,849	47,556	792
7	Alabama	212	Mining, except oil and gas	Total	2002	154	1,068,472	257,667	5,549
8	Alabama	213	Support activities for mining	Total	2002	83	152,739	41,568	1,167
9	Alabama	221	Utilities	Total	2002	503	Q	948,747	16,014
10	Alabama	236	Construction of buildings	Total	2002	2,862	7,409,912	866,960	25,486
11	Alabama	237	Heavy and civil engineering const	Total	2002	835	2,963,658	655,496	17,128
12	Alabama	238	Specialty trade contractors	Total	2002	5,648	5,208,721	1,470,274	55,941
13	Alabama	311	Food mfg	Total	2002	299	7,150,635	875,050	36,481
14	Alabama	312	Beverage & tobacco product mfg	Total	2002	25	D	D	g
15	Alabama	313	Textile mills	Total	2002	90	2,765,167	407,110	15,628
16	Alabama	314	Textile product mills	Total	2002	118	1,389,825	152,636	6,292
115	Alaska	211	Oil and gas extraction	Total	2002	18	6,997,919	254,766	2,746
116	Alaska	212	Mining, except oil and gas	Total	2002	50	524,586	92,176	1,392
117	Alaska	213	Support activities for mining	Total	2002	63	731,621	307,635	6,162
118	Alaska	221	Utilities	Total	2002	89	Q	113,593	1,721
119	Alaska	236	Construction of buildings	Total	2002	785	1,682,501	240,198	5,399
120	Alaska	237	Heavy and civil engineering const	Total	2002	295	1,375,925	331,317	6,195
121	Alaska	238	Specialty trade contractors	Total	2002	1,279	1,358,943	366,942	9,763
122	Alaska	311	Food mfg	Total	2002	148	1,338,970	198,941	7,365
123	Alaska	321	Wood product mfg	Total	2002	33	27,756	5,150	176
124	Alaska	323	Printing & related support activiti	Total	2002	57	D	D	e
125	Alaska	324	Petroleum & coal products mfg	Total	2002	17	1,906,102	41,947	632
126	Alaska	325	Chemical mfg	Total	2002	6	D	D	e
127	Alaska	326	Plastics & rubber products mfg	Total	2002	13	28,472	5,032	121
128	Alaska	327	Nonmetallic mineral product mfg	Total	2002	30	D	D	e
129	Alaska	332	Fabricated metal product mfg	Total	2002	51	69,318	17,637	417
130	Alaska	336	Transportation equipment mfg	Total	2002	16	D	D	c

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Figure 2. Illustrative Firm Data from the U.S. Census Bureau

Mechanism Integration

Taken together, the three financial layers represent different scales of interaction and variegated types of risk. The capital flow mechanism is global in scope and places national issues in the context of international investment decisions. Notwithstanding, its global interaction (see Figure 3), capital flow is the simplest of the three layers.

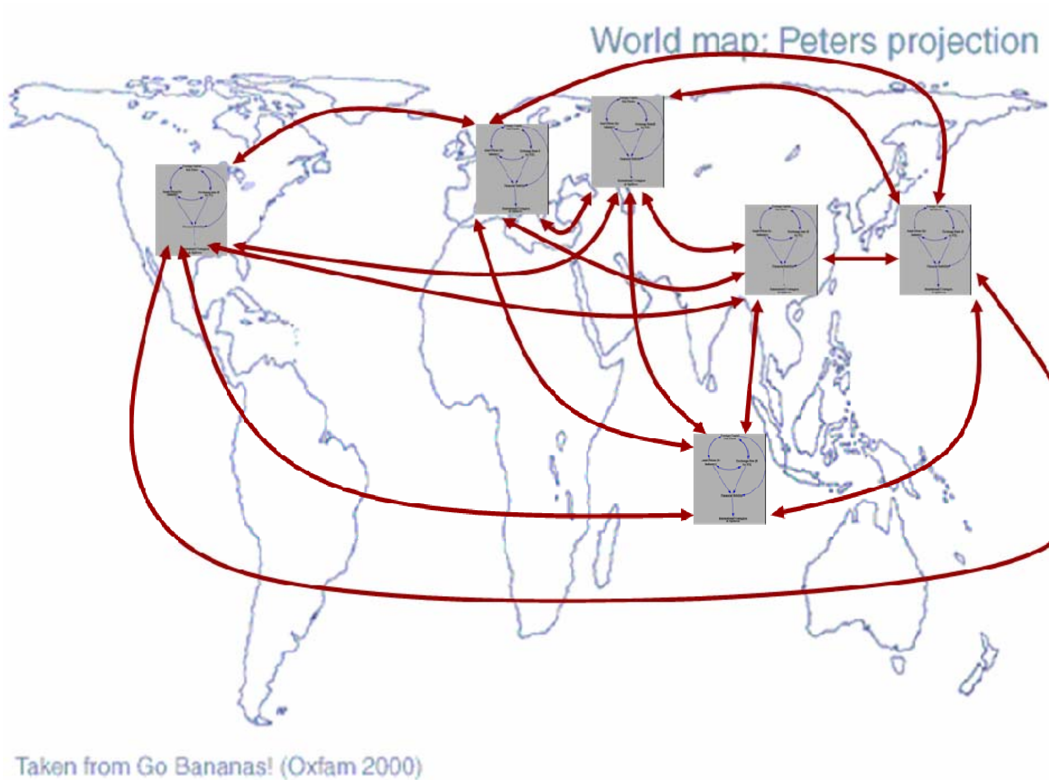


Figure 3. Global Capital Interactions

The Exchanges and Economy mechanism is national in scope, and more complex in focus. The exchanges are mostly physical and operational in form, and thus can be the direct target of attack with resulting disruption. In periods of crisis, exchanges have the protective mechanisms of circuit breakers and margin calls, which are explicitly modeled. There are payment and clearing infrastructures that can be a target of attack and thus can be disrupted causing further downstream effects. Finally, the economy incorporates diverse industries with varied geographical distributions and effects.

