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Systemic Adversarial Financial Risk: A Modeling and Mitigation Tool

Argonne National Laboratory White Paper

Decision and Information Sciences Division

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Systemic Adversarial Financial Risk: A Modeling and Mitigation Tool

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by
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EXECUTIVE SUMMARY

In the new century, the global financial system has become a terrorist target. In the 2001 attack on the World Trade Center, 74% of the 2,800 victims were from the financial industry. Shortly before the 2004 presidential election, Osama bin Laden committed to "bleeding America to the point of bankruptcy." While panics and crashes do occur periodically, the financial community must, in the face of an asymmetric threat, understand whether and how economic and financial vulnerabilities can be exacerbated and exploited by adversaries. One way of addressing this danger is to use computer models to explore the potential interaction of systemic financial risks with possible adversarial intervention. This White Paper is a report on one such initiative.

The global scale and complexity of intertwined economic and financial systems present a modeling challenge. Further, neither of the relevant academic disciplines, economics nor finance, focuses on extremal events. On the contrary, the normal range of events that concern financial institutions does not include their robustness in the face of attack.

The Systemic and Adversarial Financial Risk (SAFR) model, developed by Argonne National Laboratory, is a decision support tool designed for the financial and homeland security communities to support assessment of adversarial risks and how such risks interact with other sources of systemic risk. SAFR has three interacting levels: (1) operational institutions that can be directly disrupted (e.g., secure communications and exchanges); (2) international capital flow; and (3) firm transactions. The three levels interact and influence each others' emergent patterns of action during a disruptive event.

Analysts can generate alternate scenarios as a means of specifying diverse assumptions regarding the nature of a possible attack (or categories of attacks), enabling them to explore simulated results and how they vary based on differences in scenario assumptions. The result is the ability to perform sensitivity analyses on complex threats to the national and international financial system.

To date, the core capabilities of the SAFR model have been implemented. Five areas of development have been identified that are necessary to make the model a comprehensive and valuable analysis tool.

1 INTRODUCTION

Financial instability can be caused by internal or external pressures or a combination of the two (Johansen and Sornette 2002). External factors can not only be highly disruptive but further exacerbated by internal weaknesses (Horwich 2000; Bartram et al. 2005). An emerging kind of external threat to financial stability is posed by substate actors (van Creveld 1991). Unlike familiar military dangers, a terrorist threat takes the financial system as a target and seeks to amplify natural weaknesses of the market.

Days before the 2004 U.S. presidential election, Osama bin Laden (Worldpress 2004) released a speech to *Al Jazeera* in which he took pride in supposedly causing a million dollars of economic disruption for each dollar that Al-Qai'da spent. He warned 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 infrastructure-oriented terrorist attack goals. 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 illegal transactions,
- Generation of revenue for terrorist networks, and
- Disruption of global financial stability.

Given this range of possible objectives, the consequences of an attack or series of attacks are complex and difficult to model.

The financial system is global, dynamic, and immersed in the economic system, which is significantly larger. While there are extensive data on financial transactions, of course, most the data pertain to economic and financial interactions, and their very complexity is likely to mask the effects of a terrorist attack. A critical part of prevention and mitigation requires recognizing vulnerabilities and assessing the potential mitigation effects of various possible policy alternatives.

Necessarily, a model designed for these purposes cannot be comprehensive. It will be notional in a way that decenters endogenous economic and financial dynamics, while focusing on perturbative effects and conditions that heighten them. The resulting emphasis will be multilevel and recognizes that financial processes reflect global, national, and local aspects. Finally, in order to trace its consequences, the threat itself must be modeled.

This White Paper reports on a project that addresses these objectives. An integrated model is presented that enables specification of a particular attack scenario and then explores how the effects of the disruption spread through national, international, and regional financial and economic institutions. The attack scenario may be a single event or a complex event composed of overlapping disruptions that may result from multiple natural disasters, terrorist exploitation of a natural disaster, or coordinated terrorist attacks against various infrastructures at multiple locations.

2 THREE STYLIZED TIERS

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

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

The third level concerns *firms*, especially their operations for initiating and responding to orders and payments. Firms utilize financial infrastructures and are affected by international capital flows. Their decisions, in turn, significantly affect national and global liquidity. Taken together, these three levels provide a complex and interdependent target for terrorists, intertwined policy considerations for the relevant central banks, and a complex working environment for all financial participants (see Appendix A). The three tiers are described in Sections 2.1 through 2.3, and their integration in Section 2.4.

2.1 Exchanges and Economy

Stock markets affect and, to some extent, 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 (Kindleberger 1989; Davis 1992; Borio 2004), and (2) material and operational disruptions (Benson and Clay 2004). All such disruptions take place against the backdrop of simulated market fluctuations (Figure 1).

In the model, the infrastructure mechanism (see Section 3.4) represents flows of transactions through the payment, execution, clearance, and settlement operations (Humphrey 1995; Fry et al. 1999; Loader 2002). Trading activities are processed only during normal (user-specified) operating hours on normal operating days subject to the availability of the exchange. This availability can be limited by infrastructure and workforce availability, as well as automatic closure due to market conditions.

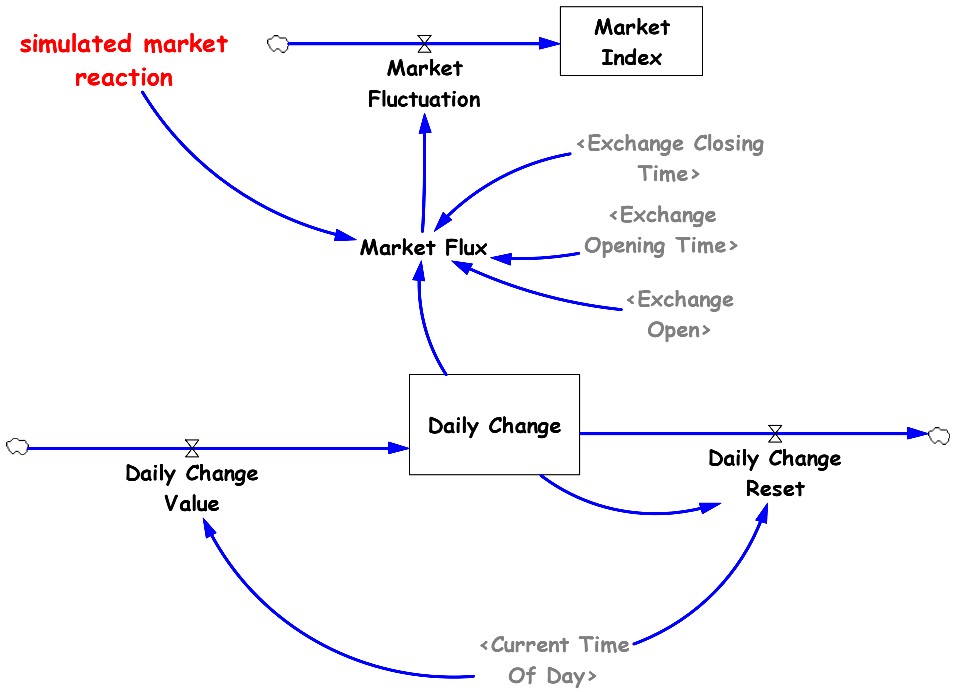

Figure 1 Simulating a Market Index

2.2 Capital Flows

The capital flow mechanism, largely drawn from Tirole's model (2002) of instability in emerging economies, 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 (see Sinclair and Shu 2001; Eichengreen 2004; Offermans and Pramer 2007) and has the potential to be exacerbated during adversarial attacks. More particularly, a massive and sustained withdrawal of capital is a potential source of deep economic disruption and, accordingly, one of the fervent goals of terrorist movements. Figure 2 summarizes the structure of the capital flow mechanism.

