Emergent Behavior in an Unregulated Financial System of Systems: Economic Meltdown

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Abstract. The need to consider the human dimension to systems engineering is no more evident than in the current global economy. The current global financial crisis can be interpreted by applying a system of systems analysis methodology that elucidates the behavior that has emerged from the unregulated US market in collateralized debt obligations (CDOs). The market for US financial obligations of collateralized debt obligation market is modeled dynamically as a system of systems covering the time period from 2000 to 2008. Behavior of home mortgage borrowers, lenders, CDO buyers and sellers, as well as specific market inputs and outputs are included in the model. Results show that an increasing rate of home loan defaults and loss of financial market liquidity is a predictable and natural consequence of the market conditions. Of particular interest are the leading indicators that result in financial instabilities.

Introduction

Perhaps the most serious event that has impacted people around the world recently is the current global economic crisis. There were several root causes and promulgating practices that have resulted in the current global economic downturn. Beginning early in the Clinton Presidential administration, there was considerable pressure from the administration to ease regulatory and conformity rules to allow lower income level home buyers to qualify for mortgages. Specifically, minority groups complained about discriminatory practices in the attribution of mortgage loans. The "Community Reinvestment Act" was enacted by Congress in 1977 (CRA 1977) and implemented by subsequent regulations to encourage depository institutions (e.g., commercial banks and savings associations) to help meet the credit needs of their local communities. The U.S. Attorney General, Janet Reno, enforced the Act through policy changes within the operations of Federal National Mortgage Association (Fannie Mae) and Federal Home Loan

Mortgage Corporation (Freddie Mac). In California, Humboldt County was designated as either distress or underserved and therefore in need of additional lending support. Those who could not literally afford to purchase housing were given waivers by the lenders. Mortgage loans were made to buyers who had no visible means of repaying. Thus the first root cause of the economic downturn had its roots in the social engineering of access to mortgage loans. These two government-sponsored agencies bought the bank mortgage debt (approximately $5 trillion (CBS News 2008)) and sold it to other financial institutions.

On 15 December 2000, Senator Richard Lugar (Republican, Indiana) introduced a measure called the Commodity Futures Modernization Act (Commodity 2000). This Act ensured that neither the SEC nor the Commodity Futures Trading Commission would be able to regulate the new financial products referred to as *swaps*. Credit default *swaps* are in essence insurance policies covering the losses on securities in the event of a default. Banks and hedge funds gambled on whether an investment (say, a pile of subprime mortgages bundled into a security) would succeed or fail (Conason 2008). Additionally, the legislation exempted energy trading from regulatory oversight. In 1999 the Gramm-Leach-Bliley Financial Services Modernization Act (Gramm 1999) was enacted which broadly deregulated the financial industry. “These unregulated *swaps* are at the heart of the subprime meltdown,” says Michael Greenberger, director of the Commodity Futures Trading Commission (Greenberger 2008).

Beginning in the late 1990s, globalization has led to a significant reduction in real wages in the US. The broad economic growth in the United States has largely been at the expense of credit (e.g., home equity loans and credit cards). In real 2007 dollars, the buying power of $34,400 in 2000 reached $41,420 in 2007 (US Dept Labor 2008). But the net result over the eight years has been no increase in the gross national income (GNI), or the buying power of the average family. Personal savings averaged 8% in the previous decades before 2000, but went negative in 2005 (US Dept Labor 2008). Further, between 1989 and 2008, credit card debt almost quadrupled, from $238 billion to $962 billion (Federal Reserve 2008). This debt is broadly based and includes states, corporations, banks, and individuals.

Earlier, venture capitalists became aware of a new phenomenon called the World Wide Web. Money from “sophisticated” investors poured into start-up companies who often had no means of business or commerce to return those investments. This became known as the DOT COM frenzy. The frenzy was heightened when several of these start-up companies held wildly successful initial public offerings. The result was a significant increase in the amount of wealth that flowed into capital markets and public exchange markets (e.g., New York and Nasdaq). As people “cashed out” many turned to investing in real estate. Dramatic increases in real estate values were prevalent in the early 2000s.

Many institutions and individuals either sat on the sidelines and did not participate in the DOT COM rise, or were unable to actively participate due to their business issues or policies. Banks that invested along side institutional investors and venture capitalist lost money when the final declines of the DOT COM market indices of 40%+ were tallied. As real estate began to boom in 2003 and 2004, enterprising executives hungry for profits began to explore new ways to add home buyers.

Sub-prime lending practices were encouraged by the nation's leading government lending institutions Fannie Mae and Freddie Mac. Government policies were blind to the consequences. And most telling were the words of Alan Greenspan (former Federal Reserve Chairman for more than 18 years) in testimony to the House Oversight and Reform Committee on 3 October, 2008. He admitted he was "shocked" when the financial system broke down. He had relied on the financial institutions ability to self-regulate their operations, using their shareholders and significant stakeholders to manage adequately.

Unqualified buyers believed the housing boom would carry their inadequate assets and cash flow until they could see 20% or more profit. The predominant starting point for the subprime loans was 2003. The subprime loans typically required balloon payments after an initial 3- 5-year period, or large increases in interest rate after an initial 3– 5-year period. Financial institutions with access to credit enhancing markets were able to package very high risk packages - known as collateralized debt obligations - of dubious mortgages and sell them to other funds and governments under the guise of being "insured". Risk was determined by relying on statistical analyses, rather than fully considering the consequences of actions. Then housing sales stagnated. Short-term borrowing tactics with credit cards and home equity loans delayed the inevitable, but when the interest rate increases kicked-in three years after the loan origination many saw their monthly payments double or triple. The result due to recent federal legislation will be a glut of government-owned houses that will need to be re-sold.