The third mechanism, representing payment resumption, is the most local and detailed of the three. It represents firm-level decisions in the face of unanticipated and disruptive circumstances. To do so effectively, the payment resumption mechanism takes into account the factors to which decision-makers give weight, some of which are summarized in the preceding section. Two alternative decision models are available, and others can be incorporated as needed.

MODELING FINANCIAL INTERACTIONS

Market Index

The Market Index as used in the model provides a diagnostic assessment for the rest of the model. While we do not explicitly model the immediate affects of a terrorist attack on the market index (the user supplies scenario data regarding the initial impact), we do model market changes as the initial impact ripples through the rest of the model. A stochastic stream of daily market fluctuations based on historical data from 1975-2005 is used to prime the system and provide a “normal” operating environment for the model. As stated, the user must provide an estimated market index adjustment profile along with the scenario data that describes the attacks.

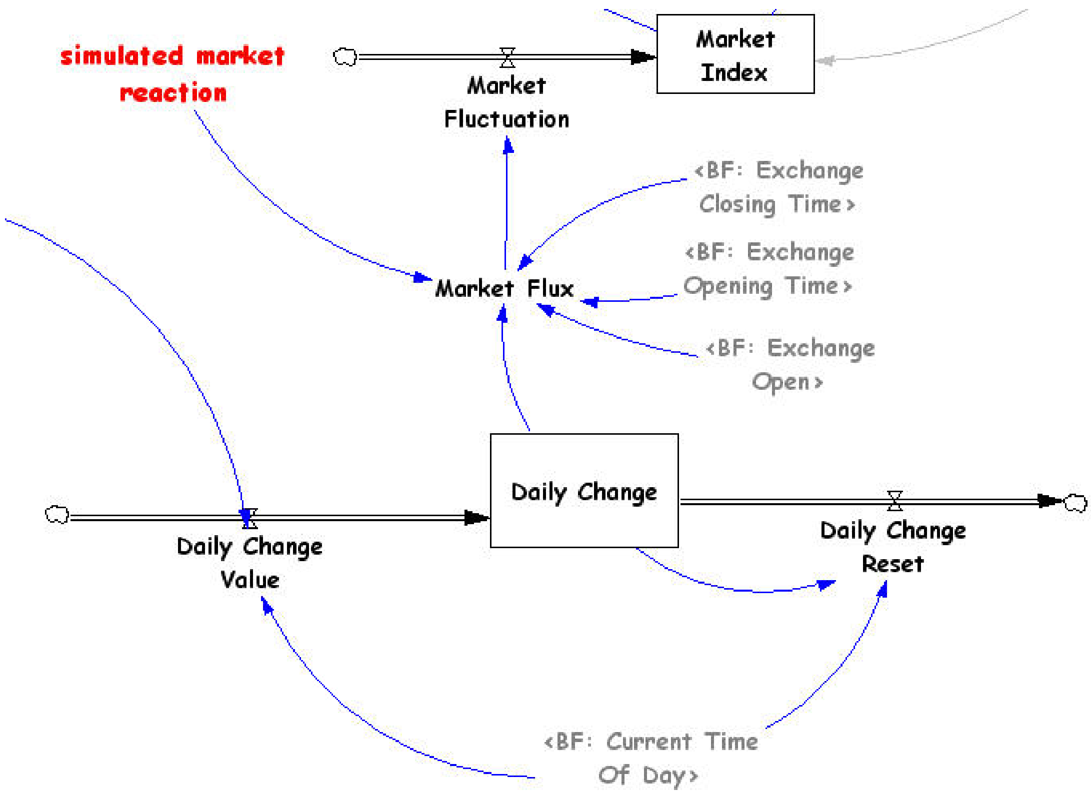


Figure 4. Monitoring the Market Index

Exchanges

The exchanges section of the model keeps track of the dollar volume flowing through the exchanges. The open hours of the exchanges are those of the New York Stock Exchange: Monday through Friday 9:00 A.M. to 4:00 P.M. Eastern Time. During closed hours, no volume flows occur. The operability of the exchanges is also dependant on a number of other factors: workforce and infrastructure availability, secure communications availability, and automatic shutdown criteria (circuit breakers) defined by NYSE (each of which is described in detail in a later section). The total time to complete a transaction on average is four days with one day each being utilized for execution and clearance and two days utilized for settlement. These dollar volumes “change state” as they flow through the system.