Aggregate flows create 'influence loops' that shape larger trends. In the Capital Flow mechanism, during normal economic periods, the importance of return on investment (i.e., interest rates and economic productivity) causes the lower loops to dominate. However, in a crisis period, risk becomes more salient, and the upper loop dominates the flow of capital.

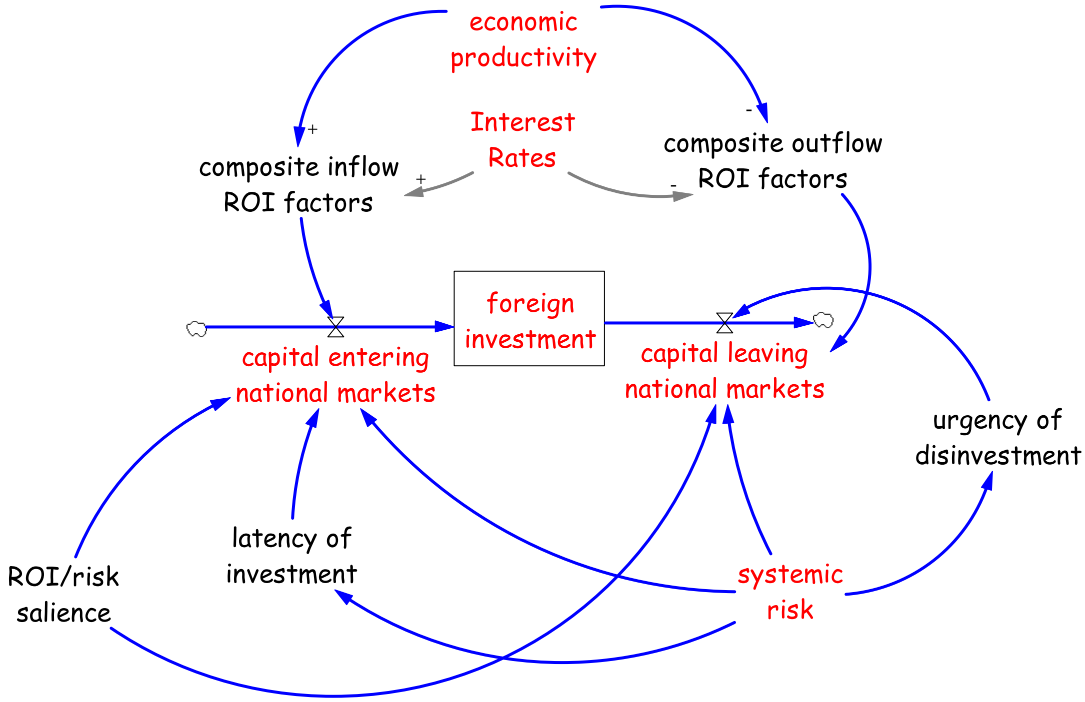

Figure 2 The Structure of Capital Flows

2.3 Transaction Practices

In addition to robustness issues related to physical infrastructure and operations, there are robustness issues related to firm responses to disruption. 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, deepening the corresponding danger of national and global systemic risk (Borio 2004).

The robustness issues inherent in payment practices are best captured by using a fine-grained, 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 on empirical data from the U.S. Census Bureau (U.S. Census Bureau 2007); see Figure 3.

2.4 Mechanism Integration

Taken together, the three financial tiers 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 inherent global interaction (see Figure 4), capital flow — because of its aggregate nature — remains the simplest of the three levels.

	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 pay	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 3 Illustrative Firm Data from U.S. Census Bureau (2007)

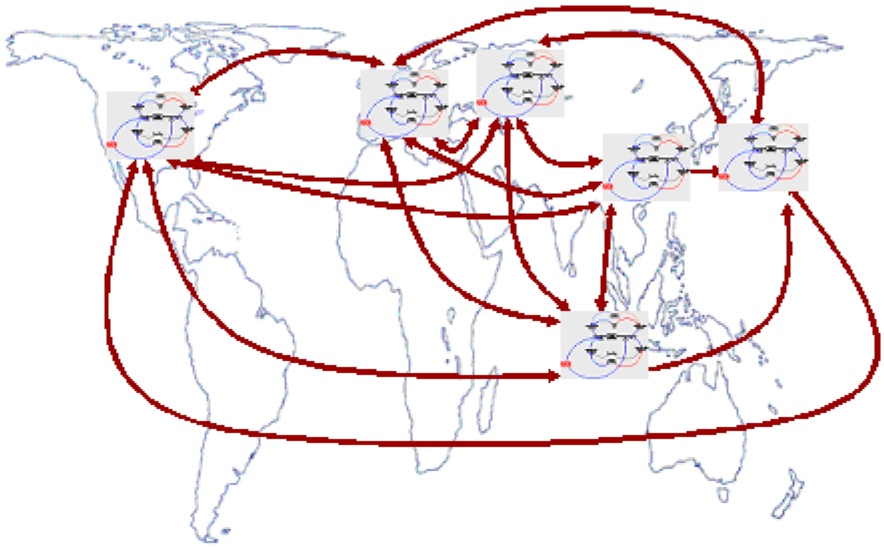

Figure 4 Global Capital Interactions

The Exchanges and Economy mechanism is national in scope and more complex in focus. Exchanges are mostly physical and operational in form (see Loader 2002) 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. Payment and clearing infrastructures can be a target of attack and, thus, can be disrupted, causing further downstream effects. Finally, the economy incorporates diverse industries that have varied geographical distributions and vulnerabilities.

The payment resumption mechanism is the most local and detailed of the three. It represents firm-level decisions in the face of unanticipated and disruptive circumstances. To be effective, the payment resumption decision model must take into account the factors to which decision makers give weight, some of which are summarized in the preceding section. Two alternative decision models (cash pinch and field effects) are also available. Interaction between the two needs to be explored, and other decision models can be incorporated as needed.

3 SIMULATING FINANCIAL INTERACTIONS

This section provides detailed descriptions of the structures and interactions of the model. The eight topics considered illustrate the rich dynamics of the interacting mechanisms.

3.1 Market Index

The market index as used in the model provides a diagnostic assessment for the rest of the model. While explicitly modeling the disruptive impact of a single terrorist attack or more complex, multiple disruptive events on the market index (a scenario defined by users and/or subject matter experts [SMEs] specifies the scale and type of initial impact), we also represent 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 (Figure 5). As previously described, users provide estimated market effects as part of the attack scenario data.

3.2 Exchanges

The exchanges mechanism generates aggregate prices that reflect the dynamics of the simulated market. The open hours of the exchanges are those of the New York Stock Exchange (NYSE), 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 dependent on a number of other factors: workforce and infrastructure availability, secure communications availability, and automatic shutdown criteria (circuit breakers) defined by the NYSE (each of which is described in detail in a later section). The total average time to complete a transaction is four days, with one day each being utilized for execution and clearance and two days for settlement. Bar graphs support visualization of the dollar volumes as they flow through the system (Figure 6).