We ask ourselves, as systems engineers, whether systems engineering methods can be used to give insight into complex financial systems of systems, not only to help understand root causes of economic problems, but also to help provide guidance for future decisions. Specifically we are interested in whether system of systems modeling and analysis is applicable to problems such as the global economic crisis.

In this paper we briefly discuss systems of systems, describe an approach to modeling systems of systems and then apply the approach to modeling the collateralized debt obligation (CDO) market. Results of simulations using the CDO system of systems model are presented and show close agreement with observed financial SoS behavior. We conclude that SoS modeling and simulation provides a holistic way of understanding complex behavior when applied to human systems such as the CDO market and, if adopted as an analytic tool early in the life of SoSs, may very well be able to predict behaviors well in advance of their occurrence.

Systems of Systems

There has been recent interest in systems of systems and systems of systems engineering. Much of the initial interest has been focused on military systems as evidenced by research in the areas of military command, control, computer, communications and information (C4I) systems (Pei 2000), intelligence, surveillance and reconnaissance (ISR) systems (Manthrope 1996), intelligence collection management systems (Osmundson et al. 2006a), and the recent publication of the US Office of the Under Secretary of Defense SoS handbook (US Dept. Defense 2008).

SoS engineering has also been applied to the commercial sector including electrical power distribution systems (Casazza and Delea 2000) (Osmundson et al 2008) and food chains (Neutel 2002), among others.

The global economy has seen the creation of large complex SoSs, particularly those that are composed of financial systems that interact with transportation logistics networks, communications networks, and energy delivery networks (Motter and Lai 2002). These systems are usually comprised of a large number of component systems and subsystems, humans and software agents. The challenge to systems engineers is to develop systems analysis and engineering techniques to analyze complex SoSs in order to be able to predict SoS behavior under a wide range of possible operating conditions so that potential unwanted behavior can be understood and mitigated through design, regulations or other means.

SoSs have been described by a number of authors and there is not universal agreement on a definition of the term 'system of systems', but many definitions have basic thoughts in common. Sage and Cuppan (Sage and Cuppan 2001) describe an SoS as having operational and managerial independence of the individual systems as well as emergent behavior. Maier and Rechtin (Maier and Rechtin 2002) describe a SoS as a collection of systems which are operationally independent, managerially independent, evolutionary developed, with emergent behavior and are geographically distributed. Boardman and Sauser (Boardman and Sauser, 2006) describe a SoS as having autonomy exercised by the constituent systems in order to fulfill the purpose of the SoS. Traditionally systems engineers have thought of systems as physical entities but SoSs that are emerging in response to the globalization of the economy often have humans and groups of humans as key elements.

A SoS may be bounded or unbounded. Of interest here are unbounded systems that have loose coupling and allow for dynamic spontaneous connections (DiMario 2006). This type of SoS may have no control mechanism. Large scale behavior emerges, and may be desirable, but the large scale behavior may be influenced by external conditions that can cause the large scale behavior to become unstable.

System of Systems Modeling

A proven approach has been developed that allows analysis of dynamic behavior of SoS, with the ability to model and simulate the important aspects of the systems, system elements and, most importantly, the interactions between systems and system elements (Osmundson and Huynh 2005). The approach models a SoS as a collection of systems that interact by transforming inputs into outputs through various processes. The systems can be physical systems, people or software systems.

System elements can be described as executable modeling icons by using modern software applications and these icons can be graphically linked to form models of physically distributed systems of systems. Models of systems of systems can be constructed in a modular manner so that factors that might influence SoS behavior are represented by an association with modeling application objects.

Large scale behavior may emerge as a result of the between systems, between systems and people and/or between systems and software agents. Following the idea in (Klir 1991) we can consider each of these interacting systems in a SoS model as elements that seek to satisfy a goal governed by a set of rules whose inputs are provided through the SoS interactions. In our approach we model systems, including humans, as following rule-based algorithms which have as inputs the outputs from the rest of the SoS model.

Modeling the Collateralized Debt Obligation Market

A high-level schematic of the CDO market is shown in Figure 1. This schematic is a simplified version of a general approach to representing a SoS as discussed by (Huynh and Osmundson, 2007). Individual borrowers obtain loans from lenders who may hold the mortgage, or more commonly, resell bundles of mortgages to a mortgage buyer, depicted in Figure 1 as the mortgage owner. Investors invest in the mortgage owner and in turn are paid dividends from the mortgage owner. Hedge funds, funded by investment funds such as government retirement funds, likewise invest in mortgage owners and in turn, are paid dividends as are the investment funds by the hedge funds. In order to attract investment the mortgages owned by the mortgage owner must be deemed to be off acceptable risk. The risk assessor provides the risk assessment and is paid by investors and hedge funds.

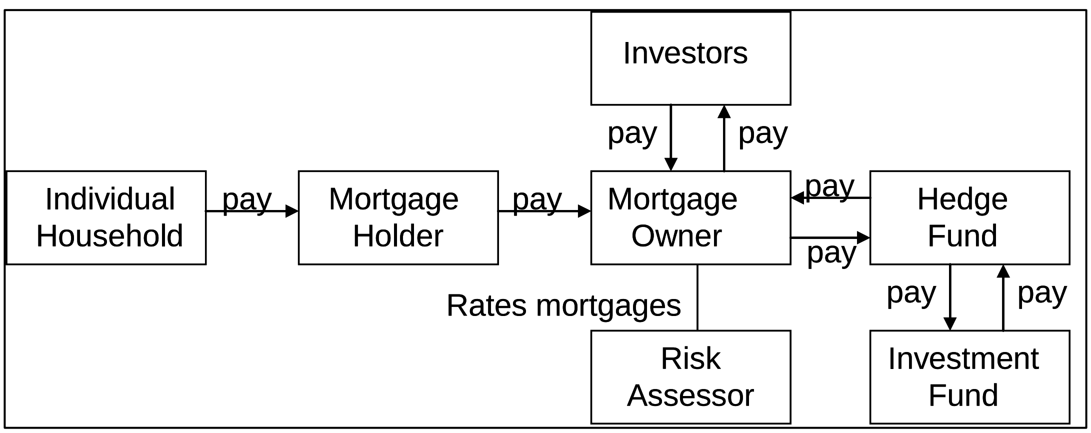

Figure 1. A high-level schematic of the collateralized debt obligation market.