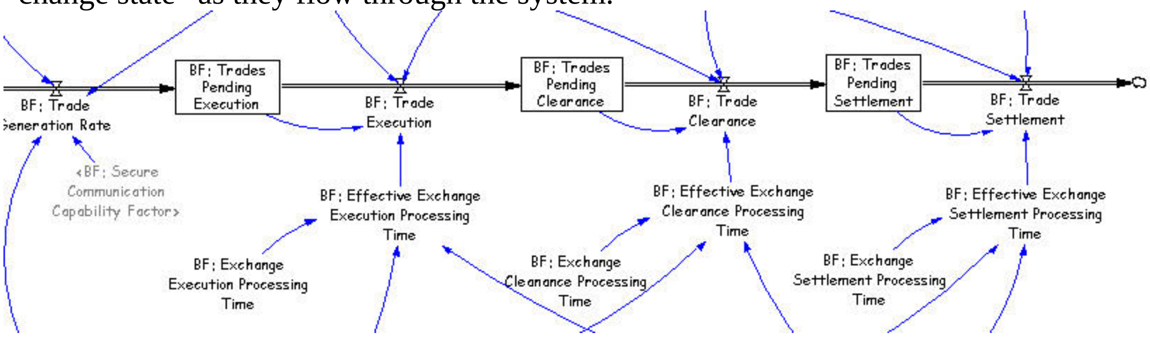


Figure 5. Monitoring the Dollar Volume Flow through the Exchanges

Workforce Availability

We want to be able to model attacks against people as well as against infrastructure (e.g. as in the anthrax release). The operation of the exchange is dependant on the availability of the workforce. If the workforce is reduced in number for any reason, there can be a decrease in the capability of the remaining workforce. We define a capacity factor that ranges from 0 through 1 where 0 indicates no capacity and 1 indicates full capacity. This capacity is then used to adjust the processing times of the various stages of the exchanges. Currently, the user specifies this workforce capacity factor profile as input. However, another model could easily be integrated that would compute this capacity based on scenario parameters. Note that the effects on workforce capacity are not limited to attacks: i.e. the model could be used to analyze the impact of a pandemic flu outbreak. There are currently workforce capability factors for the exchanges, depository institutions, and payments systems. The factors for depository institutions and payment systems are structured identically to factor for exchanges.

Infrastructure Availability

As with the workforce, infrastructure must be available for the processing of the transactions through the exchanges. An infrastructure capacity factor similar to the workforce capacity factor is defined in the range of 0 through 1. This capacity factor is then applied to the processing times of the various stages of the exchanges. This capability factor can be used to model a variety of situations from actual infrastructure damage, to infrastructure contamination, to lack of required resources from outside sources (e.g. electrical power). Currently, the user specifies the infrastructure capability profile as input. However, it would be easy to integrate additional repair or decontamination models that would define this profile. There are currently infrastructure capability factors for the exchanges, depository institutions, and payments systems. The factors for depository institutions and payment systems are structured identically as for exchanges.

Secure Communications

We model FEDWIRE and other communications in the Secure Communications segment of the model. There are a number of steps required for completing a transaction. We explicitly model execution, clearance, and settlement, each of which contains multiple information and data flows between participants. Since we are modeling at a high level of aggregation in this segment of the model, we do not track the low-level detailed communications. We also only consider the communications generated by the exchanges and payment systems. The transactions cannot complete until all communications have completed. We created a Secure Communications Capability Factor with the range of values of 0 through 1 that defines the capability of the communications system and is used to adjust the data transfer times accordingly. Secure communications are available 24 hours a day seven days a week.