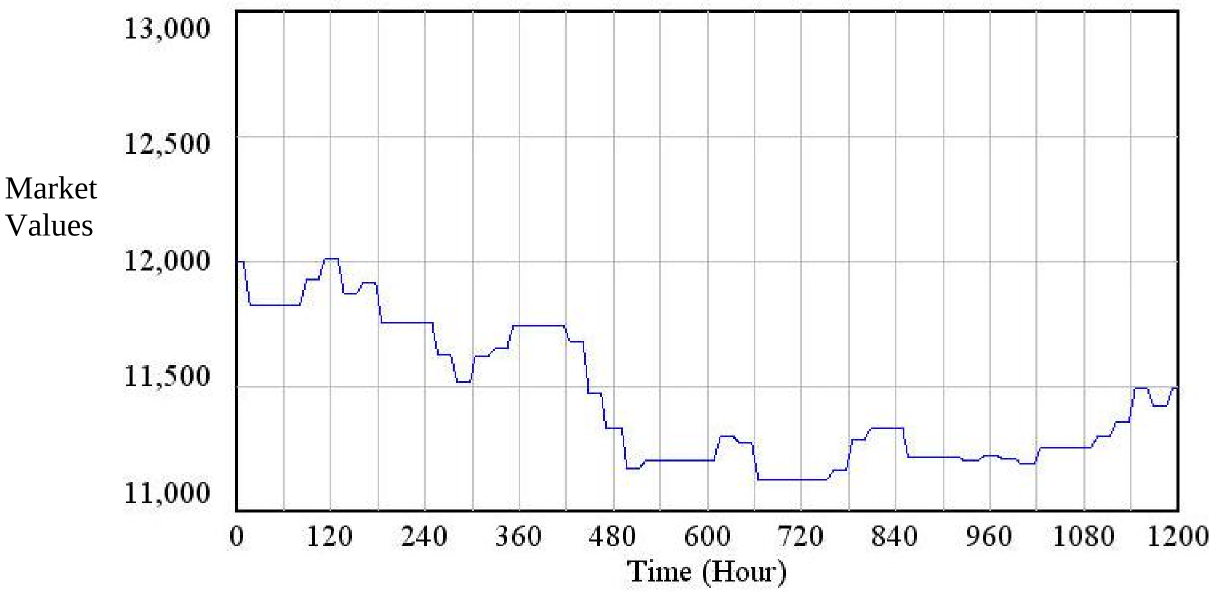

Figure 5 Generating a Market Index

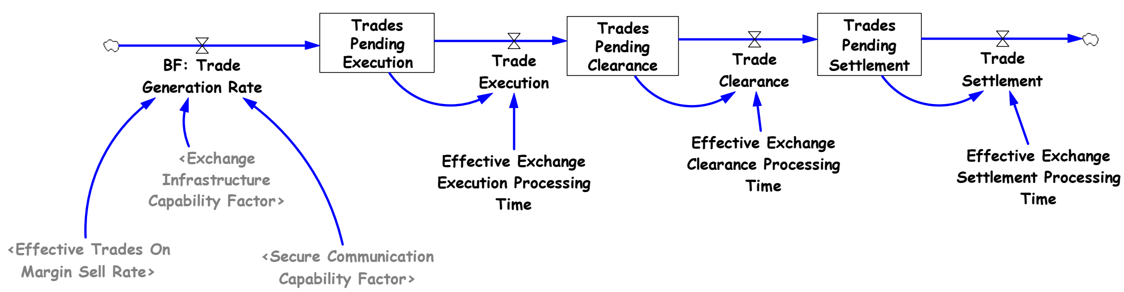

Figure 6 Monitoring Transaction Flow through Exchanges[1]

3.3 Workforce Availability

The SAFR model includes the potential for attacks against people as well as against infrastructure (e.g., as in the 2001 anthrax release). The operation of the exchange is dependent on the availability of the workforce. If the workforce is reduced in number for any reason, there can be a decrease in the efficacy of the remaining workforce. We define an availability factor that ranges from 0 through 1, where 0 indicates no availability and 1 indicates full availability. This factor is then used to adjust the processing times of the various stages of the exchanges. Currently, the user specifies this workforce availability factor profile as an input. However, with further development, another mechanism could be integrated that would compute this availability based on scenario parameters. Note that the effects on workforce availability are not limited to

[1] In this and subsequent figures, flow rates are indicated by bar and/or line graphs.

attacks (e.g., the model could be used to analyze the impact of an influenza pandemic). There are currently workforce capability factors for the exchanges, depository institutions, and payments systems. The factors are structured identically for exchanges, depository institutions, and payment systems.

3.4 Infrastructure Availability

As with the workforce, infrastructure must be available for the processing of the transactions through the exchanges. An infrastructure availability factor, similar to the workforce availability factor, is defined in the range of 0 through 1. This availability factor is then applied to the processing times of the various stages of the exchanges. It 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 an input. Further development would be needed 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 to those for exchanges.

3.5 Secure Communications

SWIFT, Fedwire, and related communication infrastructures are modeled in the Secure Communications segment of the model (Figure 7). A number of steps are required for completing a transaction. Explicitly modeled are execution, clearance, and settlement, each of which contains multiple information and data flows between participants. In modeling at a high level of aggregation in this segment of the model, low-level detailed communications are not tracked. Communications generated by the exchanges and payment systems are the only ones considered. The transactions cannot be completed until all communications have been completed. There is a Secure Communications availability 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. Under normal conditions, secure communications are available 24 hours a day, 7 days a week.

3.6 Circuit Breakers

In response to dramatic drops in the market in October of 1987 and 1988, the NYSE instituted, and the U.S. Securities and Exchange Commission (SEC) approved, a set of ‘circuit breaker’ policies to reduce market volatility and promote investor confidence.[2] These circuit breakers are tied to drops in the Dow Jones Industrial Average (DJIA) that are explicitly simulated in the SAFR model (Figure 8). Current NYSE circuit breaker policies are summarized in Table 1.

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[2] For more information, see www.nyse.com/press/circuit_breakers.html.

