Acceptable Risk and Mitigation Options: Dynamic Structure of Building Safety

David F. Gillespie[1]
Washington University-St. Louis
George Warren Brown School of Social Work
1 Brookings Drive Campus Box 1196, St. Louis, MO 63130

Tel: 314-935-6674 Fax: 314-935-8511
E-mail: davidg@gwbmail.wustl.edu

Sungsook Cho
Washington University-St. Louis
George Warren Brown School of Social Work
1 Brookings Drive Campus Box 1196, St. Louis, MO 63130

Tel: 314-935-8668 /Fax: 314-935-8511
E-mail: ssc2@gwbmail.wustl.edu

Karen J. Robards
Augsburg College
Department of Social Work

Tel: /Fax:
E-mail: robards@augsburg.edu

Abstract

This paper reports the results of a study designed to understand and facilitate disaster mitigation in communities characterized by low frequency/high magnitude earthquakes. A system dynamics model describes the distribution of building safety over time and the dynamic structure governing the decision-making that created the current distribution of building safety in a small town located near the New Madrid Fault Zone and therefore at significant earthquake risk. Data from this town is used to establish a 20-year baseline. Simulations are run over a 40-year period to examine the consequences of different building policies and the effects of a magnitude 7.0-earthquake in the year 2002.

Key word:

Disaster mitigation, building safety, conserved flow model, dynamic structure.

---

[1] Contact person.

INTRODUCTION

Federal, State and local governments are—or need to be—active participants in mitigation efforts. Requests for federal disaster assistance and relief are mandated to pass through a communication chain from the local to the state to the federal level, with each lower level stating need for additional assistance. Mitigation approaches in particular are dependent on the active promotion of such activities by lower levels of government, with the states often delegating authority related to land use to local levels (Rossi, Wright, Weber-Burdin, 1982). Thus, in many ways, local governments are kingpins in implementing disaster preparedness and mitigation efforts.

The problem is to identify the process and decision points needed to increase the preparedness and mitigation efforts of local communities and their stakeholders - local government, business, and other commercial actors. The need seems especially crucial in the area of mitigation, which can require potentially unpopular building code adoption and enforcement, and land-use zoning changes. The overall level of safety in a community is affected by what happens to buildings collectively. Individuals may be injured or killed in their homes, at work, at school, at church, or while shopping. In an earthquake, a number of buildings are likely to sustain damage, which will affect the well being of the community as a whole. Thus, the community level of analysis is crucial.

Community safety does not fall under the total jurisdiction of any one group of stakeholders. A focus on only one set of stakeholders fails to capture the whole picture and important community policy ramifications. In this study, we straddle the gap. The model developed for this study represents a broad, community level picture of building safety. However, we developed the model with government decision makers in mind as primary users of the model. Their information and perspective provide the detail for this work. This choice is justified because of local government's role as a protector against the consequences of disaster and legitimate authority for establishing and enforcing pertinent codes and laws to protect the public.

The purpose of this paper is to understand and facilitate disaster mitigation in communities characterized by low frequency/high magnitude earthquakes. We have developed a system dynamics model describing the distribution of building safety over time and the dynamic structure governing the decision-making that created the current distribution of building safety in a small town located near the New Madrid Fault Zone and therefore at significant earthquake risk. This study responds to Mileti's (1999) suggestion about the importance of understanding the systemic, interrelated nature of disaster preparedness and mitigation. After establishing the baseline of building safety over a 20-year period, we examine the consequences of different policies as well as the impact of a major earthquake.

RESEARCH PLAN

One small community near the New Madrid Seismic Zone (NMSZ) in Illinois was selected by Mid-America Earthquake Center staff as the focus for a number of related studies being conducted by the Center, from loss estimates to cost/benefit analyses to potential mitigation projects. The site of the study reported here has a reputation of being highly active in mitigation. The community is a university town of approximately 20,681 (U.S. Census Bureau, 2000), with significantly over half the population student transients. Since 1990, the city has lost about 23.5% of its 1990 population (U.S. Census Bureau, 2000). Illinois emergency management officials identified the city as a leader in the implementation of building codes and concern about seismic safety, which relate to mitigation efforts.

Both archival and interview data were used for this study. We used some archival data such as Census figures for 1980 and 1990, and the identification of buildings and their corresponding contact names, addresses, and phone numbers. A mail survey, with follow-up calls, was distributed to these essential facilities requesting data that would help set parameter estimates for the model. When the response rate to this survey was low and the amount of missing data high, we shifted data collection efforts to face-to-face interviews with key officials. Another piece of valuable archival data was the life safety risk of the non-residential city buildings.

The tasks being studied were widely dispersed within the city and community. Eleven semi-structured interviews were conducted with fourteen decision makers. Six personnel from the city were interviewed, two from the local hospital, and six from the public schools (one from the elementary school district, two from the high school district, and three from the university). With one exception, each interview lasted from 1 to 1 ½ hours.

While one of the valuable characteristics of system dynamics modeling is its ability to show behavior over time, this also creates special challenges for data collection. It is often extremely difficult if not impossible to get access to old archival records, such as budgets, staffing levels, and public opinion, since they may not be available at all, and their physical retrieval can be expensive in time and dollars for the organization's staff. When necessary, educated recollections by knowledgeable informants, particularly those with longevity in the system, are used for assigning values to parameters. For instance, interviewees provided estimates on the amount of non-structural mitigation carried out over the past 20 years. While there is a degree of imprecision in this data, it is acceptable because in systems modeling, the key focus is on identifying the interrelationships (Richardson & Pugh, 1981). The behavior of the system modeled is more dependent on the structure (relationships between the variables) than on the precision of the parameter values.

