Conceptual Modeling and Dynamic Simulation of Brownfield Redevelopment

Todd K. BenDor
Department of Urban and Regional Planning
University of Illinois at Urbana-Champaign
111 Temple Buell Hall
611 Taft Drive
Champaign, IL 61820
Tel: 217-333-5172
Fax: 217-244-1717

Sara S. Metcalf
Department of Geography,
University of Illinois at Urbana-Champaign
Urbana, IL 61801
ssm@uiuc.edu

Abstract

The negligent upkeep of many abandoned industrial sites ("brownfields") throughout the twentieth century has had grave impacts on the urban landscape of American and European cities. In recent years, brownfield redevelopment has come to be viewed as a strategy for sustainable land use and urban revitalization. This study assesses the feasibility of the construction of a dynamic simulation model of urban brownfield redevelopment. Literature surrounding brownfield redevelopment is reviewed and used to construct a dynamic hypothesis of brownfield redevelopment as it relates to site liability, economic viability, and availability of redevelopment funding. Finally, an initial system dynamics model of the brownfield redevelopment process is constructed. This quantitative analysis is performed using the 2003 US Conference of Mayors brownfield survey, which serves as a dataset on brownfield distribution and average site size. We conclude with suggestions for the extension of the model to capture spatial feedback in order to assess redevelopment effects on the surrounding matrix of urban land-uses.

Keywords: Brownfields, brownfield redevelopment, urban development, urban modeling, urban planning, urban revitalization

Introduction

The negligent upkeep of many industrial sites throughout the twentieth century has had grave impacts on the urban landscape of North American and European cities (De Sousa, 2001; Harrison and Davies, 2002). Only during the last several years has the failure to reuse and redevelop contaminated urban lands become a major concern for many municipalities. This heightened awareness of the brownfield problem has occurred as estimates of the number of brownfields in the United States have grown to between 500,000 and 1 million (Kretchik, 2002). The mid-1980s saw a shift in planning and policymaking attention towards measures designed to improve the quality of life in urban areas (De Sousa, 2001; De Sousa, 2003) with the United States Environmental Protection Agency (U.S. EPA) creating a mission to "empower States, communities, and other stakeholders in economic development to work together in a timely manner to prevent, assess, safely clean up, and sustainably reuse brownfields (U.S. EPA, 2003b)." One aspect of urban revitalization garnering widespread political support has been the redevelopment of under-utilized brownfield sites that are often located in dilapidated urban core areas. In recent years, brownfield redevelopment has emerged as a sustainable land use strategy and one of several ways to address urban sprawl and promote economic development through new job creation (Thomas, 2002; Kirshenberg *et al.*, 1997 Tam and Byer, 2002).

However, as we will show throughout this study, much of the literature on brownfield redevelopment has highlighted a critical paradox created by state and federal legislation: past decades have seen governmental attempts to revitalize contaminated urban lands into areas beneficial to the surrounding community. While doing this, the same governments attempt to ensure public health by enacting regulations that impose uncertain liability risks on individuals interested in redeveloping a contaminated area. These conflicting actions have slowed the possibility of revitalization in areas whose economic viability is already inherently in question (otherwise they already would have been redeveloped) and undermined the original societal goal of urban revitalization. This paradox was evidenced in a survey of 231 American cities in which the most frequently identified barrier to redevelopment of brownfields was lack of clean-up funds (82 percent), liability issues (59 percent), and the need for environmental assessments (51 percent) (US Conference of Mayors, 2003).

The project described herein was initiated as part of a set of Illinois state-funded ventures to assist in community and land-use planning issues in the St. Louis metropolitan area. These projects include the East St. Louis Action Research Project (ESLARP) and the Land-use Evolution and Impact Assessment Model (LEAM), among others. Several of these projects are specifically focused on addressing East St. Louis, a city that has experienced significant economic collapse over the last forty years and is the current focus of intense redevelopment efforts and academic research by the University of Illinois at Urbana-Champaign (Reardon, 1995, 1998; Reardon and Shields, 1997). [1]

There are two major objectives of this study. Our first aim is to create a framework for understanding the redevelopment process. We initiate this through an exploration of literature looking at the barriers to urban brownfield redevelopment, followed by the construction of a dynamic hypothesis incorporating these elements. Here, the hypothesis of system behavior is dynamic since it tries to explain the dynamics characterizing the system in terms of the underlying feedback mechanisms that control system or problem structure.