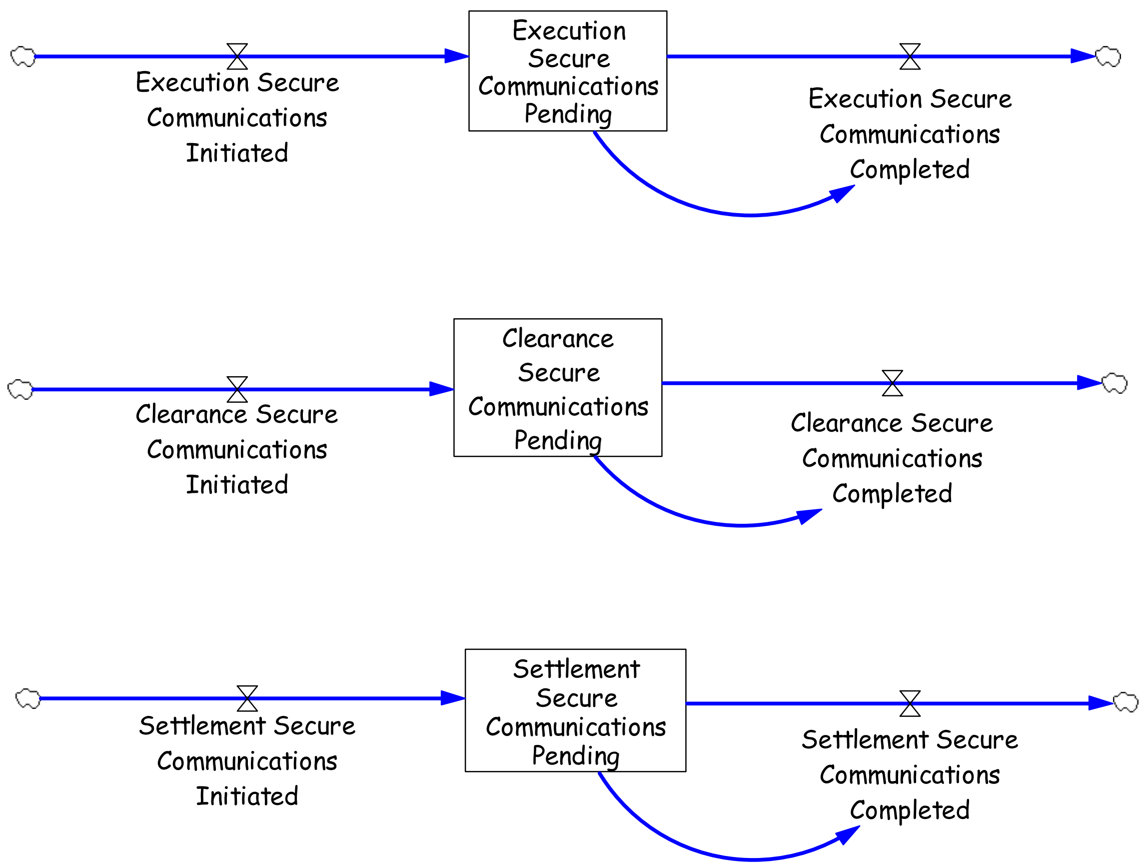


Figure 7 Secure Communications Processing Dependencies

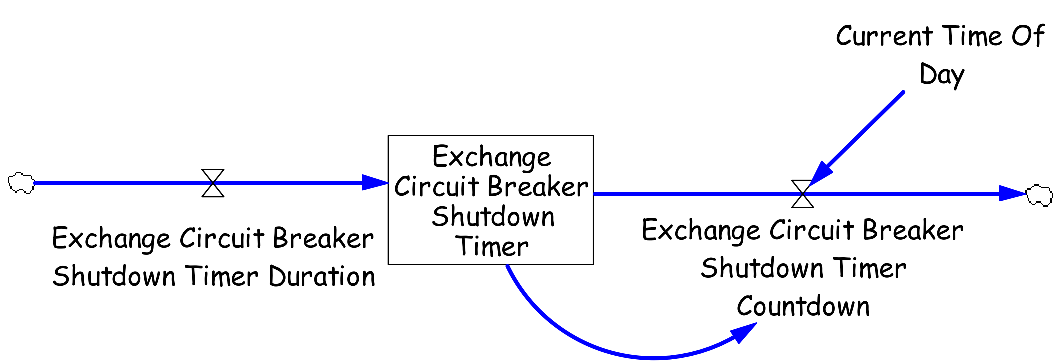


Figure 8 Circuit Breaker Shutdown Timer

Table 1 NYSE Circuit Breaker Policies

Event (Measured from start of trading day)	**Time of Day** (Eastern)	**Halt Trading?**
Ten percent drop in the DJIA		
	Before 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		
	Any time	Close exchange for the day

3.7 Margin Calls

Investors can purchase securities on margin by using their available cash along with cash borrowed from the broker. The investor intends that the value of the securities increases sufficiently so that the loan from the broker can be paid and a profit 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 level. If the value falls below this level, a margin call is issued, and the investor must provide additional cash or securities. If the investor does neither, the broker can sell securities owned by the investor.

Because 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) by using a mechanism similar to that used for circuit breakers and with an additional component (Figure 9). While circuit breakers are triggered only during extreme market conditions, margin calls occur daily regardless of market conditions. So we add stochastic margin call transactions to the system on the basis of 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.

3.8 Payment System

Figure 10 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) is tracked by the model. Three sources of payments are available within the model: exchange payments, foreign indirect investment payments, and sector payments (payments by individual firms). The

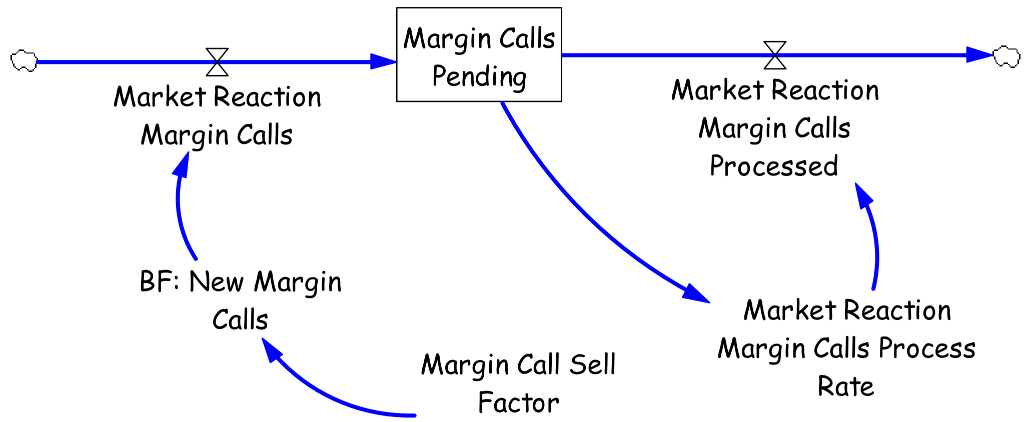


Figure 9 Monitoring Market Fluctuation with Respect to Margin Calls

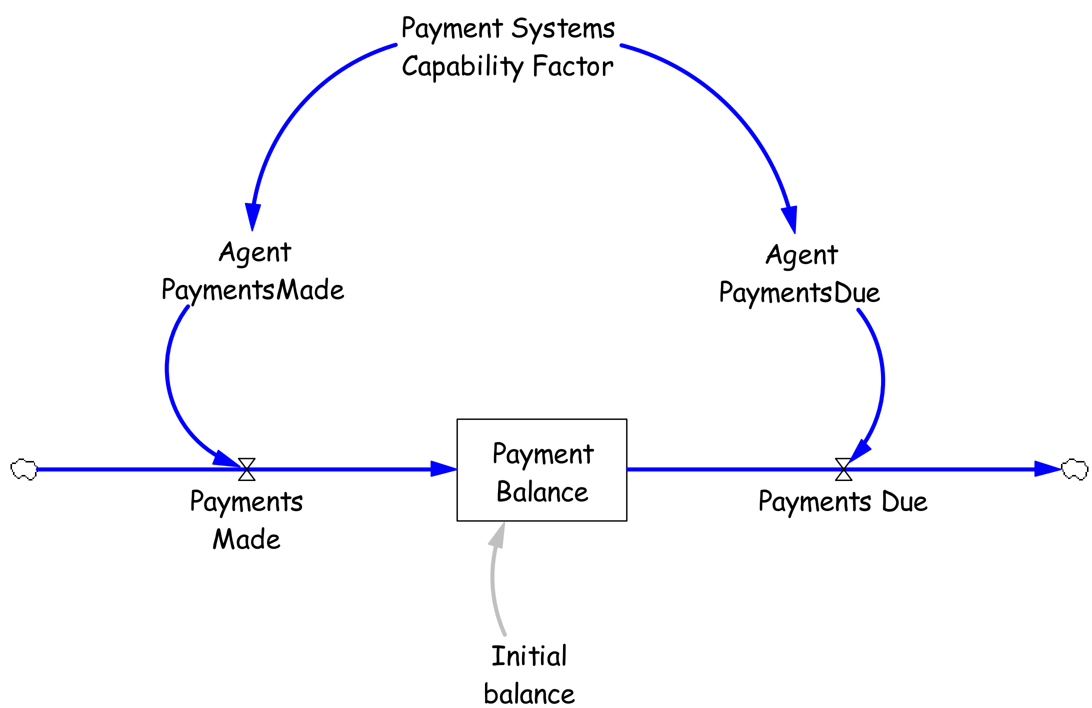


Figure 10 Payment Systems Linkage to Agent Models

Payment System is dependent on four separate capability factors: PS Infrastructure Capability, PS Workforce Capability, Depository Institution Infrastructure Capability, and Depository Institution Workforce Capability.