The data collected was used to formulate and initialize a model describing the distribution of building safety in this small town. The time period modeled was from 1980 to 1999. This period was selected because it was recent enough so that information was available (many key respondents have worked for the city for much of this period) and long enough to show change over time.

MODEL OF THE CITY'S BUILDING SAFETY

The modeling process described above was used to create a model that could help guide the mitigation efforts of a city in Illinois. The goal of mitigation is to increase the level of safe buildings. The model represents the distribution of building safety over time and factors that influence that distribution. Building safety is defined as the annual average level of life safety risk associated with the essential facility buildings. The model distinguishes three primary levels of safety: safe buildings, moderately safe buildings, and unsafe buildings. There are three ways to increase the number of safe buildings: by building new buildings to the most current building code, by structurally retrofitting existing buildings, and by non-structurally retrofitting existing buildings. There are also three ways to decrease the number of safe buildings: by doing nothing (i.e., physical deterioration over time), by planned destruction such as razing for development, and by unplanned destruction such as fire or disaster. In addition, buildings may move between the points on a continuum of safe to unsafe buildings; for instance, buildings may start safe and become less safe, or start unsafe and become moderately safe or safe.

The structure of this model is referred to as a "conserved flow" or "main chain infrastructure" (Richmond, 2000). As a main chain structure, there is a built-in tendency for the buildings to be distributed among the stocks in proportion to the relative amounts of time spent in each respective stock. The amount of time that a building spends in a stock depends on the rates of deterioration, rates of removal, and rates of mitigation. For example, if we assume that safe buildings hold up on average for 30 years before deteriorating to the point of becoming moderately safe, and moderately safe buildings hold up for 20 years, and unsafe buildings are retained for 40 years, then this main chain structure would seek to distribute buildings among the three levels in a 3:2:4 ratio. This ratio may be different from the distribution that the community is seeking to achieve. Therefore, becoming aware of such "implicit goal structures" (Richmond, 2000) can help community leaders to make decisions that overcome this built-in systemic tendency and more quickly achieve their desired distribution of building safety.

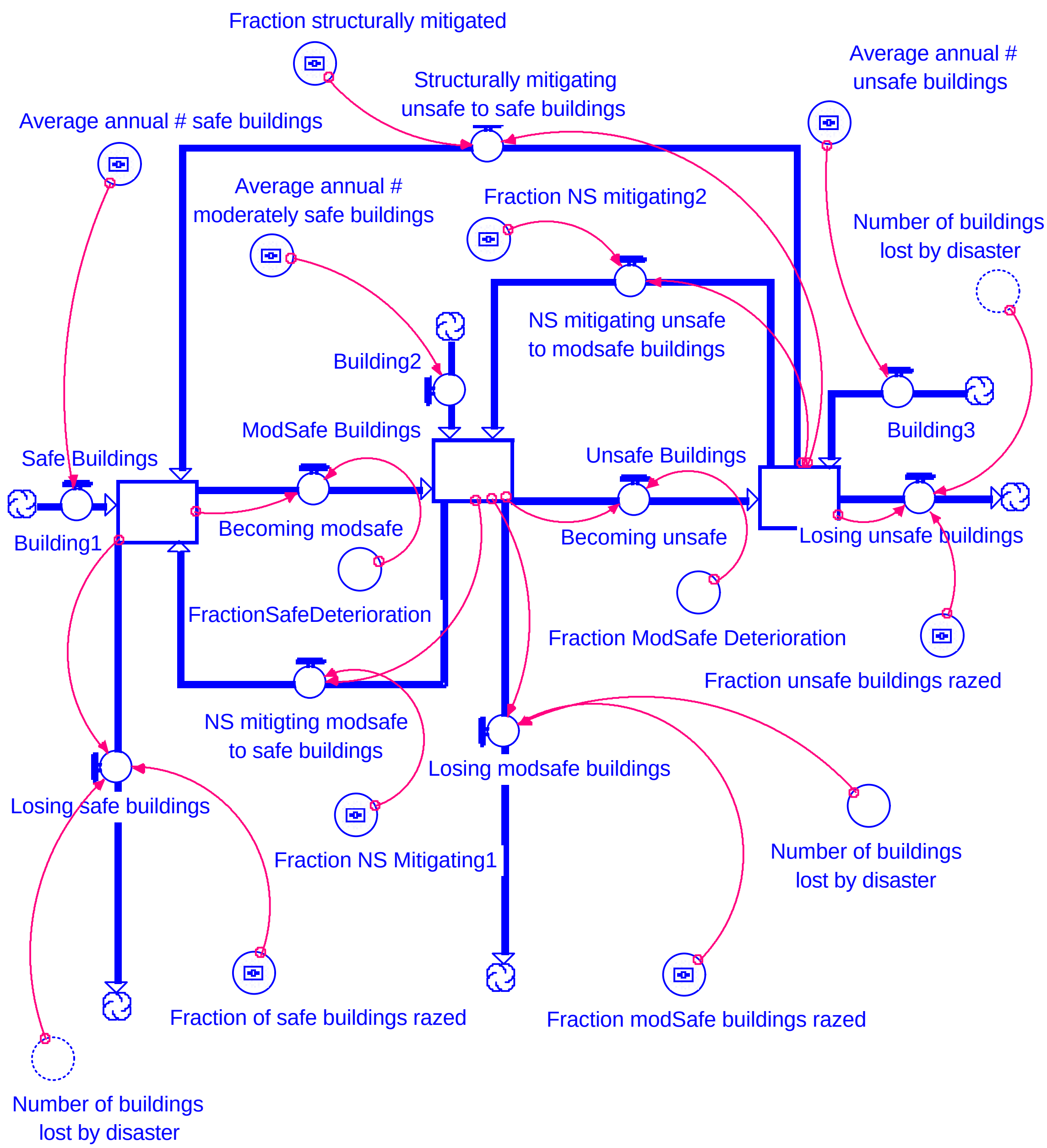
The variables and process depicted in the model were identified through a theoretical understanding of the system, supplemented by interviews with key city informants. The model was initialized with data from an Applied Technology Council survey (ATC-21) along with educated assumptions about the various rates of construction, building deterioration, and mitigation. Both informant and archival data were used to refine the model's initial quantification. City personnel responsible for mitigation provided information and verified assumptions about most of the variables in the model.