The collateralized debt obligation market shown in Figure 1 is modeled in executable form, using the modeling application Extend™, as shown in abstracted form in Figure 2. Deregulated operation is modeled with borrowers, lenders, CDO sellers and buyers operating normally in order to optimize profit. Also included in the model is the US housing market which the authors abstracted by incorporating the Standard and Poor's Case-Schiller index (Standard and Poor's 2008) to portray the indirect interaction of borrowers and the housing market. Fundamental interactions between SoS elements are those where there is a direct exchange between systems, such as the exchange of money between a lender and a borrower, and are shown as solid lines. Indirect interactions that represent influences of one system on another through intermediate steps, such as the effect on house prices by increases or decreases in the number of home mortgage borrowers, are shown as dashed lines.

The model initiates with borrowers seeking loans from lenders at the lowest rate of interest possible and lenders bidding for borrowers' business. Borrowers are distributed between those qualified for conventional loans and those whose risk for default is higher and who obtain subprime loans. The loans are also categorized by the year in which they are issued, beginning with year 2000. Subprime loans are assumed to be of an adjustable rate mortgage (ARM) type with a low introductory rate that allows subprime borrowers to initially qualify and then a rate that increases by 4% after three years. A portion of the conventional loans are also assumed to be ARMs with a rate that increases by 4% after three years. Loan default rate is made proportional to the interest rate divided by the last three years percentage increase in house prices. The assumption is that a borrower has an increased probability of refinancing an ARM if house prices have experienced large increases, since the borrower will now have substantial equity and is more likely to qualify for a conventional long term, fixed interest rate loan. Borrowers have an effect on the housing market since as more borrowers who previously did not qualify for home loans enter the market, the demand for housing increases and house prices increase more rapidly than the cost of living index. The housing market also has an indirect effect on borrowers since house price increases make it easier to refinance and encourages more borrowing and lending, and house price decreases have the opposite effect.

CDO sellers and lenders have a direct connection since the lenders bundle their loans and offer them as CDOs to CDO sellers through a bidding process. CDO sellers in turn sell derivatives to leveraged and highly leveraged funds that are financed by investors.

Investment raters and insurers have a direct connection to CDO sellers in that both analyze the risk of the bundled loans and, based on the risk, assign an investment rating to the derivative. A rating of AAA would indicate a low level of risk with at least 97% of the loans performing, that is, providing an expected return, with lower ratings corresponding to lower levels of expected performance. There is an indirect link between investment raters and insurers and investors, reflecting the investors' reliance on the raters to accurately determine the investment risk.

A hedge fund is an example of a highly leveraged CDO buyer. A hedge fund can be leveraged as much as 30 times, meaning that a fund leveraged nine times purchase $100 M of CDOs for approximately $11M, giving the potential for very high rates of return when default rates are low. Investors in hedge funds can often have trigger points built into their investments so that if the default rate of a hedge fund's CDOs goes above a certain rate the investors demand repayment of their investment and the hedge fund is obligated to immediately repay the money, recover their investment in turn from the CDO seller, or go bankrupt. Alternatively a higher default rate than expected can cause the investment rater to lower the CDO rating, requiring the CDO buyer to increase reserves to offset the higher expected losses. In the case of a bank holding CDOs, the bank is required to maintain a certain level of liquidity and a requirement to increase their reserves may require them to obtain a new infusion of cash.

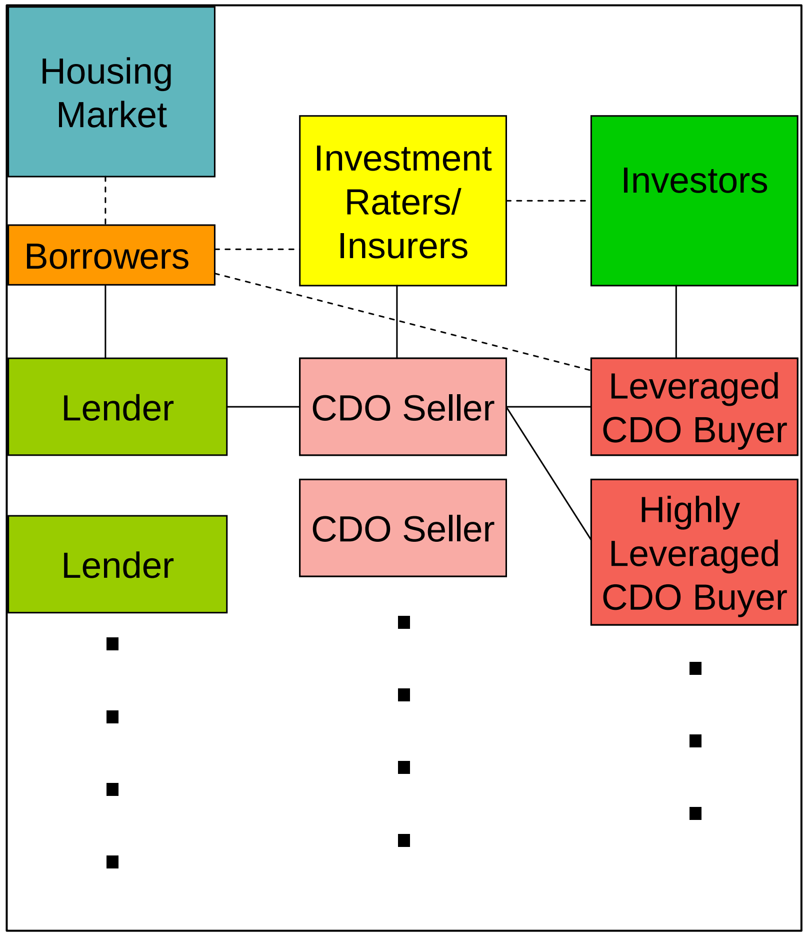

Figure 2. Representation of a model of the collateralized debt obligation market system of systems