Integration of system dynamics and agent-based models occurs in the Payment System segment of the model. Specifically, the agent models aggregate their generated results and provide them in a form compatible with system dynamics.

4 INTERNATIONAL CASH FLOW

The International Cash Flow mechanism models the secondary effects of a terrorist attack on the United States through the direct effects on economic productivity, interest rates, and systemic risk. The model considers both Return on Investment (ROI) risk and a prospective undermining of the 'safe haven' assumption (Upper 2000) of foreign investors reacting to investment opportunities in the United States. When the opportunities are favorable, foreign investment tends to increase; when unfavorable, they tend to decrease.[3] When foreign investments flow out of a disrupted economy (Figure 11), an investment influx to other markets is likely (see Figure 12). At present, only three economies are represented. Depending on the scenario, outflow from the disrupted economy may flow to other major economies in a more diffuse manner or entirely outside of the financial system.

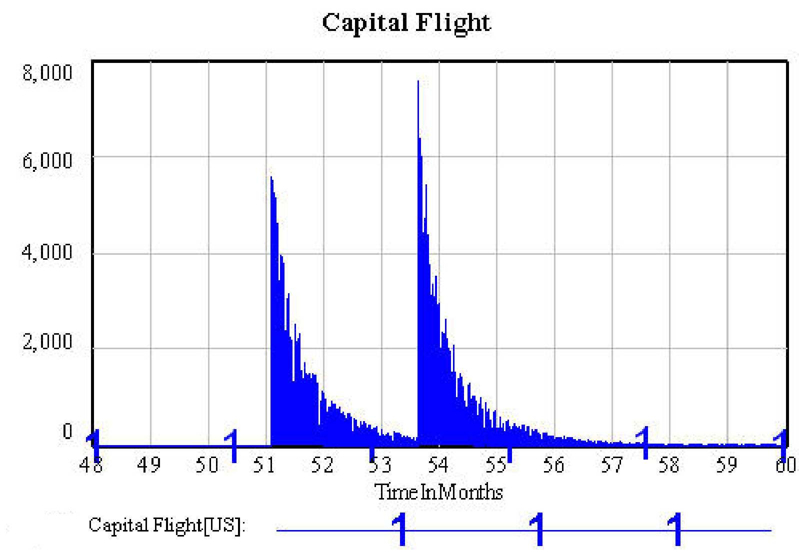


Figure 11 Notional Capital Flight after Disruptions During Months 51 and 53

3 Flow assumptions are parameterized with data made available by the Center for Financial Studies (Offermans and Pramer 2007).

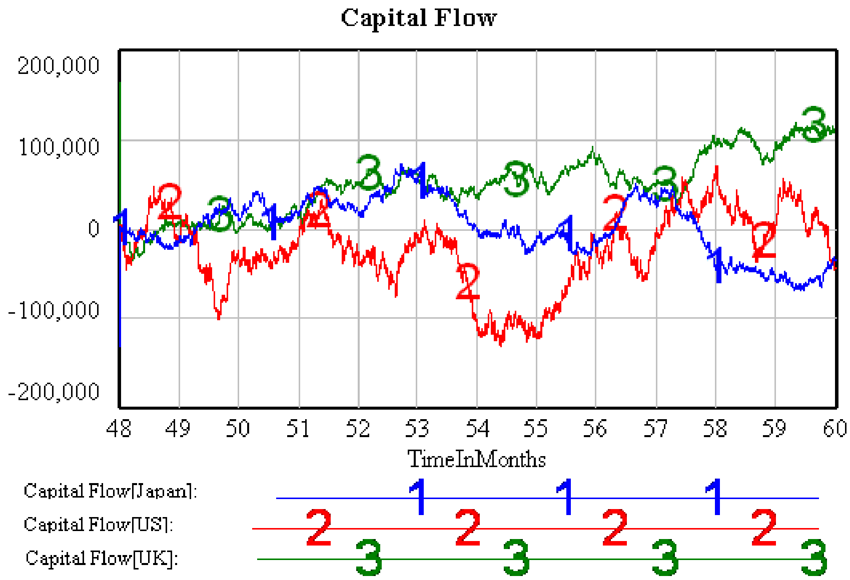


Figure 12 Comparative Flow of Capital with Disruption at Month 53

Two agent models have been integrated with the system dynamics mechanisms from the Capital Flow and Exchange and Economy tiers. Each models the payments made and received by individual firms. They implement two different firm-level philosophies of payment resumption after a terrorist attack, as described below.

5 FIRM 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 (U.S. Census Bureau 2007). On the basis of this data, individual firms are created that belong to a specific industry (with a four-digit North American Industry Classification System [NAICS] code) and geographic region (in this case, a U.S. state) that have expected annual payments and receivables by using a Pareto distribution. The expected annual payments are distributed into expected daily payments and then into expected hourly distributions by 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 (see Figure 13). The two mechanisms are described in the following sections.

5.1 Field Effects

The propensity of the firms to pay any outstanding dues is modeled by using a field effects framework. Field effects are defined by industry, region, and firm size. User inputs estimate responses to the adverse conditions (e.g., terrorist attacks) in terms of firm propensity to resume standard payment practices, as well as for the recovery period. A 'propensity field' (see Popper 1990) is used to integrate the effects of a variety of factors. Simulated hourly payments are a function of expected hourly payments as mediated by 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.

5.2 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. A monthly schedule is used to calculate the daily expected payment. This procedure is repeated for each month in the simulation.

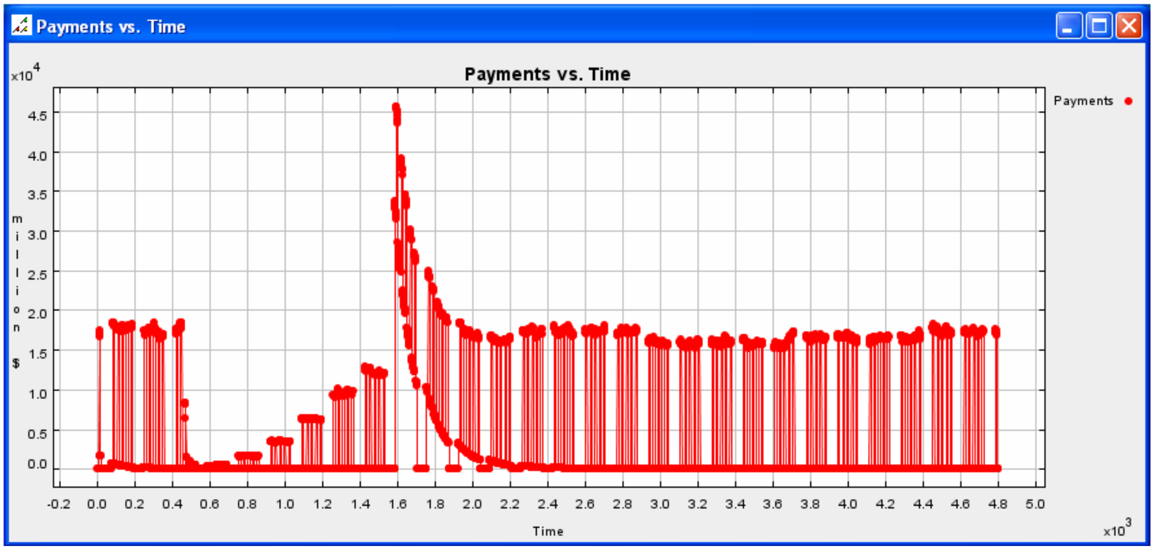


Figure 13 Firm Payment Resumption (Aggregate View)

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 (allocated by hour) and determines whether there are sufficient funds to pay all bills. When there is a cash shortfall, the firm determines which, if any, of its bills will be paid on time. Discretionary spending is curtailed first. 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, during normal conditions, the business makes a profit. During times of anticipated financial problems, the firms will divert available cash to ensure the solvency of business operations.