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[1] East St. Louis lies on the Illinois side of the Mississippi River, directly adjacent to the City of St. Louis, MO.

Our second objective is to abstract this process through the use of the system dynamic modeling methodology, which has the ability to incorporate feedbacks and delays into dynamic models. Throughout this construction we utilize a number of probabilistic elements to represent the uncertainty underlying the many facets of the redevelopment process. We envision that the model created herein will have the further potential to examine specific, location-dependent policing relating to brownfield redevelopment.

In addition to policy testing possibilities, we recognize the importance of considering social attitudes relating to urban revitalization and contaminated urban areas. We will explore what we have identified as the major factors contributing to the likelihood of redevelopment, while attempting to capture these aspects as part of a dynamic hypothesis of brownfield redevelopment.

Literature Review and Background

As brownfield redevelopment has become a major part of urban revitalization as a whole, a growing body of literature has formed around the brownfield redevelopment process. In 1997 the U.S. EPA promulgated a widely accepted definition of brownfields that defined them as, "abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination (De Sousa, 2003)." The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 (42 U.S.C 9601, sect. 101) defined brownfields as, "…real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant (EPA, 2003a)."

This definition characterizes an enormous number of properties as brownfields since the severity of contamination is not specific. Characterizing brownfields using this definition also permits areas containing perceived contamination to be classified as brownfields with the same ease as areas containing documented contamination. Brownfields are often located in urban core areas and industrial suburbs whose history has included intense periods of traditional manufacturing (McCarthy, 2002). These sites can also include small commercial and residential lots such as gas stations and dry-cleaners that are suspected of contamination.

U.S. law creates a distinction between extremely contaminated sites and sites possibly contaminated with low levels of ordinary, non-hazardous waste. Hazardous sites are generally governed federally by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). This law placed a tax on the chemical and petroleum industries and provided broad Federal authority to respond directly to releases or threatened releases of hazardous substances that posed a threat to public or environmental health. Over five years, $1.6 billion was collected for a trust fund targeted at cleaning up abandoned or uncontrolled hazardous waste sites (commonly called the Superfund). One of CERCLA's goals is to initiate "long term remedial response actions, that permanently and significantly reduce the dangers associated with releases or threats of releases of hazardous substances (EPA, 2003c)," on contaminated sites that are placed on the National Priorities List (NPL). In 2002, there were approximately 1300 Superfund sites on the NPL containing toxic waste or dangerous heavy metals such as lead or mercury (McCarthy, 2002).

Most brownfield sites have relatively low levels of contamination when contrasted with Superfund sites. As such, most sites are not governed directly by CERCLA, but rather fall under the jurisdiction of state superfund laws often modeled after CERCLA that contain similarly strict liability provisions (Kirschenberg, 1997). Each state has different types of cleanup standards, procedures for identifying sites and provisions for apportioning liability.

Brownfield sites containing even small amounts of contaminants may still be extremely challenging to remediate. In light of this, the benefits of redeveloping brownfields often do not immediately outweigh the costs. McCarthy (2002) argues that brownfield redevelopment presents a "dual policy challenge." Barriers to private-sector redevelopment of brownfields must be reduced while encouraging the connection of brownfield reuse to the broader goals of the community. Uncertainties surrounding the first policy challenge in reducing the barriers to redevelopment include uncertain liability provisions, cleanup standards, funding opportunities, and legal regulations.

Barriers to Redevelopment: Liability Issues

Entities interested in redevelopment activities must be aware of the potential *liability problems* associated with a brownfield site. In the past, U.S. law (both federal and state) has held that anyone working with contaminated sites can be held liable for all cleanup costs, thus prompting business owners and potential developers to avoid abandoned industrial sites, even if contamination problems are relatively minor. Liability concerns are commonly believed to be responsible for a diversion of capital away from brownfield redevelopment, thus limiting the possibility of redevelopment (Wright, 1997, Tam and Byer, 2002).