Levels of Building Safety

The data on building safety was obtained from a companion MAE Center project that conducted ACT-21 risk assessments for the city chosen. ATC-21 scores are based on a rapid screening procedure (FEMA-154, July 1988; FEMA-155, September 1988; Olshansky, 1995) that yields values of 0-6. The scores are related to the probability of major building damage, defined as damage exceeding 60 percent of building value. A score of one (1.0) indicates the probability of major damage being 1 in 10, a score of two (2.0) indicates a probability of 1 in 100, a score of three (3.0) indicates a probability of 1 in 1000, etc. In application, buildings with a score greater than two are considered an acceptable life safety risk. The Applied Technology Council recommends having buildings with scores of 2 or less examined by a professional engineer experienced in seismic design. In the current study, buildings with scores of 2 or less are considered unsafe ("Unsafe Buildings"), those with scores of 2.1 to 4.0 are considered moderately safe ("ModSafe Buildings"), and those with scores greater than 4.0 are considered safe ("Safe Buildings").

The model is illustrated in Figure 1 using a stock and flow diagram. The equations for this model are presented in Appendix A. Here we summarize the features of this model. The mitigation process reflected in this model is structured around a chain of three stocks: safe, moderately safe, and unsafe buildings. These three stocks represent the distribution of building safety across the city selected. In this model, buildings are constructed to be safe, moderately safe, or unsafe with respect to the area's earthquake hazard. Over time, safe buildings deteriorate into moderately safe buildings, and moderately safe buildings deteriorate into unsafe buildings. At any point in time, buildings can be lost to development, fire, or disaster, or, alternatively, unsafe buildings can be mitigated to become safe or moderately safe.

Figure 1: Stock and Flow Diagram of the City's Building Safety



<u>Variables affecting the level of safe buildings</u>

The stock for Safe Buildings is on the left side of the model. There are three flows that add buildings to this stock and two flows that remove buildings. The number of buildings that are constructed safely ("Building1"), the number of buildings that are structurally mitigated ("Structurally mitigating unsafe to safe buildings"), and the numbers of buildings that are non-structurally mitigated ("NS mitigating modsafe to safe buildings”) all serve to increase the number of Safe Buildings. On the other hand, the number of buildings that deteriorate to become moderately safe (“Becoming modsafe”) and the number that are destroyed/removed (“Losing safe buildings”) serve to decrease the number of Safe Buildings.

The ATC-21 data show that in 1980 there were 37 safe buildings. In 1999, there were 72 safe buildings. The gain of 35 safe buildings between 1980 and 1999 represents an average annual net gain of 1.75 safe buildings. During this period of time, one of the essential facility buildings was structurally mitigated. As reflected in the name of the variable above, structural mitigation is represented in this model by retrofitting an unsafe building to make it safe. Also during this period of time, we estimate that between five and six buildings were non-structurally mitigated. Non-structural mitigation is more easily and inexpensively achieved but at the same time less effective. There is no amount of non-structural mitigation that can make an unsafe building safe, but this type of mitigation can make moderately safe buildings safe. Few safe buildings were lost over this 20-year period. We estimate that over the 1980 to 1999 period about 14 safe building were lost due to fire or development, and approximately 16 deteriorated to the point of becoming moderately safe. These patterns are consistent with our assumption that buildings constructed safely will deteriorate to become unsafe in 50 years. In 1980, the average essential facility building in the city was approximately 25 years old.

Variables affecting the level of moderately safe buildings

The stock for moderately safe buildings (“ModSafe Buildings”) is located in the middle of the model. There are three flows that add buildings to this stock and three flows that remove buildings. The number of buildings that are constructed moderately safely (“Building2”), the number of buildings that are non-structurally mitigated (“NS mitigating unsafe to modsafe buildings”), and the number of safe buildings deteriorating (“Becoming modsafe”) all serve to increase the number of moderately safe buildings. On the other hand, the number that deteriorate to become unsafe (“Becoming unsafe”), the number of moderately safe buildings receiving non-structural mitigation to make them safe (“NS mitigating modsafe to safe buildings”), and the number that are destroyed/removed (“Losing modsafe buildings”) serve to decrease the number of safe buildings.

The ATC-21 data show that in 1980 there were 41 moderately safe buildings. In 1999, there were 72 moderately safe buildings. The gain of 31 moderately safe buildings between 1980 and 1999 represents an average annual net gain of 1.55 moderately safe buildings. During this period of time, we estimate that about 46 buildings were constructed moderately safe, about 16 safe buildings deteriorated to the point of becoming moderately safe, and about 5 unsafe buildings were non-structurally mitigated to become moderately safe. Relatively few moderately safe buildings were lost over this 20-year period. We estimate that over the 1980 to 1999 period about 15 moderately safe building was lost due to fire or development, and approximately 20 deteriorated to the point of becoming unsafe.