6 GENERATING ADVERSARIAL SCENARIOS

To benefit from a multi-tier model of systemic risk, it is necessary to be able to explore the consequence of attacks under a diverse set of assumptions, including complex scenarios in which multiple attacks seek to broaden the impact and intensify the effect. Accordingly, a flexible scenario generator is a crucial part of the overall decision support tool. Among its features, the scenario generator must enable: (1) scenarios to be specified by stakeholders and analysts; (2) relatively complex scenarios to be specified in a clear, comprehensible way; and (3) a range of likely consequences to be specified as part of the scenario, including secondary effects that are shaped by industry and region.

To illustrate the SAFR's scenario-generation capabilities, a reference scenario was documented in some detail.

> On the third Wednesday in June, three coordinated attacks, two on the global energy infrastructure and one on the American financial infrastructure, combined to disrupt and destabilize the Western economic system. For reference, this attack is named 'Moderate Intensity Oil and Finance Coordinated Attack'
>
> The first attack occurred at 1:15 Greenwich Mean Time (GMT). A team of 50 Iraqi insurgents, including several engineers, entered Kuwait and proceeded to set off explosive charges at more than 50 wells in the Raudhatain oil field. Once the charges were set and the wells began to ignite, Kuwaiti defense forces attacked the group, killing 12 and wounding 17. More than 20 were able to escape back into Iraq, where they are being hunted by Iraqi and American forces. Three Kuwaiti soldiers were killed and four wounded.
>
> The second attack occurred at 8:30 GMT. A Boghammar speedboat equipped with a Hadad mobile rocket launcher fired approximately 60 Arash rockets into the Port Arthur, Texas, refinery complex. Five people were killed and five injured, and refinery production was reduced to 25% of normal capacity.
>
> The third attack occurred in New York at 13:30 GMT. A rental truck packed with fertilizer was exploded adjacent to the 15-story New York Mercantile Exchange building at One North End Avenue. The blast killed 52 people and injured 85. The building was immediately evacuated. It was later considered structurally unstable and determined that it would take more than a year to restore. The market was closed, reopening eight business days later.

The Moderate Intensity Oil and Finance Coordinated Attack scenario was used, along with two other scenarios, to design, develop, and explore the mechanisms described in this White Paper. In particular, these scenarios have provided a focus for the Scenario Generation mechanism. By making this mechanism as flexible as possible, it allows the financial mechanisms to be explored under widely divergent circumstances.

The first two Scenario Generation panels (not shown) allow the scenario to be named and the assumptions about predisruption dynamics to be specified. The third enables specification of particular attacks that constitute the larger scenario. Figure 14 illustrates the specification of the first two attacks in the scenario. Note that the numbered attacks have a time of occurrence, a category of attack, the alert level at the time of attack, the industry primarily affected, industries dependent upon the primary industry (and thus subject to secondary effects), and a field effect value. The latter can be regarded as a specification of a propensity field for firms to maintain/resume normal business operations. It is thus an indicator of the disruptive effect of the attack(s) and their combined effect.

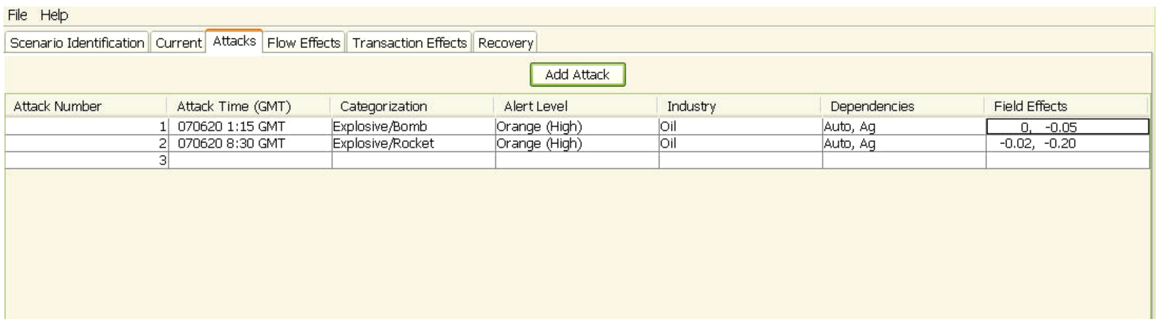


Figure 14 Panel Specifying Attack Scenario

The Flow Effects panel (Figure 15) enables specification of the factors influencing capital flow. In particular, as shown in Figure 2, current relative interest rates and the rate of economic productivity are assumed to be primary factors in attracting or repelling capital. However, there are also tacit 'safe haven' assumptions that the attacks can reinforce or undermine — indeed, may be intended to undermine — depending on the scenario in question. Significant increases in systemic risk have the potential to generate increased attention to the 'safe haven' assumption and reduce the relative salience of narrowly economic considerations. The nature of the attack(s), coupled with the broader context, determines their effect on 'safe haven' assumptions.

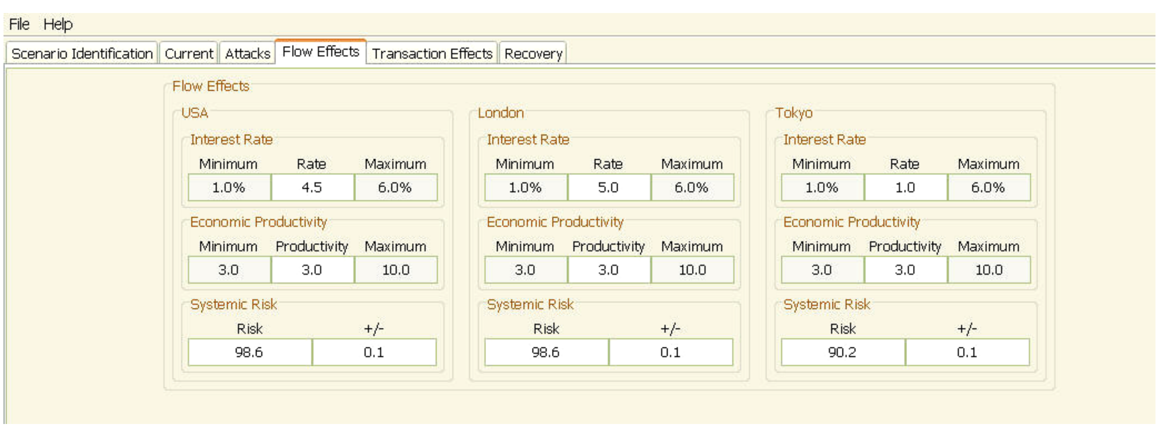
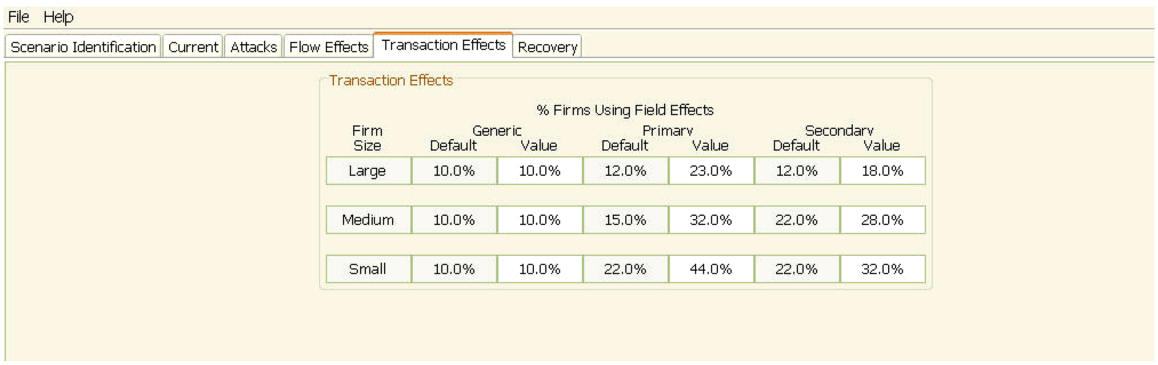