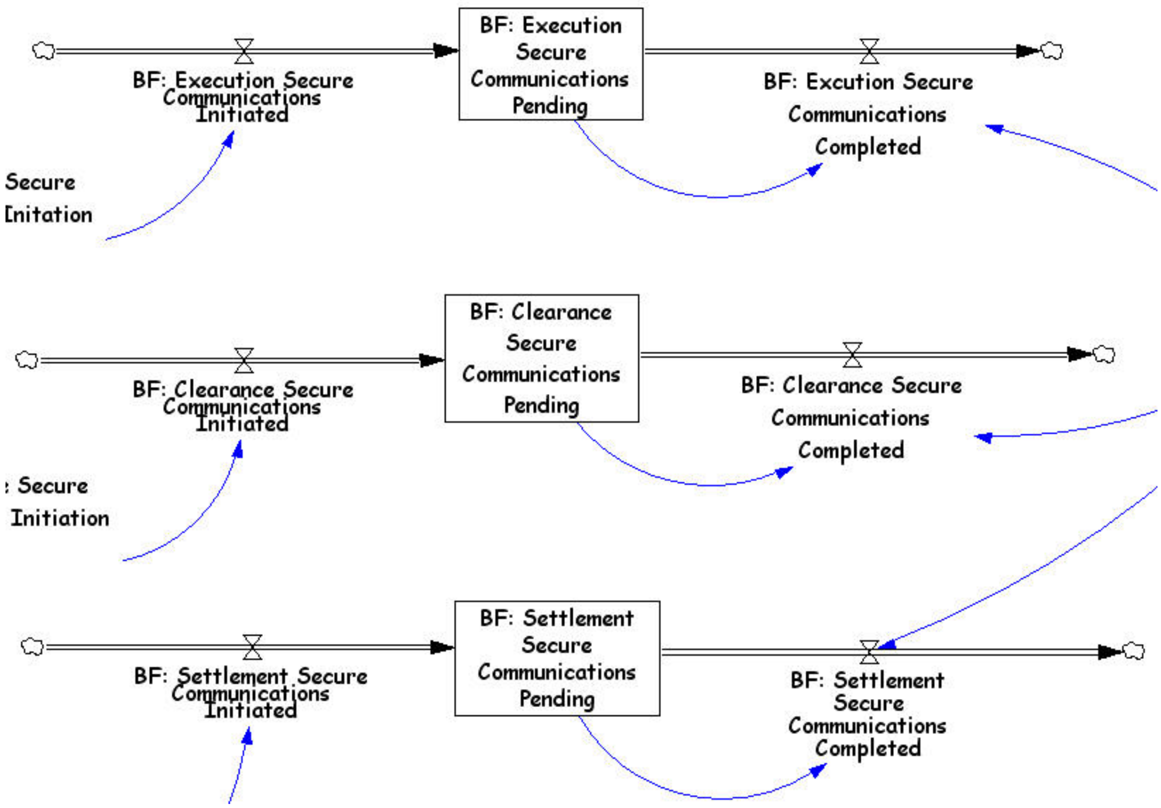


Figure 6. The State of Secure Communications awaiting Completion

Circuit Breakers

In response to dramatic drops in the market in October of 1987 and 1988, the New York Stock Exchange instituted, and the U. S. Securities and Exchange Commission (SEC) approved, a set of circuit breakers to reduce market volatility and promote investor confidence (see www.nyse.com/press/circuit_breakers.html for complete details). These circuit breakers are explicitly modeled and are tied to drops in the DJIA. They are summarized in Table 1.

Event (measured from the start of the trading day)	**Time of Day** (Eastern)	**Halt Trading?**
Ten percent drop in the DJIA		
	Prior to 2:00 p.m.	For one hour
	2:00 to 2:30 p.m.	For 30 minutes
	After 2:30 p.m.	No halt
Twenty percent drop in the DJIA		
	Before 1:00 p.m.	For two hours
	1:00 to 2:00 p.m.	For one hour
	After 2:00 p.m.	Close exchange for the day
Thirty percent drop in the DJIA		Close exchange for the day

Table 1. NYSE Circuit Breaker Policies

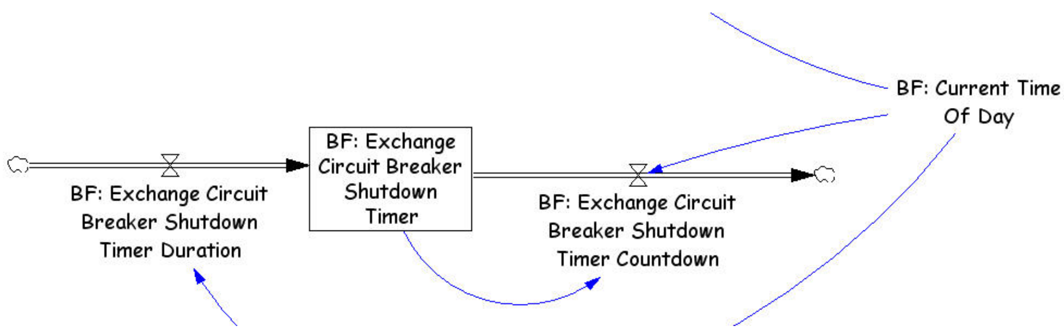


Figure 7. Circuit Breaker Shutdown Timer

Margin Calls

Investors can purchase securities on margin using some personal cash along with cash borrowed from the broker. The investor intends that the value of the securities increase sufficiently so that the loan from the broker can be paid and a profit is realized. To protect the broker, the investor must keep cash or other securities in a margin account with the broker. The value of this account must be kept at or above a minimum requirement. If the value falls below this minimum requirement, a margin call is issued and the investor must provide additional cash or securities. The investor can accomplish this by providing additional cash or by selling securities. In the event the investor does neither, the broker himself can sell securities owned by the investor.

Since such forced sales have the potential to shift prices in the market, as well as have a negative effect on investor confidence, we explicitly model these margin calls (at a high level of aggregation). We use a mechanism similar to that used for circuit breakers with an additional component. While circuit breakers are triggered only during extreme market conditions, margin calls occur on a daily basis regardless of market conditions. So we add stochastic margin call transactions to the system based on historical data. We then monitor the changes in the market index and amplify the margin calls as the market index drops beyond the user-specified limits.