Variables affecting level of unsafe buildings

The stock for UnSafe Buildings is on the right side of the model. There are two flows that add buildings to this stock and three flows that remove buildings. The number of buildings that are constructed unsafely ("Building3") and the number that deteriorate to become unsafe ("Becoming unsafe") each serve to increase the number of unsafe buildings. On the other hand, the number of buildings that are structurally mitigated ("Structurally mitigating unsafe to safe buildings"), the number of buildings that are non-structurally mitigated ("NS mitigating unsafe to modsafe buildings"), and the number that are destroyed/removed ("Losing unsafe buildings") serve to decrease the number of safe buildings.

The ATC-21 data show that in 1980 there were 145 unsafe buildings. In 1999, there were 151 safe buildings. The gain of 6 safe buildings between 1980 and 1999 represents an average annual net gain of 0.30 safe buildings. Few safe buildings were lost over this 20-year period. We estimate that over the 1980 to 1999 period six unsafe buildings were lost due to fire or development, one was structurally mitigated, and about 5 unsafe buildings were non-structurally mitigated to become moderately safe.

Policy variables

The stocks and flows described above can be influenced by nine policy variables. Policy variables are goals, protocols, or rules of thumb that govern the decisions made within a process. In this model, the policy variables influence how many buildings are built, removed, or mitigated. Three of these policy variables represent the number of buildings built each year. The "average annual number of safe buildings" determines Building1, the flow that adds new safe buildings. The baseline parameter for this variable is 2.6 buildings per year. The "average annual number of moderately safe buildings" determines Building2, the flow that adds new moderately safe buildings. The baseline parameter for this variable is 1.13 buildings per year. The "average number of unsafe buildings" determines Building3, the flow that adds new unsafe buildings. The baseline parameter for this variable is .15 buildings per year.

Another three of these variables represent the number of buildings lost each year. The "fraction of safe buildings razed" determines how many safe buildings are lost each year. The baseline parameter for this variable is .0012 of the safe buildings each year. The "fraction of moderately safe buildings razed" determines how many moderately safe buildings are lost each year. The baseline parameter for this variable is .0009 of the moderately safe buildings each year. The "fraction of unsafe buildings razed" determines how many unsafe buildings are lost each year. The baseline parameter for this variable is .001 of the unsafe buildings each year.

The last three of the nine policy variables represent mitigation, two for structural mitigation and two for non-structural mitigation. The "fraction structurally mitigated" determines the number of unsafe buildings that are retrofitted to become safe. The baseline parameter for this variable is .0003 of the unsafe buildings each year. The "fraction of non-structural mitigating1" determines the number of moderately safe buildings that are mitigated to become safe. The baseline parameter for this variable is .005 of the moderately safe buildings each year. The "fraction of non-structural mitigation2" determines the number of unsafe buildings that are non-structurally mitigated to become moderately safe. The baseline parameter for this variable is .0045 of the unsafe buildings each year.

There is one final variable in the model that represents the number of buildings lost by an earthquake ("number of buildings lost by disaster"). Although this is not a policy variable, it operates like a policy variable in that a certain number of buildings are lost when a damaging earthquake strikes. This variable is included to study the consequences of an earthquake on the distribution of building safety. Since there was not a damaging earthquake in this area during the 1980 to 1999 period, the baseline parameter for this variable is zero. Subsequently, this variable is initialized as a pulse function set to trigger the loss of buildings at a specified time.

Feedback loops among the variables

There are 15 feedback loops in this model. Four of these loops are associated with safe buildings, six with moderately safe buildings, and five with unsafe buildings. Eight of these feedback loops are direct links between each stock and its outflows. Looking at Figure 1, there are two direct feedback loops for safe buildings, one between safe buildings and becoming moderately safe and the other between safe buildings and losing safe buildings. There are three direct feedback loops for moderately safe buildings, one between moderately safe buildings and non-structural mitigating modsafe to safe buildings, one between moderately safe buildings and losing moderately safe buildings, and one between moderately safe buildings and becoming unsafe. There are also three direct feedback loops for unsafe buildings, one between unsafe buildings and structurally mitigating unsafe to safe buildings, one between unsafe buildings and non-structural mitigating unsafe to moderately safe buildings, and one between unsafe buildings and losing unsafe buildings. The remaining seven feedback loops are more complex.

There are two indirect feedback loops for safe buildings. The first one shows four links: from safe buildings to becoming moderately safe, from becoming moderately safe to being moderately safe, from moderately safe to non-structural mitigating of moderately safe, and from non-structural mitigating back to safe buildings. The second loop shows six links: from safe buildings to becoming moderately safe, from becoming moderately safe to being moderately safe, from moderately safe to becoming unsafe, from becoming unsafe to being unsafe, from unsafe to structurally mitigating unsafe to safe, and from structurally mitigating unsafe back to being safe.

There are three indirect feedback loops for moderately safe buildings. The first one shows four links: from moderately safe buildings to non-structural mitigating moderately safe, from non-structural mitigating moderately safe to safe buildings, from safe buildings to becoming moderately safe, and from becoming moderately safe to being moderately safe. The second shows six links: from moderately safe buildings to becoming unsafe, from becoming unsafe to unsafe buildings, from unsafe buildings to structurally mitigating unsafe buildings, from structurally mitigating unsafe buildings to safe buildings, from safe buildings to becoming moderately safe, and from becoming moderately safe to being moderately safe. The third loop has four links: from moderately safe buildings to becoming unsafe, from becoming unsafe to unsafe buildings, from unsafe buildings to non-structural mitigating unsafe buildings, from non-structural mitigating unsafe buildings to moderately safe buildings.