Figure 15 Panel Specifying Capital Flow Considerations

The disruptive effects of attacks influence not only financial flows internationally but domestic economic transactions. Assumptions governing those consequences can be specified in the Transaction Effects panel (Figure 16). Under the scenario being specified, a certain number of firms will switch from strict accounting considerations (the cash pinch mechanism) to a broader, more intuitive response (the field effect mechanism). This switch may be influenced by firm size and whether the firm is in a primary or secondary industry (region), rather than in a sector that is not directly affected by the disruption.



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%

Figure 16 Panel Specifying Firm Resumption of Payments Assumptions

Finally, depending on the nature of a scenario, overall economic conditions, and the sector under consideration, recovery may take place at varying rates, with diverse effects for the overall financial system. These assumptions can be specified in the Recovery panel (Figure 17). Rates of recovery can be specified for diversely situated firms and fine-grained time periods, thus enabling maximal flexibility in scenario articulation.

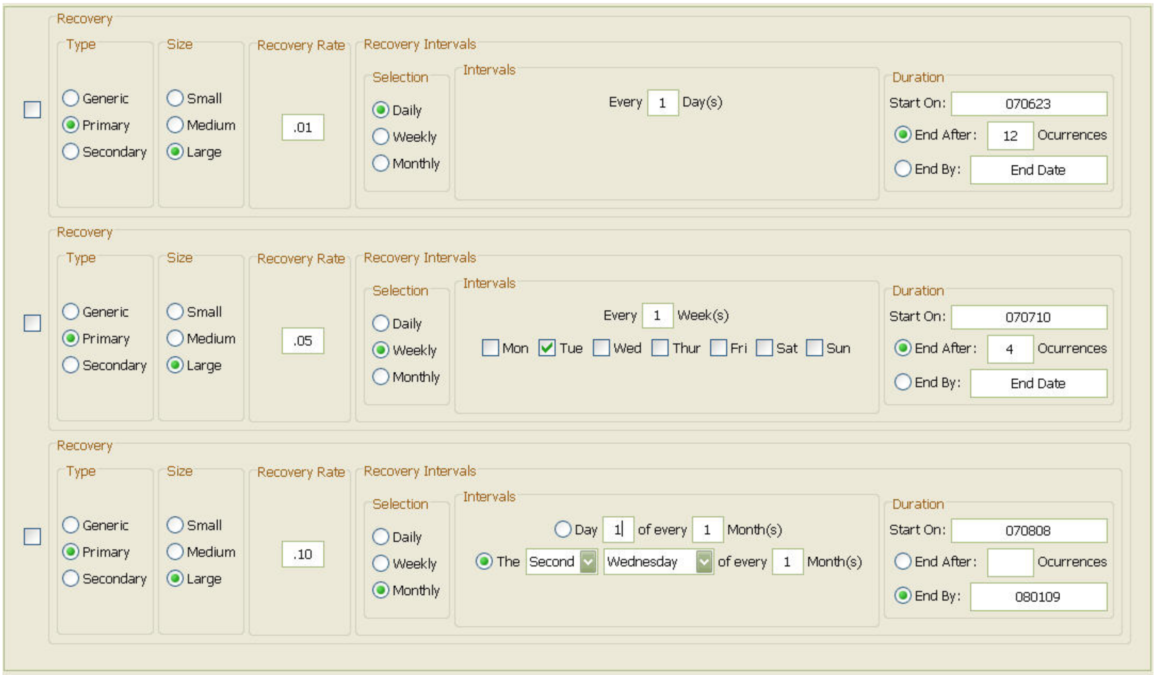


Figure 17 Panel Specifying Recovery Assumptions

Taken in combination, the panels for user specification of scenario assumptions allow a broadly articulated exploration of financial and economic risks associated with a range of possible terrorist attacks. Many of the scenario assumptions can be specified as ranges, enabling the simulation of a family of scenarios. This further capability supports sensitivity analysis and, thus, an assessment about the extent to which systemic threats are dependent upon particular conditions or responses.

The SAFR team has designed this decision support tool to be comprehensive enough to explore a wide range of financial and economic risks while, at the same time, intuitive enough to be used effectively by diverse analysts and decision makers. We believe that these design goals have been achieved. The team will be pleased to see SAFR applied in the analysis of the types of problems for which it is intended.

7 FUTURE DEVELOPMENT NEEDS

Design horizon. SAFR is a decision support model designed to support the homeland security community in assessing adversarial financial risks and how they interact with other sources of systemic risk. Five enhancements to SAFR have been identified that are necessary to make the model a comprehensive and valuable analysis tool:

1. *Scenario generator*. Presently, scenarios are customized manually and on an as-needed basis. By developing a scenario generator capable of creating large families of parameterized structures and events, including complex events such as multiple coincident or coordinated events, the pattern of consequences will be more rapidly and fully explored over a distribution of disruption types.
2. *Infrastructure networks*. Currently, while there are ‘hooks’ in SAFR to allow the financial infrastructure to interact with other models of critical infrastructures, SAFR has not been integrated with any existing set of infrastructure models. By defining interaction linkages between SAFR and other critical infrastructures and the financial sector, consequences that may result from multiple interdependent sources will more readily explored.
3. *Capital markets*. Currently, the SAFR capital flow model focuses on direct investment in institutionalized security markets. To represent the more comprehensive and interdependent structure of the market requires that SAFR be expanded to include other types of capital markets, including, especially, the role of derivative instruments and over-the-counter transactions. With this enhancement, the broader global impact and interdependencies of possible disruptions can be more fully assessed.
4. *Industries and regions*. Presently, relevant industries are selected for SAFR runs on the basis of the scenario specified. By developing a full global dataset of industries and interdependencies, SAFR could be set up and run more quickly and thus would be much more supportive of the type of quick-turn-around analyses typically required during real-time events, such as natural disasters, financial marker crises, large infrastructure failures, and terrorist events.
5. *Central bank policies*. Central banks play critical roles in maintaining stability in the financial infrastructure, especially when the infrastructure is under stress from external events of large magnitude. However, because of resource limitations, central bank policies and responses are not currently represented within the SAFR model. By incorporating within SAFR a range of alternative forms of central bank intervention, financial mitigation of disruptive attacks can be explored and assessed.