The model is run with a set of realistic assumptions for the time period 2000 to 2008 and the resulting loan default rate is shown on Figure 3. The housing market over this period of time is captured with the Standard and Poors Case-Schiller index of house price changes. During this period there was a rapid increase in US house prices from a base index of 1.00 in 2000 to 1.88 in 2006, followed by a decline to 1.85 in 2007 and 1.59 in mid-year 2008. The period of rapidly increasing house prices is referred to as the housing bubble and the decrease marks the collapse of the overheated housing market.

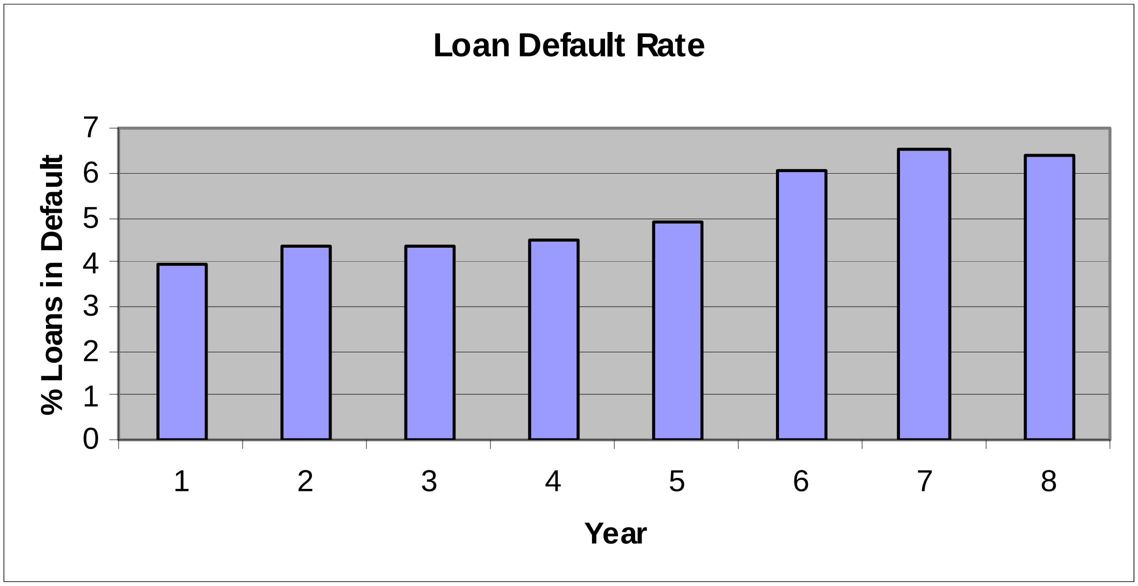

Figure 3. Home Loan Default Rate, 2001 to 2008

The home loan default rate is combined with the model's accumulation of total home loans over time to determine the asset value of a highly leveraged (9X) hedge fund over the 2000 to 2008 time period, as a function of the percentage default rate (the trigger point) at which a call would be made on the hedge fund. These results are shown in Figures 4-7. Each of the figures shows the results of four simulation runs.

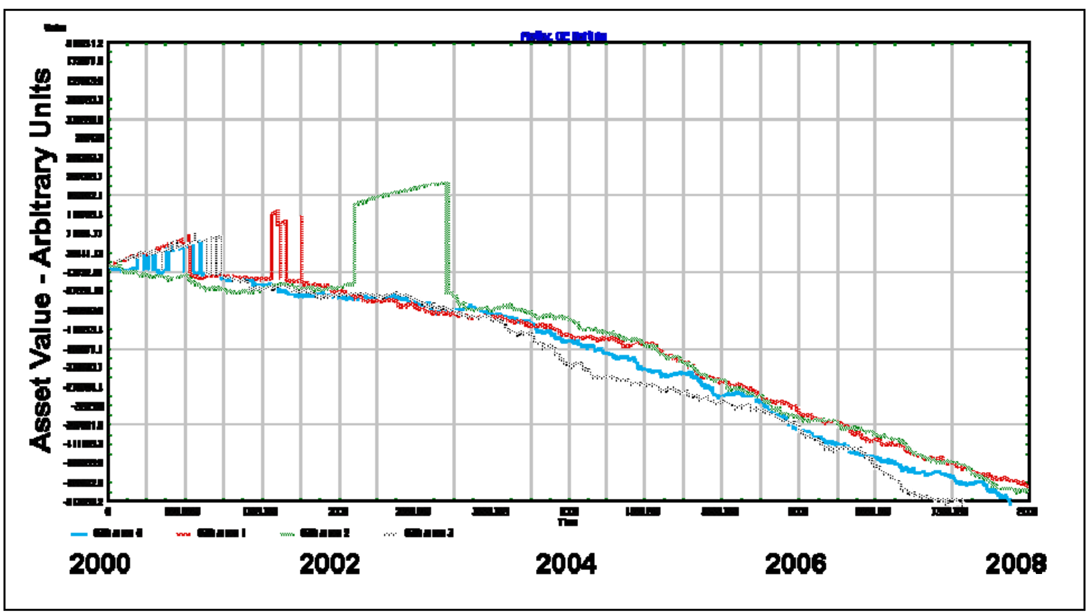

Figure 4. Asset value from 2000 to 2008, leveraged fund. Trigger point is 4%.