There are two indirect feedback loops for unsafe buildings. The first loop shows four links: from unsafe buildings to non-structural mitigating unsafe, from non-structural mitigating unsafe to moderately safe buildings, from moderately safe buildings to becoming unsafe, from becoming unsafe to unsafe buildings. The second loop shows six links: from unsafe buildings to structurally mitigating unsafe, from structurally mitigating unsafe to safe buildings, from safe buildings to becoming moderately safe, from becoming moderately safe to moderately safe, from moderately safe to becoming unsafe, from becoming unsafe to unsafe buildings.

It is through the feedback loops of this model that the community decision makers can influence the distribution of safe buildings. An understanding of the leverage points in this model may help community decision makers compose the most useful configuration of policies. Also, being aware of how long it takes to alter an unfavorable distribution may help community decision makers adopt and remain committed to longer-term policies. For this study, we have selected a time horizon of 20 years into the future (2000-2019). This time period was selected because it corresponds to the 20-year record of historical data collected (1980-1999), and because 20 years is near enough in time that current policy makers might find the results useful in considering possible policy changes.

Two different policy configurations are tested and compared to baseline results. Retaining the 1980-1999 policies though the 2000-2019 period creates the baseline results. The two policies are:

1) Building only safe buildings 2000-2019. All other parameters remain set at the 1980-1999 values. This policy appears to be consistent with the current practice in this town. Almost all buildings built since the early 1990s have been constructed to meet the ATC-21 rating of safe.

2) Building only safe buildings 2000-2019, increasing the rate of all types of mitigation, and increasing the rate of removing unsafe buildings. Four tests are conducted: 2x, 3x, 4x, and 5x the baseline rates. We assume increased rates of greater than 5x are unlikely to be feasible.

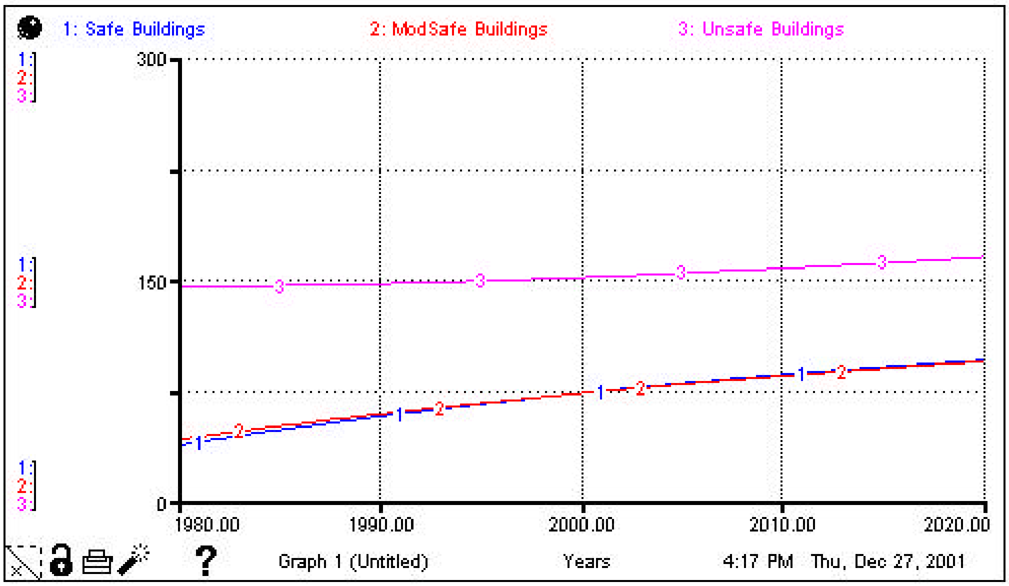
The best results from each of the policies are examined under an earthquake scenario. This scenario assumes that 65 (18%) of the buildings are destroyed. This figure corresponds to the estimated losses from a 7-point magnitude earthquake.

FINDINGS

The distribution of building safety that currently exists in the community has evolved from policies influencing the feedback loops in this model. As pointed out above, these policies involve building codes, removing unsafe buildings, and mitigating. Since earthquake provisions were not included in building codes until the late 1980s, this town, like most other Mid-western communities, has a backlog of unsafe building stock. In 1980, the community had 145 (65%) unsafe buildings, 41 (18%) moderately safe buildings, and 37 (17%) safe buildings. By the end of 1999, the city had 151 (51%)

unsafe buildings, 72 (24.5%) moderately safe, and 72 (24.5%) safe buildings. Keeping the 1980-1999 policies intact and running the model out to the year 2019 results in a gain of 56 buildings, from 295 to 351, with 94 (27%) safe, 93 (26%) moderately safe, and 164 (47%) unsafe buildings. These baseline results are used to compare the relative effectiveness of alternative policy scenarios. Figure 2 illustrates the baseline results.

Figure 2: Distribution of Building Safety in the City 1980-1999, and Distribution Expected 2000-2019 if 1980-1999 Policies Retained



The first policy configuration tested is to build only earthquake safe buildings 2000-2019. Executing this policy results in the same gain of 56 buildings as the baseline policies, from 295 to 351, but there are 131 (37%) safe, 64 (18%) moderately safe, and 156 (44%) unsafe. Compared to the baseline policies, this policy adjustment yields a 10% gain in the number of safe buildings, an 8% loss in moderately safe buildings, and a 3% loss in unsafe buildings.