Liability as a disincentive for redevelopment has been well documented by the banking industry, where loan officers often require costly environmental assessments in order to assure that by providing a mortgage the bank cannot be held liable under the same *strict liability* logic placed on other developers (Rafson and Rafson, 1999). Under CERCLA (and many similarly worded state laws), liability for property contamination may be imposed on the owner of property based solely on his or her status as property owner. U.S. common law imposes strict liability where a person undertakes an "ultra-hazardous" or "inherently dangerous" activity (Nurad, Inc. v. W.E. Hooper & Sons, Inc., 966 F.2d 837, 1191, 10th Cir. 1997). Courts have concluded that storage of hazardous substances can constitute an inherently dangerous activity. Therefore, under CERCLA, "a property owner may be held responsible for remediation of property even if the environmental condition was in existence prior to the current owner's purchase of the property (Rafson and Rafson, 1999, pg. 10)." Concurrently, CERCLA imposes *joint and several liability* on individuals or entities identified as partial brownfield owners. This type of liability holds that where the conduct of two or more persons combines to create an indivisible harm, either defendant can be held responsible for the entire harm (Wisconsin Natural Gas Co. v. Ford, Bacon & Davis Construction Corp., 291 N.W.2d 825, Wis. 1980). Thus, the fear of liability surrounding brownfield redevelopment is compounded. An individual who may not have been responsible for contamination may be forced to assume the entire burden of the cleanup cost with no outside assistance.

A 1990 American Bankers Association survey found that 62.5% of U.S. lending institutions had rejected loan applications based purely on the possibility of environmental liability (Byrne and Greco, 1994). Liability concerns have also forced many industrial site owners to stop placing old sites on the market in order to avoid discovery of contamination that might force them to initiative an expensive remediation program. Tam and Byer (2002) develop a flexible decision methodology looking at the preferred remedial action and future use of contaminated sites from the perspective of site owners. This methodology focuses on the creation of a cost/benefit analysis of various future land-uses and remediation methods which attempts to maximize site value, while minimizing liability and remediation cost. Although this decision methodology delves more into more detail in terms of the quantification of liability and the resolution (site scale) that is much more fine-grained and agent-based than we explore in this study, it holds the promise of being an extremely important component of more sophisticated future models of urban brownfield redevelopment.

The 1990s saw an effort by many state and federal agencies to lower the role that liability plays in slowing brownfield redevelopment. Since most brownfield sites are not contaminated to a point that would warrant federal involvement, many states have responsibility over brownfield programs. Many states have created State Voluntary Action Programs (VAPs) intended to allow private parties to voluntarily investigate and remediate a property while receiving some level of protection from future state enforcement action (Wright, 1997; McCarthy, 2002). On the federal level, the EPA has attempted to calm fears of federal action by entering into Superfund Memoranda of Agreement (MOAs) with individual states. MOAs create agreements to refrain from direct federal involvement at sites utilizing VAPs. The critical problem from a federal and state governmental perspective is achieving a liability balance which encourages redevelopment while ensuring that sites are adequately remediated and do not pose a danger to public and environmental health.

Barriers to Redevelopment: Uncertain Cleanup Standards

Uncertainty surrounding site assessment considerations can also represent a major barrier to redevelopment based on the lack of straightforward site remediation standards. State and federal regulators can require remediation at many different levels depending on the anticipated future use of the site. Sites whose future use will be restricted to industrial functions may require less remediation than sites slated for residential or open space use by young children or other individuals that may be endangered by very low levels of contamination. Contaminated groundwater often requires remediation to drinking water standards before it leaves the property and enters wells used for drinking, showering, and cooking (McCarthy, 2002). This failure of state and federal agencies to determine widespread cleanup standards and the complex and interconnected legal nature of federal and state agency involvement in redevelopment coordination can form a major barrier to brownfield redevelopment.