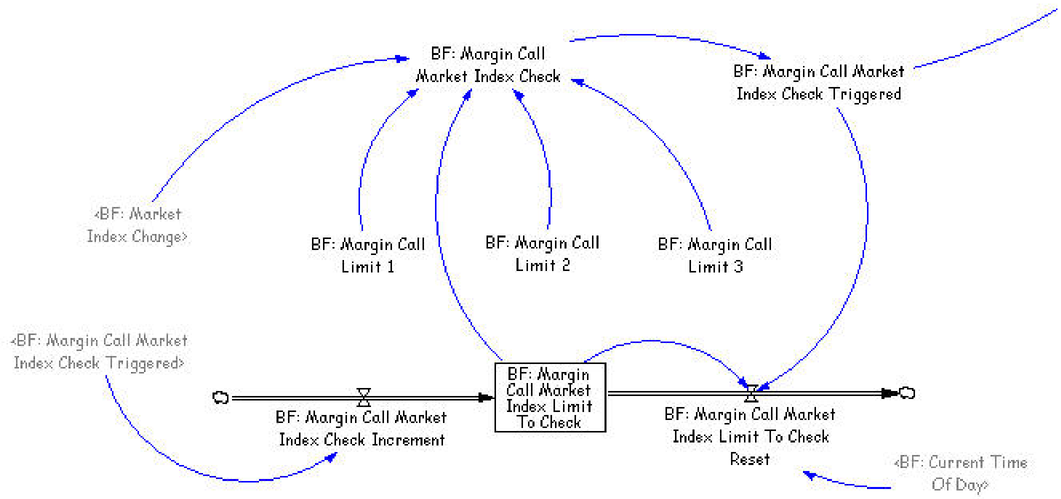


Figure 8. Monitoring Market Fluctuation with respect to Margin Calls

Payment System

The model explicitly models the Payment System (PS) of the U. S. economy. The dollar volume of payments that requires clearance and settlement (such as the issuance of a check) are tracked by the model. Three sources of these payments are available within the model: exchange payments, foreign indirect investment payments, and sector payments (payments by individual firms). The Payment System is dependant on four separate capability factors: PS Infrastructure Capability, PS Workforce Capability, Depository Institution Infrastructure Capability and Depository Institution Workforce Capability. The integration of the System Dynamics model with the Agent models of Transactions and Cash Pinch occurs in the Payment System segment of the model. The agent models aggregate their data and provide it in a System Dynamics-compatible form.

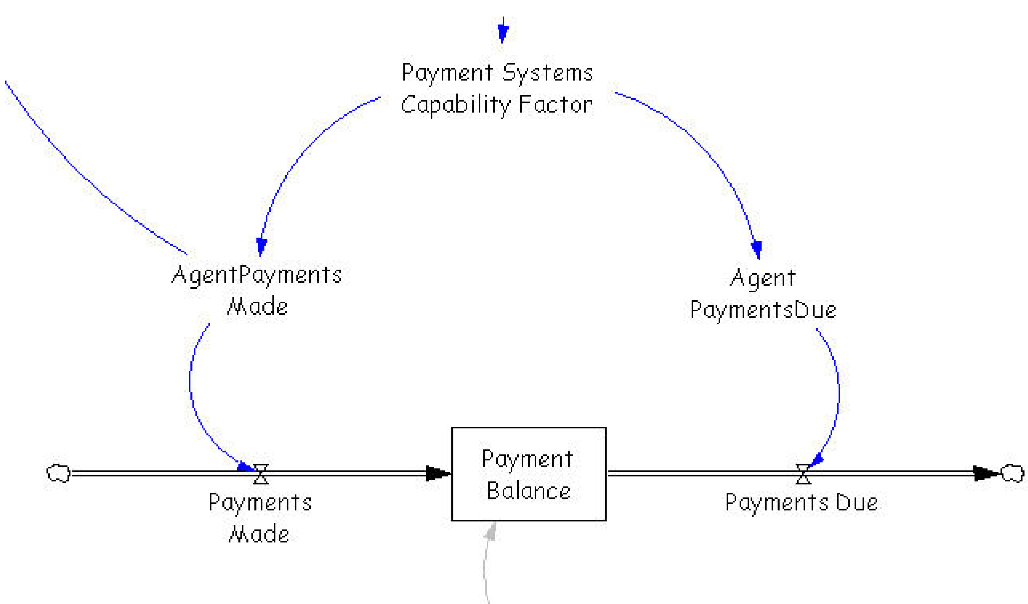


Figure 9. Payment Systems linkage to Agent Models

International Cash Flow

The International Cash Flow segment of the model analyzes the indirect effects of a terrorist attack on the U. S. through the direct effects on Economic Productivity, Interest Rates, and Systemic Risk. The model considers both Return on Investment Risk (ROI) and prospective undermining of the Safe Haven assumption of foreign investors reacting to investment opportunities in the U. S. When the opportunities are favorable, foreign investment tends to increase; when unfavorable, they tend to decrease.

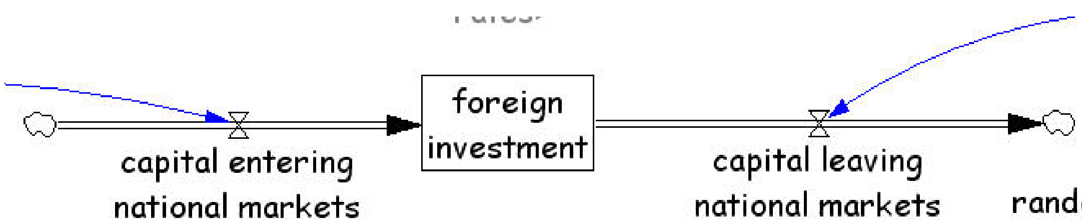


Figure 10. Monitoring Foreign Investment

Two agent models have been integrated with the System Dynamics. Each models the payments made and received by individual firms. They implement two different firm-level philosophies of payment resumption after a terrorist attack.

Transactions

The Transactions segment of the model generates the hourly payables from and receivables to the Firms that are of interest within a geographic region, industry and size for the scenario under consideration. The annual payments, receivables and the number of firms are collected from the U.S. Census Bureau online database. Based on this data, individual Firms are created which belong to a specific industry (four digit NAICS) and geographic region (U.S. State) that have expected annual payments and receivables using a Pareto distribution. The expected annual payments are distributed into expected daily payments and then into expected hourly distributions using Gamma distributions. Each hourly payment is categorized into mandatory, necessary and contingent portions. The actual transactions (payments and receivables) can be modeled either by Field Effects or Cash Pinch mechanisms. The two mechanisms are described below:

Field Effects

The propensity of the Firms to pay any outstanding dues is modeled using the Field Effects. The field effects have components that are generic, regional and industry specific. The user inputs the field effects for the adverse conditions (e.g. terrorist attacks) and for the recovery period. The actual hourly payments are a function of expected hourly payments and field effects. Any payments that are not paid in the current hour are accumulated into a backlog and scheduled into the next month's expected payments.