The second policy to be tested is to build only safe buildings, increase all rates of mitigation, and increase the rate of removing unsafe buildings. Again, four variations are tested: 2x, 3x, 4x, and 5x the rates of structurally and non-structurally mitigating moderately safe and unsafe buildings, and, at the same time, 2x, 3x, 4x, and 5x the rate of removing unsafe buildings. Results are presented in table 5.

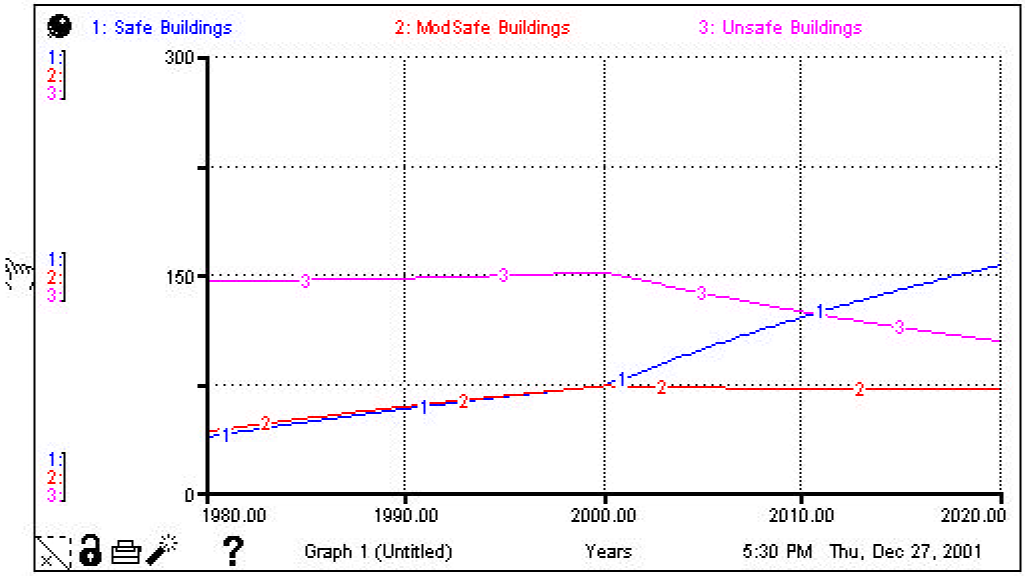
Table 1: Building Only Safe Buildings,
Increasing the Rates of Structurally and Non-Structurally Mitigating,
and Increasing the Rate of Removing Unsafe Buildings

Rate Increases	Safe Buildings	Moderately Safe Buildings	Unsafe Buildings	Total
2x	137 (40%)	67 (19%)	140 (41%)	344
3x	143 (42%)	69 (20%)	127 (37%)	339
4x	149 (45%)	70 (21%)	114 (34%)	333
5x	155 (47%)	70 (21%)	103 (31%)	328

Compared to the baseline, this policy yields a 13% to 20% gain in the number of safe buildings, a 5% to 7% loss in moderately safe buildings, and a 6% to 16% loss in unsafe buildings. The changes in distribution from the least to most extreme form of this policy show 2% to 10% shifts, a slightly higher proportion of safe building, a slightly lower proportion of moderately safe buildings, and lower proportions of unsafe buildings.

It appears from these results that some adjustment in the policy configuration would be desirable. The community has already adopted the policy of constructing only earthquake safe buildings. Over time, this adjustment does improve the distribution of building safety. In 20-years, the proportion of safe buildings will be 10% higher than it is today. Complementing the construction of only safe buildings with a policy of removing unsafe buildings could speed up the process of improving the distribution of building safety. This two-pronged approach would over a 20-year period bring about an almost equal number of safe and unsafe buildings. The rates of structural mitigation are so small that even 5x the rate showed little improvement. On the other hand, non-structural mitigation appears to be potentially quite useful. Non-structurally mitigating moderately safe buildings to become safe adds 5% more safe buildings over the building only safe practice, but does not affect the proportion of unsafe buildings. In contrast, non-structurally mitigating unsafe buildings to become moderately safe has the effect of reducing the proportion of unsafe buildings by 8%, but does not affect the number of safe buildings. Of course, the multi-pronged approach of constructing safe buildings, mitigating, and removing unsafe buildings is the most effective. If adopted, this approach could lead in 20-years to more than two-thirds of the essential facility buildings in the city being safe or moderately safe. Figure 3 illustrates the results from this multi-pronged approach.

Figure 3: Distribution of Building Safety in the City 1980-1999, and
Distribution Expected 2000-2019 if Building Only Safe Buildings,
Increasing by Five-Times the Rates of Structurally and Non-Structurally Mitigating,
and Increasing by Five-Times the Rate of Removing Unsafe Buildings