Figure 4 shows asset value with time for a trigger point of 4% which is slightly higher than the first year default rate. In this case the fund's assets become negative no later than year 2003 and the fund becomes insolvent and never recovers.

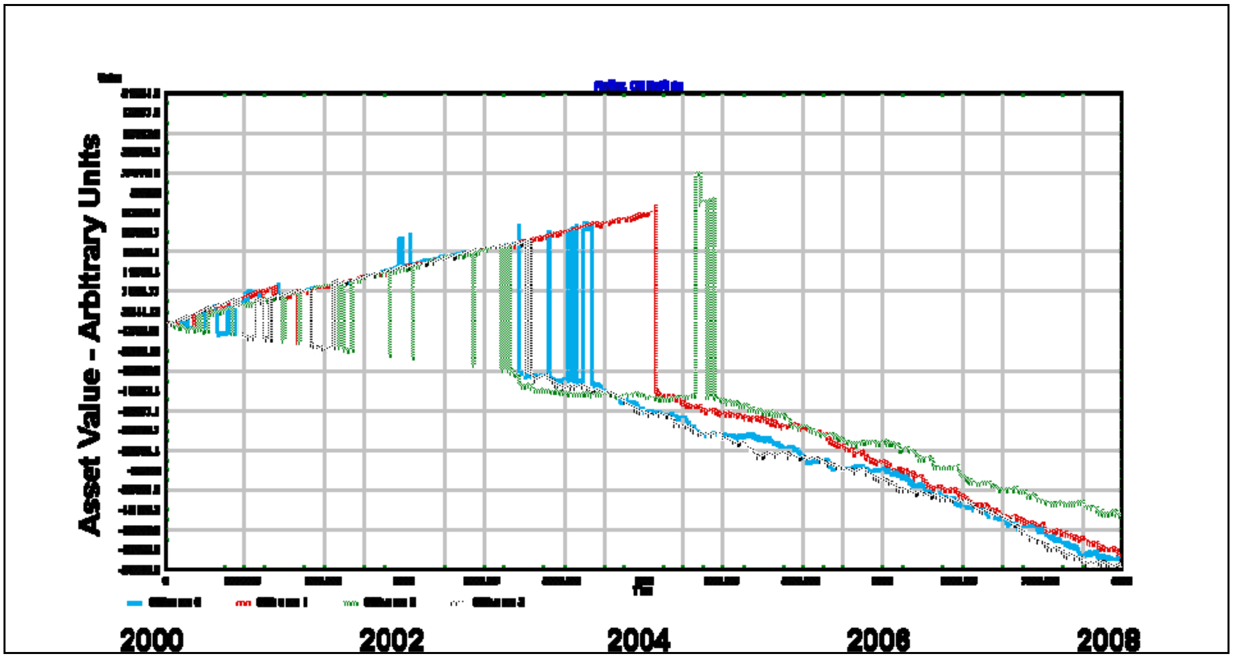

Figure 5. Asset value from 2000 to 2008, 9X leveraged fund. Trigger point is 4.5%

Figure 5 shows the fund's assets as a function of time for a trigger point of 4.5%. In this case the funds assets again go negative, but at later time, approximately in the year 2004-2005 time frame.

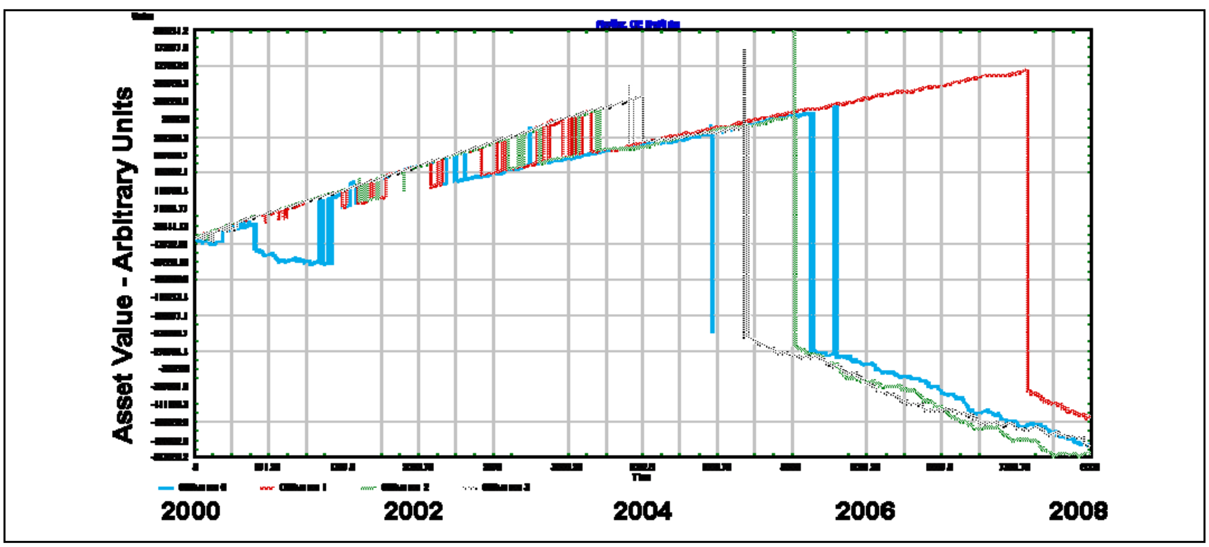

Figure 6. Asset value from 2000 to 2008, 9X leveraged fund. Trigger point is 5%.