Cash Pinch

The Cash Pinch agent model uses a Cash-On-Hand perspective to determine which, if any, payments will be made. Each individual agent (firm) starts off with a specific amount of cash in its possession along with a schedule of expected payments and receivables. The schedule is per month and it is repeated for each month in the simulation.

All spending is classified as either discretionary or nondiscretionary. As the model executes, the firm compares the cash on hand with its payments and receivables for the day and determine if there are sufficient funds to pay all bills. When there is a cash shortfall, the firm will determine which if any of its bills will be paid on time. Discretionary spending is first curtailed. Any discretionary payments in arrears are considered nondiscretionary at the point at which the new payable date is assigned. The goal is to remain solvent through the time frame. The model makes the simplified assumption that business makes a profit. During times of anticipated financial problems, the firms will divert available cash to run the business.

CONCLUSION

The banking and financial sector provides services to the American economy and, increasingly, to an integrated global economy. Accordingly, it is vast, dynamic and interwoven in complicated, evolving ways. No model can do full justice to its complexity.

At the same time, the banking and financial infrastructure is a target for terrorism, both directly and as a collateral consequence of attacks on other primary targets. A successful attack on the financial infrastructure is likely to have ripple effects throughout the country and the world. Thus, for the sake of protection and mitigation, it is imperative that we model the financial infrastructure, including its vulnerabilities, interactions and the threats it faces.

The present project assembles three interaction layers, global, national and regional, each with distinct dynamics, in order to explore the types of risks the financial sector faces. The model that connects the three layers is a hybrid, with the first two mechanisms being systems dynamics, and the third being an agent simulation. Currently, a variety of scenarios is used to exercise the model, and a scenario generator that will perform sensitivity analysis is in the near-term plan.

A METHODOLOGICAL APPENDIX

Propensity fields are an underutilized conceptual innovation of Karl Popper, the respected philosopher of science (1990; 1959). Popper originally developed the propensity interpretation as contribution to the foundations of probability theory, and as an alternative to the frequency interpretation of statistics.

Using examples from physics and gaming, *inter alia,* Popper maintains that sequences of outcomes can best be understood as a product of their generative conditions. Loaded dice, for example, depart from a uniform distribution of outcomes (between 1 and

6 per die) whether they are rolled once or 10,000 times. Probability is thus not a property of the sequence of rolls, but of the generating conditions.

Popper's insight can be expressed using the same formalism as conditional probability and/or Bayesian probability:

$$pp(a \mid b)$$

which may be read as: 'The probability of event a, given conditions b'. However, in view of the potential complexity of the generating conditions, this formulation can be regarded as deceptively simple.

Thus, the propensity interpretation alters analytical attention toward the potentially complex conditions that generate stable statistical sequences. In addition, the focus is shifted from an individual unit (actor, mechanism, etc.), to the broader situation in which the focal unit operates. Popper regards the propensity interpretation as defining a *physical* hypothesis. That is, the set of generating conditions exists (Popper 1990:12):

> Propensities, it is assumed are not mere possibilities but are physical realities. They are as real as forces, or fields of forces. And vice versa: forces are propensities.

Urbach (1980) observes that propensities apply to social phenomena as well. He uses Durkheim's (1897 [1951]) analysis of suicide rates (which vary in stable ways based upon ethnicity, religious affiliation, economic trends, etc.) as a recognized example of social propensities. From the standpoint of modern complexity theory, we can say that social propensities are not just physical, inasmuch as they manifest emergent forms of interaction and organization that exhibit their own dynamics.

Since the propensity interpretation of statistics is initially an interpretive framework within the philosophy of science, (cf., Gillies 2000), it might be seen as only an abstract refinement of the search for philosophical clarity. However, there is a second aspect to propensity theory, revealed in Popper's assertion that 'propensity' articulates a physical hypothesis.

Viewed from the standpoint of realism, propensity fields provide a new way of modeling and integrating forces and fields of diverse types. Popper, continuing the above quote, writes:

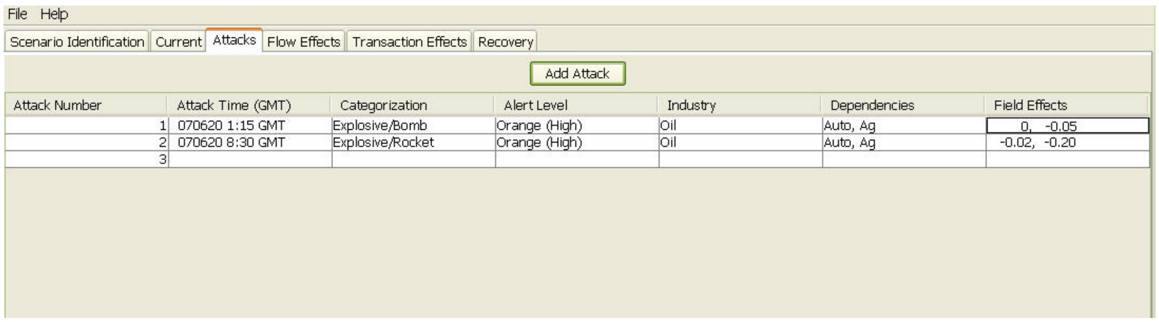
> Forces are propensities to accelerate and fields of forces are propensities distributed over some region of space and perhaps changing continuously over this region … Fields of forces are fields of propensities. They are real, they exist.