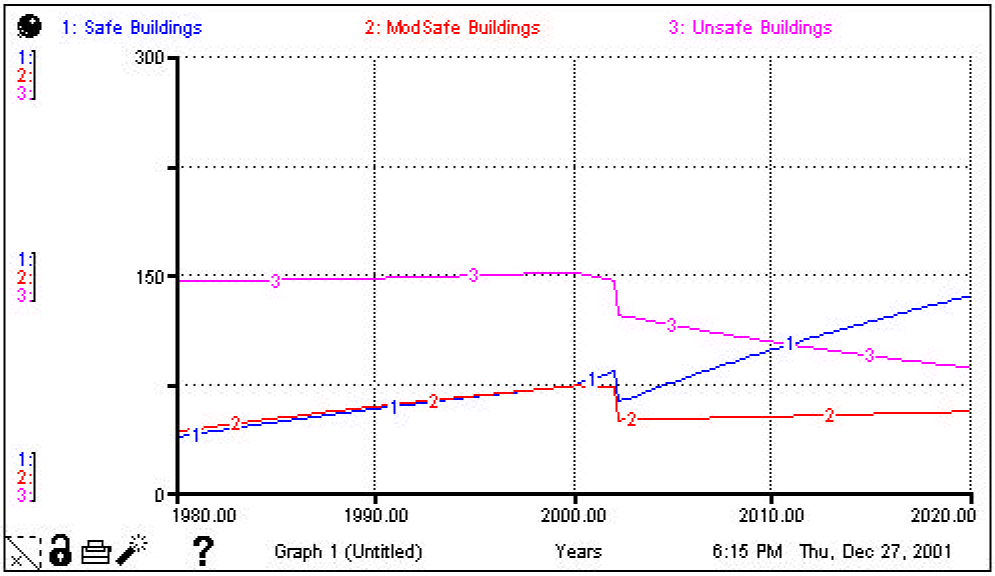
First Earthquake Scenario: Year 2002

In testing the policies under the earthquake scenarios, we use only the most extreme versions of the policies. Under the baseline policy with a 2002 earthquake, we find a loss of 3 buildings, from 295 to 292, with 78 (27%) safe, 76 (26%) moderately safe, and 138 (47%) unsafe buildings. The percentage distribution is the same as the original baseline. Again, we use these baseline results to compare the relative effectiveness of alternative policy scenarios.

The first policy configuration tested is to build only earthquake safe buildings 2000-2019. Executing this policy results in a gain of 9 buildings, from 292 to 301, with 123 (41%) safe, 48 (16%) moderately safe, and 130 (43%) unsafe. Compared to the baseline policies, this policy yields a 14% gain in the number of safe buildings, a 10% loss in moderately safe buildings, and a 4% loss in unsafe buildings.

The second policy to be tested is to build only safe buildings, increase all rates of mitigation, and increase the rate of removing unsafe buildings. Again, we test 5x the rates of structurally and non-structurally mitigating moderately safe and unsafe buildings, and, at the same time, 5x the rate of removing unsafe buildings. The findings show a loss of 20 buildings, from 292 to 272, with 134 (49%) safe, 54 (20%) moderately safe, and 84 (31%) unsafe. Compared to the baseline, this policy yields a 22% gain in the proportion of safe buildings, a 6% loss in moderately safe buildings, and a 16% loss in unsafe buildings. Figure 4 illustrates these results.

Figure 4: Earthquake in 2002 with Distribution of Building Safety in the City 1980-1999, and Distribution Expected 2000-2019 if Building Only Safe Buildings, Increasing by Five-Times the Rates of Structurally and Non-Structurally Mitigating, and Increasing by Five-Times the Rate of Removing Unsafe Buildings



If the community suffered a severe earthquake in 2002 and had 65 (18%) of its essential facility buildings destroyed, it would take more than 17-years to regain the number of essential facilities existing in 1999. None of the policy configurations brought the city back to the 1999 level of 295 buildings. The total number of buildings estimated to exist in 2019 ranges from 292 for the baseline case to 272 for the multi-pronged policy. If the multi-pronged 5x policy was implemented following the earthquake, the overall distribution of safe buildings is slightly better than it would have been without the earthquake. This is because the earthquake destroys more unsafe buildings that safe ones.

CONCLUSION

Even though this town began in the late 1980s to build only earthquake safe buildings, the distribution remains skewed in favor of unsafe buildings. The small change over this 20-year period in the number of unsafe buildings shows a practice of retaining old buildings, which are more likely to be unsafe. This practice plus the implicit systemic goal of buildings being distributed among the stocks in proportion to the relative amounts of time spent in each respective stock creates a structure that perpetuates an unfavorable distribution of building safety. The baseline ratio of safe to moderately safe to unsafe buildings is about 1:1:2. There are twice as many unsafe buildings as safe ones, and with the average age of the essential buildings being in the neighborhood of 25 years old, it will take an extra emphasis on removing unsafe buildings to counter the built-in tendency governing the current process.

Non-structural mitigation is a useful complement or alternative to removing unsafe buildings. While it would be most beneficial to encourage non-structural mitigation of both unsafe and moderately safe buildings, with limited funds an emphasis on the unsafe buildings appears to be more effective. Concentrating on the unsafe buildings would be expected to bring an 8% drop in the proportion of unsafe buildings over a 20-year period.

A limitation of the research presented in this paper is the lack of data on costs associated with the various policies. The amount of money required to implement a policy is always an important part of the decision-making process. There are good reasons for building owners to keep old buildings, and information about earthquake probabilities is unlikely to convince such owners to replace their buildings. Another limitation is the fuzzy definition of "essential facilities." We doubt that all 295 of the buildings counted as essential facilities are in fact critical to the response efforts in the aftermath of an earthquake.

Since cost is a primary objection to mitigation, more work need to focus on ways to reduce its cost. More consciously publicizing the tie-in between earthquake and other engineering designs (such as for wind) will help to build and reinforce an awareness and acceptance of earthquake design that does not now exist. Also, as shown in the experiments conducted in this study, shifting the emphasis from structural mitigation to non-structural mitigation is likely to be helpful.