Customized applications. In addition to homeland security, SAFR should be of value to other communities as well. As a decision support tool focused on providing simulations of disruptive events that affect financial agencies and institutions, it is designed to provide insight into the prerequisites of institutional continuity of operations. This objective includes the issues of: (1) identifying potential vulnerabilities; (2) devising policies that help mitigate adverse effects; and (3) estimating and, where feasible, expediting the pace of recovery. To the extent that these objectives can be achieved, SAFR may also prove to be relevant for financial risk management planning components within businesses or industries as well as government agencies.

Within this broad context, SAFR is based on a fairly general model. Accordingly, it is likely that specific agencies, institutions, industries, or businesses will need to customize and/or enhance SAFR capabilities to achieve their specific goals. Initially, this customization would include the incorporation of policy alternatives available to decision makers within the specific institution or industry. This step would place the decision maker 'within the loop,' aligning supported explorations with the relevant institutional decision space.

A similar refinement concerns representation of financial relations that are specific to the user institution. Currently, consequences and responses are allocated either generically or by industry, region, and/or firm size. However, it is likely that any specific institution will benefit by also representing particular banking or business relations. While such relationships have been conceptualized in the SAFR model, their empirical implementation necessarily awaits the specific needs of the prospective user.

It is assumed that such customization will be necessary for effective SAFR utilization. Beyond such policy and decision-oriented customization, some institutions may prefer to refine other aspects of the model. As an example, both infrastructure disruptions and capital flows are presently represented at the aggregate level. For some purposes, a finer-grained representation, such as that used in the firm transaction mechanism, may be desirable. While this representation can be readily achieved, the requirements of the institution in question would need to be incorporated into the design specifics.

Finally, for specialized institutional purposes, interaction-rich mechanisms may provide a level of verisimilitude that Argonne has pioneered: an interpretive agent architecture in which strategic decisions are undertaken by agents that are oriented by interpretations arising endogenously from agent interaction (Sallach 2003a and 2007; Sallach and Mellarkod 2005; Ozik et al. 2007). These agents would normally be used to model interaction-rich settings, such as policy committees, multifaceted negotiations, or jury deliberations. For particular requirements, interpretive agent models are feasible and can provide the basis for a customized enhancement to the SAFR model.

8 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. Although no model can do full justice to its complexity, it is vital to explore and understand structural vulnerabilities, possible responses of decision makers, and possible combinatorial consequences.

The banking and financial infrastructure is a target of 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 larger financial world. Thus, if we are to protect financial systems against potential terrorist attacks and mitigate the consequences of an attack, it is imperative that we model the systematic risks that inhere within the current financial infrastructure and practices, including vulnerabilities, interactions, and threats.

The SAFR system is a decision support model designed to support the financial and homeland security communities in assessing adversarial risks and how those risks interact with other sources of systemic risk. In order to represent financial complexities in a cogent way, SAFR distinguishes three interacting levels: (1) operational institutions that can be directly disrupted (e.g., exchanges, secure communications), (2) international capital flow, and (3) firm-level transactions. The three levels interact and influence each other's emergent patterns.

The model that combines the three-layered mechanism is a hybrid; the first two mechanisms are rooted in systems dynamics (Sterman 2000) and the third in agent-based simulation (Sallach 2003b; North and Macal 2007). Currently, a variety of scenarios is used to exercise the model, and a scenario generator that enables flexible sensitivity analysis is available for scenario customization.

As described previously, five enhancements to SAFR have been identified that will make the model more comprehensive and valuable as an analysis tool. These are:

- Scenario generator
- Infrastructure networks
- Capital markets
- Industries and regions
- Central bank policies

The project team believes that completing these proposed enhancements will take the SAFR model from a proof-of-concept prototype to an effective decision support system with the capacity to provide valuable, customized insights to the strategic planning process and during a real-time financial disruption.

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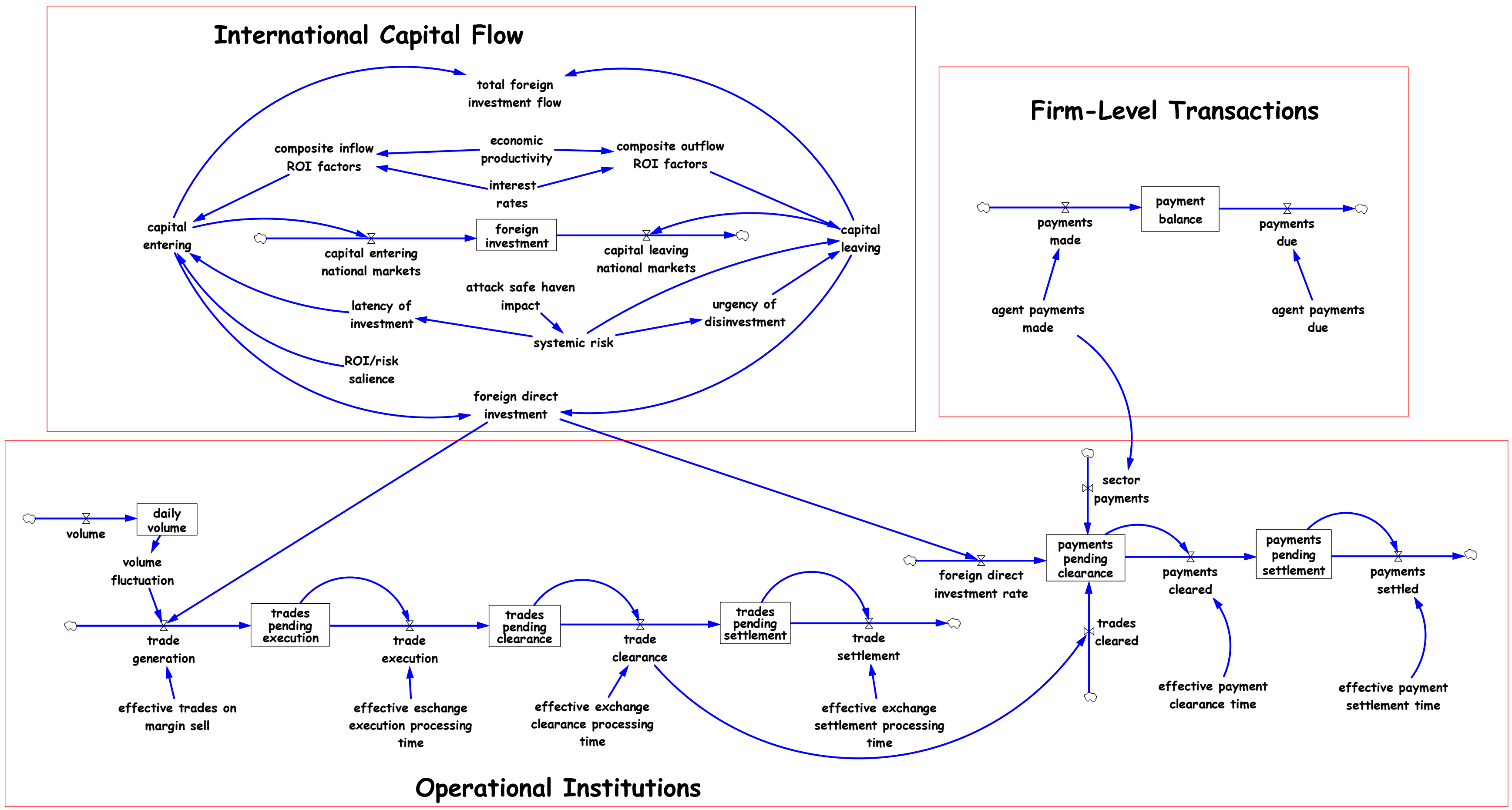
APPENDIX A THREE-TIER OVERVIEW



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