From this perspective, any force that contributes to a propensity field can be incorporated into a more inclusive field (while its distinct contribution remains analytically available). This is critically important for computational social science, because it introduces a conceptual framework with which multiple factors and complex interactions can be integrated within a common model.

From a project perspective, multiple disciplines and/or experts can contribute particular types of insights, making the overall model stronger. Cross-disciplinary interactions can then be explored, compared and assessed. The use of propensity *fields* also allows representation of the (spatially, temporally, structurally and dispositionally) situated nature of many social propensities and, thus, provides a mechanism for examining consequences across high-dimensional and dynamic topologies.

SAFR Propensity Fields

SAFR incorporates an innovative attempt to define and use propensity fields in a policy-oriented application. As shown in Table 2, an overall attack is characterized in terms of its 'field effects' (column seven of the input panel). The fields being referred to are propensity fields, actual physical and socio-economic fields that shape responses to an unexpected attack.



Attack Number	Attack Time (GMT)	Categorization	Alert Level	Industry	Dependencies	Field Effects
1	070620 1:15 GMT	Explosive/Bomb	Orange (High)	Oil	Auto, Ag	0, -0.05
2	070620 8:30 GMT	Explosive/Rocket	Orange (High)	Oil	Auto, Ag	-0.02, -0.20
3						

Table 2. Attack Effects on a Propensity Field

The model assumption is that there are standard (and largely rational) operational practices that define 'business as usual'. An unexpected disruption can cause business and institutional decision-makers to depart from the prevailing practices (which are themselves propensities), and these changes will ripple through the financial system in diverse, and often unexpected ways. Financial system interactions resulting from such impact(s) are what the model is designed to identify.

Characterization of the impact of an attack requires judgment on the part of the analyst. Given the complexity of the economic/financial system, there may be dozens or hundreds of factors that would mitigate or intensify such an attack, ranging from the immediacy and severity of recent attacks, and the element of surprise, to the overall health of the economy including, especially, the industries most directly disrupted.

During normal business operations, propensity to place orders, pay bills, etc., are assumed to proceed at a relatively high-level. For the sake of discussion, assume that level is 0.95 on a 1.0 to -1.0 scale. Two specific effects reducing the systemic propensity field are designated by the user for each attack. The first is the impact of a change (or non-change) in the alert level (column four), and the second is the impact of the attack itself.

The field effects for the example are found on the left and right sides of column seven, respectively. They are listed separately because the two responses are only loosely coupled, and an analyst may wish to distinguish a reaction to an attack from the reaction to a change in an alert level notwithstanding that, for calculation purposes, **SAFR** will combine the two effects, as the joint impact spreads to more detailed aspects of the model.

The analyst may further specify how attack effects move through the model. Attack effects specified in Table 1 may be seen has causing a shift in ‘safe haven’ assumptions. In Table 3, as indicated in the bottom row, assessment of systemic risk may

File Help

Scenario Identification | Current | Attacks | Flow Effects | Transaction Effects | Recovery

Flow Effects

	USA			London			Tokyo		
Interest Rate	Minimum	Rate	Maximum	Minimum	Rate	Maximum	Minimum	Rate	Maximum
	1.0%	4.5	6.0%	1.0%	5.0	6.0%	1.0%	1.0	6.0%
Economic Productivity	Minimum	Productivity	Maximum	Minimum	Productivity	Maximum	Minimum	Productivity	Maximum
	3.0	3.0	10.0	3.0	3.0	10.0	3.0	3.0	10.0
Systemic Risk	Risk	+/-		Risk	+/-		Risk	+/-	
	98.6	0.1		98.6	0.1		90.2	0.1	

Table 3. Shifts in Systemic Risk Assessment Alter In/Out Flow of Capital

be changed by an attack. Since attacks are characterized in Table 1, such shifts can be considered to be a function of the field effects there specified. This is the first example of how propensity effects propagate through the model, and the effect is to recalibrate a systems dynamics mechanism. The impact on capital flow may vary by field location (in this case, proximity to the attack, similarity of political positions and/or vulnerability profile, and assessment of overall risk). Since each nation/market will vary in their topological location within such a framework, in the context of attack assessment, each function will be individually specified. While the three nations represented in Table 3 constitute only a small field, scenario generation is designed to support all major international markets and will, thus, benefit from the full expressiveness of the propensity field to adequately represent global safe haven assumptions.

In Table 4, propagation of the propensity field effects continues, this time by as input to an agent simulation mechanism. Specifically, firms within the larger economy are distinguished along two dimensions: 1) firm size, and 2) the industry of the firm, specifically, its proximity to the attack. Both dimensions are divided into tripartite

File Help

Scenario Identification | Current | Attacks | Flow Effects | Transaction Effects | Recovery

Transaction Effects

% Firms Using Field Effects

Firm Size	Generic Default	Generic Value	Primary Default	Primary Value	Secondary Default	Secondary Value
Large	10.0%	10.0%	12.0%	23.0%	12.0%	18.0%
Medium	10.0%	10.0%	15.0%	32.0%	22.0%	28.0%
Small	10.0%	10.0%	22.0%	44.0%	22.0%	32.0%

Table 4. Transaction Effects of an Attack

categories (large, medium & small; and primary [disruption], secondary & generic) although, when supported by available data, finer grain distinctions would be feasible.