Figure 6 shows the fund's assets as a function of time for a trigger point of 5%. Here the fund's assets increase in value until the year 2006 to 2007 time frame.

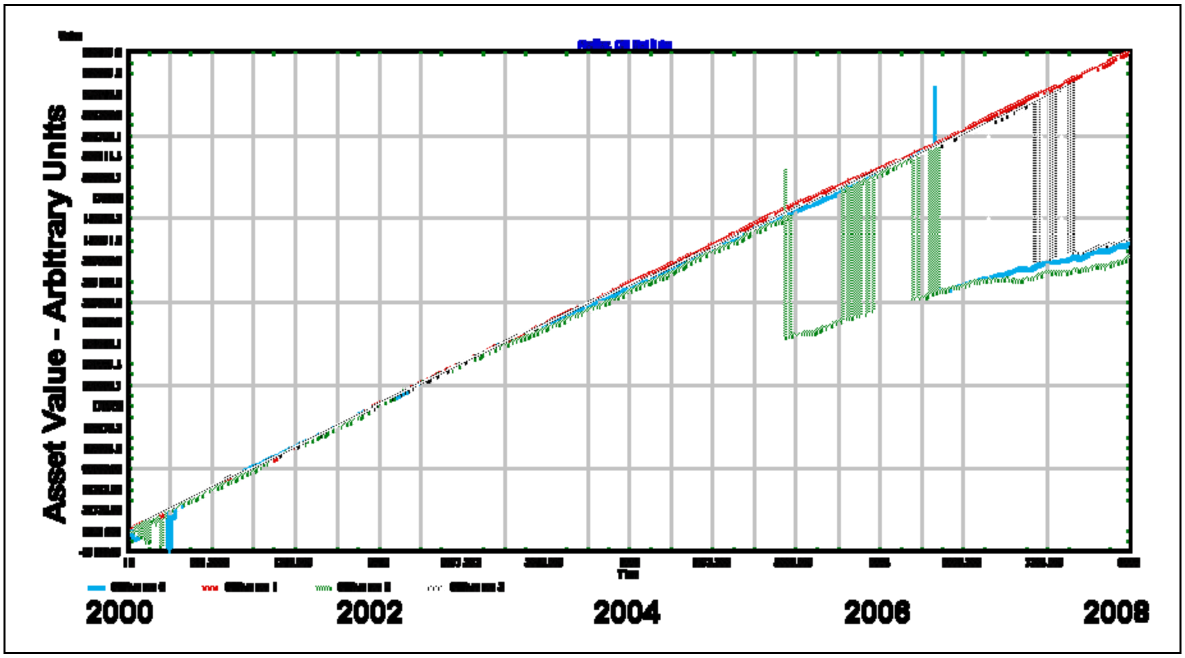

Figure 7. Asset value from 2000 to 2008, 9X leveraged fund. Trigger point is 5.75%

Figure 7 shows the fund's assets as a function of time when the trigger point is raised to 5.75%. At this higher level of trigger point the fund's assets continue to accumulate value from year 2000 to 2008. A conclusion resulting from this SoS modeling approach is that while investors in the unregulated CDO market can reap substantial profits, the market is highly unstable and easily result in catastrophic losses.

Figure 8 shows a comparison of asset values of a 3X leveraged fund compared to a 9X leverage fund for the time period year 2000 to 2008 and a trigger point of 4.5% for both funds. Both funds lose value at the same time, but while the 3X leveraged fund recovers and remains solvent the 9X leveraged fund never recovers and becomes insolvent. Thus as CDOs are resold to higher and higher leveraged funds, the risk of financial loss increases dramatically.