A different structure for financial incentives to do mitigation work in new and existing buildings might be in order. Targeting the private sector, specifically insurance companies and associations, may be more effective in encouraging mitigation than getting the government to mandate it. The private sector is seen as having a legitimate right to offer a range of insurance prices, based on the level of protection desired by the consumer. (This is opposed to the government, which creates resentment when it tries to regulate without the same financial incentives.) Perhaps policy makers should be focusing efforts on that direction, using local governments as an avenue for technical assistance and education about various mitigation measures.

Finally, maybe we can find a way to start picking away at the short term "I don't want to spend my money today" mentality that accompanies this and so many issues today. Our social norms increasingly emphasize the short term, bottom line approach to many things. Perhaps we need to increase the social discussion about the need for a long-range perspective, one that considers the benefits of our actions today to future generations. System dynamics models represent powerful tools for focusing the discussion and exploring possible options.

REFERENCES

Federal Emergency Management Agency. (July 1988). *Rapid visual screening of buildings for potential seismic hazards: A handbook.* (ATC-21). FEMA-154. Washington, D.C.: Author.

Federal Emergency Management Agency. (September 1988). *Rapid visual screening of buildings for potential seismic hazards: Supporting Documentation*. (ATC-21-1). (FEMA-155).

Mileti, Dennis S. (1999). *Disasters by design: A reassessment of natural hazards in the United States*. Washington, D.C.: Joseph Henry Press.

Olshansky, Robert B. (May, 1995). *Rapid visual screening of buildings for potential seismic hazards: A guide for communities in the central United States*. Prepared for the Central United States Earthquake Consortium, Memphis Tennessee.

Richardson, G. & Pugh, A. (1981). *Introduction to system dynamic modeling with DYNAMO*. Cambridge, MA: MIT Press.

Richmond, Barry. (2000). *An Introduction to Systems Thinking*. Hanover, NH: High Performance Systems, Inc.

Rossi, Peter H., Wright, James D., & Weber-Burdin, Eleanor. (1982*). Natural hazards and public choice: The state and local politics of hazard mitigation*. New York, NY: Academic Press.

U.S. Census Bureau (2000). [Online] Available: http://venus.census.gov/cdrom/lookup.

APPENDIX A

Equations for the Carbondale Model of Building Safety

Equations

ModSafe_Buildings(t) = ModSafe_Buildings(t - dt) + NS_mitigating_unsafe_to_modsafe_buildings + Building2 + Becoming_modsafe - Becoming_unsafe - NS_mitigting_modsafe_to_safe_buildings - Losing_modsafe_buildings) * dt

INIT ModSafe_Buildings = 41

INFLOWS:

NS_mitigating_unsafe_to_modsafe_buildings = Unsafe_Buildings*Fraction_NS_mitigating2

Building2 = Average_annual_#_moderately_safe_buildings

Becoming_modsafe = Safe_Buildings*FractionSafeDeterioration

OUTFLOWS:

Becoming_unsafe = ModSafe_Buildings*Fraction_ModSafe_Deterioration

NS_mitigting_modsafe_to_safe_buildings = ModSafe_Buildings*Fraction_NS_Mitigating1

Losing_modsafe_buildings = ModSafe_Buildings*Fraction_modSafe_buildings_razed+Number_of_buildings_lost_by_disaster

Safe_Buildings(t) = Safe_Buildings(t - dt) + (Building1 + Structurally_mitigating_unsafe_to_safe_buildings + NS_mitigting_modsafe_to_safe_buildings - Becoming_modsafe - Losing_safe_buildings) * dt

INIT Safe_Buildings = 37

INFLOWS:

Building1 = Average_annual_#_safe_buildings

Structurally_mitigating_unsafe_to_safe_buildings = Unsafe_Buildings*Fraction_structurally_mitigated

NS_mitigting_modsafe_to_safe_buildings = ModSafe_Buildings*Fraction_NS_Mitigating1

OUTFLOWS:

Becoming_modsafe = Safe_Buildings*FractionSafeDeterioration

Losing_safe_buildings = Safe_Buildings*Fraction_of_safe_buildings_razed+Number_of_buildings_lost_by_disaster

Unsafe_Buildings(t) = Unsafe_Buildings(t - dt) + (Becoming_unsafe + Building3 - Losing_unsafe_buildings - NS_mitigating_unsafe_to_modsafe_buildings - Structurally_mitigating_unsafe_to_safe_buildings) * dt

INIT Unsafe_Buildings = 145

INFLOWS:

Becoming_unsafe = ModSafe_Buildings*Fraction_ModSafe_Deterioration

Building3 = Average_annual_#_unsafe_buildings

OUTFLOWS:

Losing_unsafe_buildings = Unsafe_Buildings*Fraction_unsafe_buildings_razed+Number_of_buildings_lost_by_disaster

NS_mitigating_unsafe_to_modsafe_buildings = Unsafe_Buildings*Fraction_NS_mitigating2

Structurally_mitigating_unsafe_to_safe_buildings = Unsafe_Buildings*Fraction_structurally_mitigated

Average_annual_#_moderately_safe_buildings = 2.3

Average_annual_#_safe_buildings = 2.93

Average_annual_#_unsafe_buildings = .15

FractionSafeDeterioration = .014

Fraction_modSafe_buildings_razed = .013

Fraction_ModSafe_Deterioration = .0175

Fraction_NS_Mitigating1 = .005

Fraction_NS_mitigating2 = .0035

Fraction_of_safe_buildings_razed = .013

Fraction_structurally_mitigated = .0003

Fraction_unsafe_buildings_razed = .002

Number_of_buildings_lost_by_disaster = PULSE(23,2002,25)

Back to the Top