This portion of the larger field illustrates how propensity fields can be used to express and integrate more complex processes. In this case, two distinct business decision frameworks are available: a strict accounting mechanism (cash pinch), and a more holistic 'sense of the business climate' mechanism (intuitive response). In normal times, most businesses are presumed to operate on a strict accounting basis, although a few (mostly smaller) businesses organize their operations intuitively. However, after a disruption, a portion of firms of various sizes will intuitively assess the scale of the disruption and the pace at which a normal business climate will return. Currently, the intuitive mode of operation is assumed to be correlated with larger disruptions and smaller firm sizes. As recovery progresses, more firms will return to strict accounting as the organizing principle. In the **SAFR** model, these decision frameworks are implemented in software based on specific receivable/payable data.

The final example shows propensity fields that are temporally structured. Table 5 illustrates the rate of recovery as distributed across firm size, industry and regional impact, as well as time intervals expressed in diverse units. The panel illustrates the detailed specification of such recovery assumptions, but it is also possible to indicate the recovery patterns using probability distributions. The ability to use either, and to combine them with supplementary approaches, illustrates the flexibility of the propensity field as a socio-technical modeling mechanism.

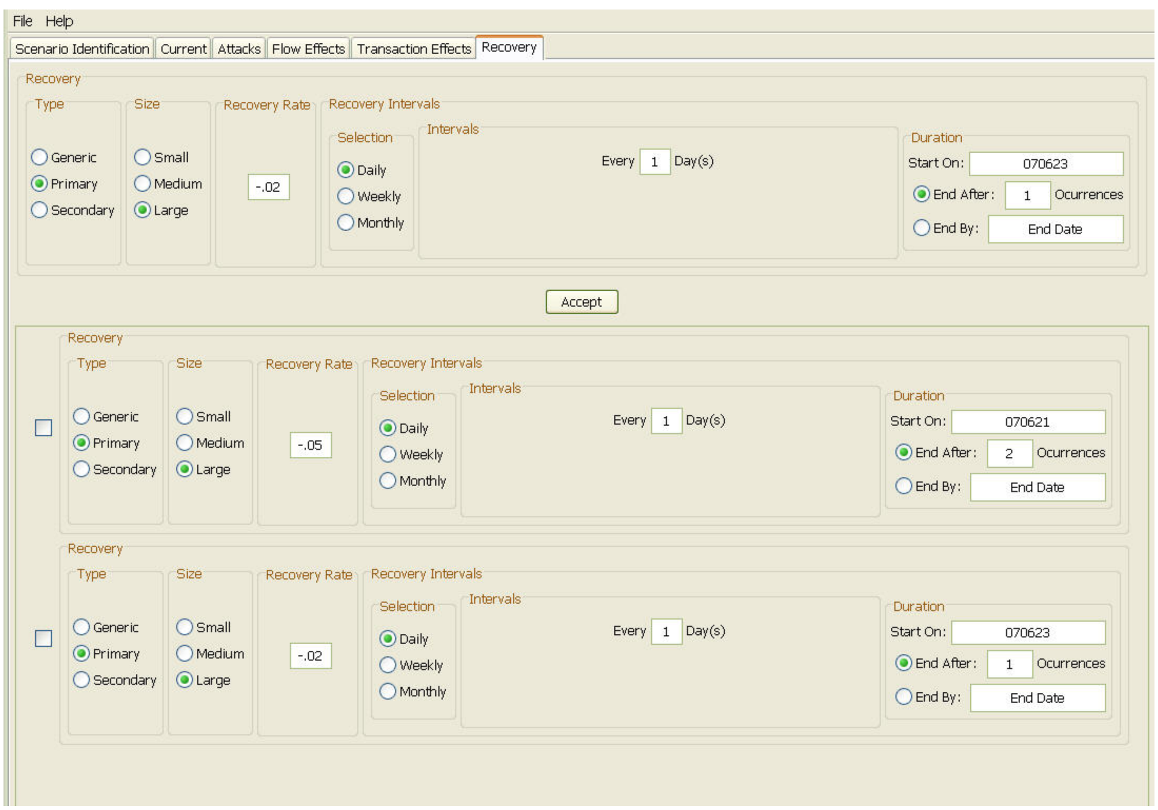


Table 5. Recovery Rates across Intervals and Assumptions

The Virtues of Propensity Fields

As illustrated, the overall propensity framework, as articulated by Popper, Urbach and others, can be used to integrate propensities arrived at in strikingly divergent ways, from simple assumptions to complex empirical and/or theoretical models. As previously shown, both aggregate results arising from systems dynamics models and patterns emerging from agent simulation mechanisms can be expressed as propensity fields. The latter can also calibrate available mechanisms based upon the actor's location in a more comprehensive propensity field. This combination of flexibility, expressiveness and integration makes the propensity field a highly useful modeling framework.

At the same time, while propensity theory provides a formalism that can represent diverse mechanisms, actors, situations, states and outcomes, it does not provide protection against the development of weak or inappropriate generative mechanisms. Indeed, the identification, representation, integration and validation of relevant propensities are among the vital challenges inherent in the modeling of complex systems of various types.

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