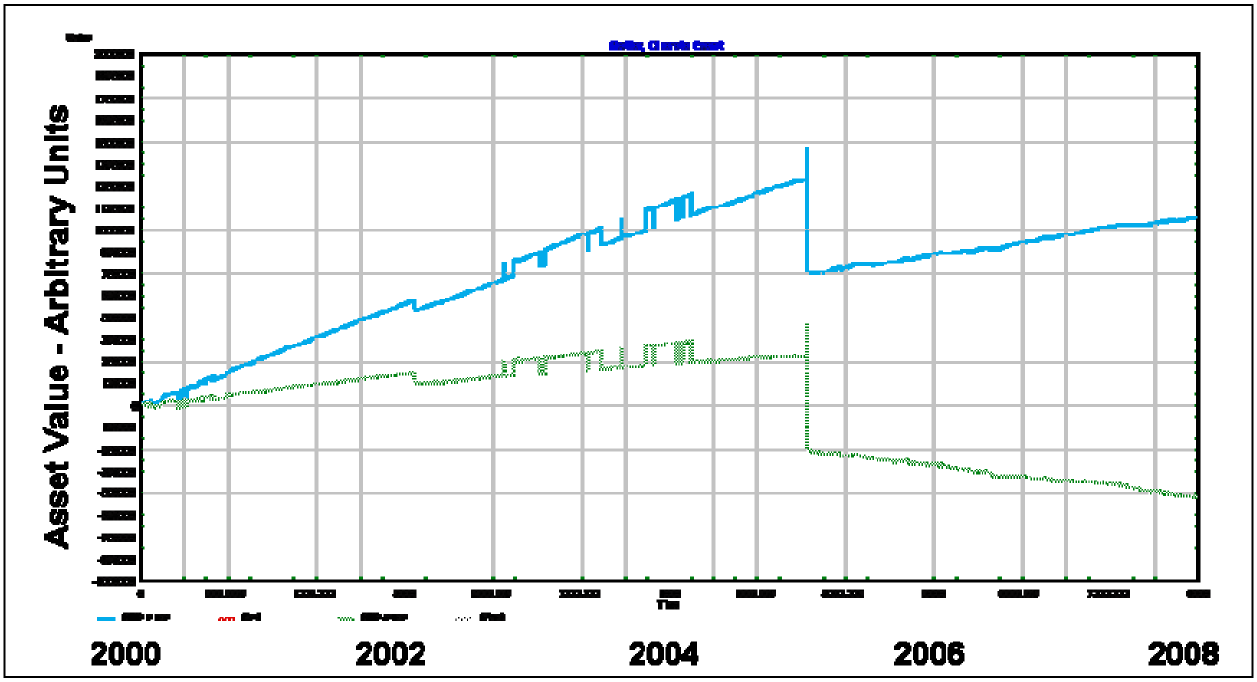

Figure 8. Asset value for a 3X leveraged fund (upper blue trace) and a 9x leveraged fund (lower green trace) for the time period 2000 to 2008. Trigger point is 4.5%.

By comparison, the net income history of Lehman Brothers Holding Company, which was leveraged 30 times in the CDO market, is shown in Figure 9. The Lehman Brothers net income shows increasingly highly profitable results from 2003- 2007 to large losses early in 2008, in agreement with both the shape and the timing of the results of our systems of systems model.

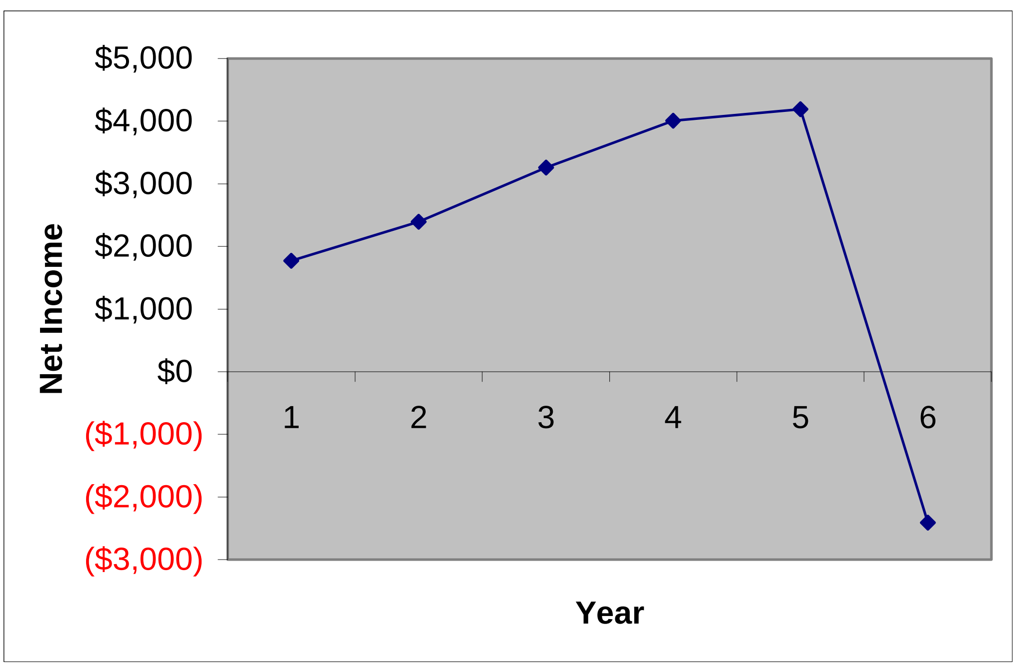

Figure 9. Lehman Brothers Holding net income, in millions of dollars, 2003 -2008. (Money Central, 2009)

The schematic model shown in Figure 1 and the executable model shown in Figure 2 can be expanded to include more detail, either to refine preliminary results or to determine the importance of various factors to SoS behavior. For example, the model could include the effect of the cost of living as a function of time, consumer credit usage, the cost of oil, or any other factors that might be considered to have a significant effect. However, results show that for even an extremely simple model the results are consistent with the actual behavior of the deregulated CDO market, and this suggests that such a systems engineering analysis of the market behavior would have been valuable in providing quantitative evidence of unwanted large scale behavior in advance of encouraging unregulated markets. A systems engineering analysis would also have shown the leading indicators that should be monitored, measured and input into a dynamic SoS model in order to give advance warning of the magnitude and timing of market instabilities.

We now consider a system of systems model that may predict future economic conditions given the initial conditions in the US midway through 2009. The system of systems model is shown in abstract form in Figure 10. The elements of the model are the job market in terms of overall employment (or, equivalently, unemployment) rate, government investment, consumer confidence, the housing market, credit availability and consumer spending. There are other related elements that could be included, such as stock market indicators, but for the purpose of illustrating a system of systems model as a predictive instrument, the simplified model shown in Figure 10 suffices. As in the CDO model the important direct interactions are shown as solid connectors and indirect interactions are shown as dashed connectors.

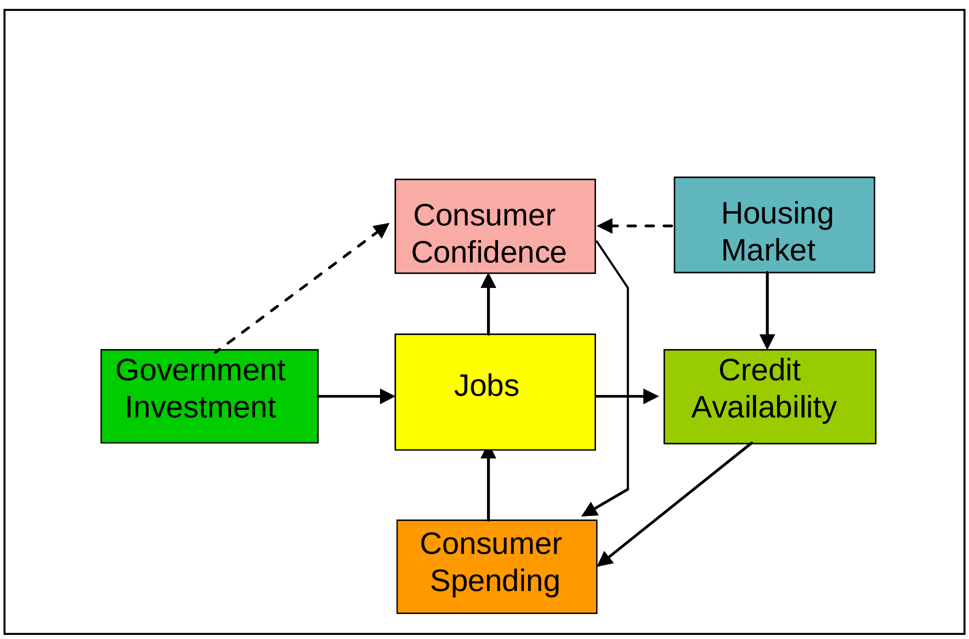

Figure 10. Representation of a Model of the Near Term Future US Job Market.

The current financial crisis in the US is now due to lack of consumer and business confidence in the economy. The current administration has enacted a $787 B US stimulus bill that includes $280.8 B in tax cuts, $308.5 B in discretionary spending and $198 B in direct spending (San Jose

Mercury News 2009). These actions are intended to stimulate the economy by creating new jobs as well as improving the production infrastructure. The 2/3 of the US gross disposable product (GDP) is due to consumer spending, which in turn is driven by consumer confidence. There are several factors that influence consumer confidence, but among the most important are the job market and changes in the job market, the housing market and confidence in the government, often reflected in presidential approval ratings.

The model is run beginning with March, 2009 initial conditions and continuing over a 30 month time period. Results are shown in Figure 11 for two cases. The first case, reflected by the upper curve in Figure 11, assumes that as the job market improves due to government investment, consumers' confidence will be fully restored and they will spend at rate consistent with the average rate earlier in the decade. The lower curve assumes that they will lack confidence in the long term health of the economy and will save at very high rates, and spend at low rates. The upper curve shows an increase in unemployment to about 11% early in 2010 and then a decrease in unemployment to about 5% late in 2011. The lower curve shows a decrease in unemployment to about 7% late in 2011. There is an important difference between the two cases. The upper curve would likely result in a self-sustaining economic recovery and would likely not require further government intervention. The lower curve might likely result in a non-sustainable recovery and would require further government intervention or other action.

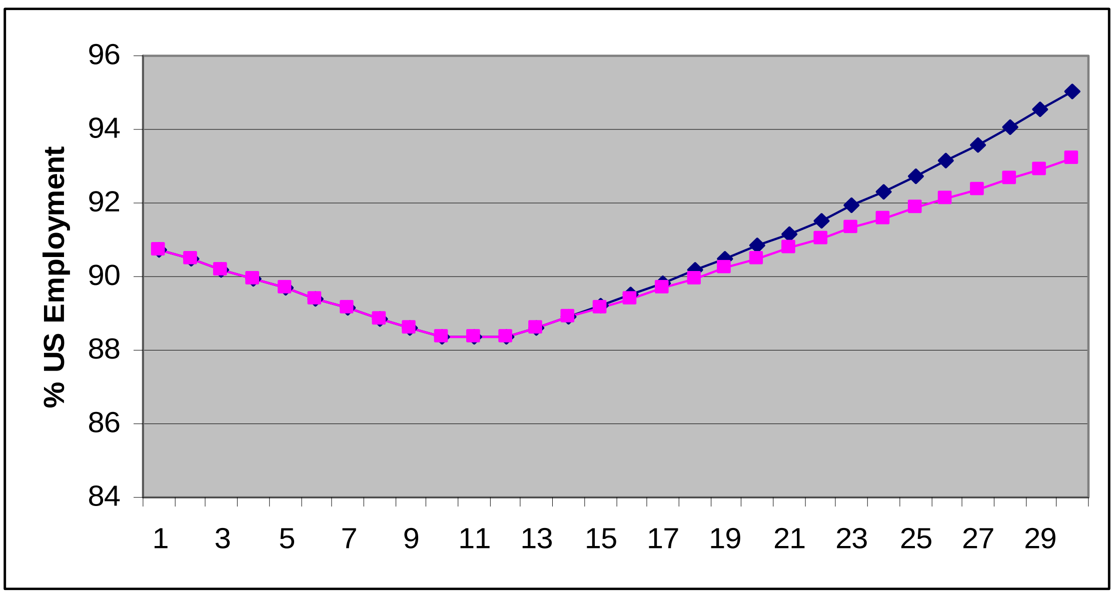

Figure 11. Predicted US employment rate in percent for the period mid-2009 - late 2011. Top curve reflects historical consumer spending as a function of consumer confidence and the bottom curve reflects a high rate of saving and a low rate of spending.

Conclusion

The importance of systems of systems in today's global markets requires that systems engineers develop methods for analyzing complex SoS behavior, in order to predict favorable and unfavorable consequences and in order to inform the architecture and operating principles of SoSs to better assure desired results. Modeling SoSs in executable form, with emphasis on the interacting elements of SoSs, shows promise for providing systems engineers with a suitable technique that can be applied to a wide variety of SoSs, including those that have people as an important element and adds the human dimension to systems engineering. A systems engineering approach also provides a framework for analyzing SoSs such as the CDO market in a holistic way that goes beyond more narrowly focused analyses, giving a more broad understanding of the potential origins of SoS large scale behavior.

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