Barriers to Redevelopment: Availability of Funding

Another major barrier to brownfield redevelopment is derived from the uncertainty surrounding the possible cost of environmental assessments and remediation. Significant financial investment is often required in order to remediate areas to the level required by law. Thus, many private investors require assistance from lending institutions, insurance firms and government agencies (McCarthy, 2002). In fact, of the 12 major federal brownfield revitalization programs reviewed by the Interdisciplinary Environmental Clinic (2003) at Washington University in St. Louis, every single one involved the creation of grant or loan programs to assist with brownfield redevelopment. Many individual state and local governments also attempt to provide grants, loans, loan guarantees and tax credits to stimulate redevelopment. With the increase in redevelopment funding made available to investors during the mid-1990's came an increase in the number of funding organizations – increasing the complexity in securing loans and grants for redevelopment. Heightened complications in securing funds have also confronted investors in recent years through the regulatory system that governs the redevelopment of brownfields in different places throughout the country, thereby making fund acquisition complicated from both a local and regional perspective.

Barriers to Redevelopment: Complicated Network of Regulation

Compliance with federal, state and local remediation regulations can involve substantial time and financial costs, thus creating another major barrier to redevelopment. This process has also been complicated by a lack of information or database integration among the different levels of regulatory oversight agencies. Most local and state GIS programs have not integrated brownfield maps into their databases or websites. In a survey of 23 cities, 57% indicated that they held brownfield redevelopment partnerships with their county or state governments (US Conference of Mayors, 2000). These partnerships are not necessarily archived in any widely accessible database that would facilitate regional brownfield redevelopment. One suggested solution to the complex regulatory framework that has emerged is the establishment of local brownfield redevelopment authorities that could act as major points of contact for information and financial assistance (Borak and Meek, 1999; Papper, 1997). However, disagreement exists as to whether or not this entity would function in the private or public sector (McCarthy, 2002).

Brownfield Redevelopment and the Community

Although brownfields can be found almost anywhere, they commonly occur in the urban core areas of major cities. Observations of the patterns of growth across the nation have shown an exodus of capital and population away from major downtown areas during the last several decades (Interdisciplinary Environmental Clinic, 2003; Simons, 1998; Wright, 1997). Much of the downtown areas of major industrial cities such as St. Louis have suffered significantly as relocating entities settle in suburban “greenfields” which are easily cleared for new development and contain no actual or perceived contamination. Viewed in this frame, brownfield redevelopment can be perceived as one of several methods currently being sought by many historically industrial cities in revitalizing the economic and environmental health and viability of the urban core (Wright, 1997). McCarthy (2002) argues that the pattern of redevelopment of these contaminated lands therefore must be connected to broader community goals in order to revitalize inner cities. Any attempts to remove the aforementioned barriers to redevelopment must avoid conflict with the ever-present need to protect the environmental and economic health of local residents. McCarthy (2002) is arguing here that governmental responsibility necessitates studies of the future marketability of brownfield sites as well as a social cost-benefit analysis of brownfield redevelopment coinciding with the ongoing development of participatory dialogues with the community.

Another issue relating to community goals is the allocation of brownfield redevelopment funds. Should redevelopment funds be focused on areas that suffer from higher contamination or should they be channeled specifically to brownfields in good locations that are more likely to be economically viable? McCarthy (2002) discusses a common strategy in which redevelopment funds are channeled towards high profile brownfields with strong prospects for successful reuse in an attempt to trigger a “domino effect” of revitalization. However, this strategy neglects the large number of non-economically viable sites in dilapidated communities where many brownfields have little or no market value and negative images of crime drive a vicious cycle of economic hardship.[2] The practice of avoiding the lowest market value parcels commonly excludes disadvantaged neighborhoods from redevelopment programs. This behavior may widen inequalities between wealthier and poorer neighborhoods thus undermining the basis of inner-city revitalization (Leigh, 2000). Given this situation, there are currently few strategies for remediating and redeveloping economically non-viable sites even if site redevelopment is socially desirable (Leigh, 2000).

The Redevelopment Process

The EPA has constructed an outline of the brownfield redevelopment process which the progression into Five major phases: Site Assessment and Due Diligence (Phase I), Site Investigation (Phase II), Development of Remedy Plan, Remedy Implementation, and Redevelopment Activities (Construction) (EPA, 2002). For our purposes, we will be assuming that the development of a plan of remediation will take place during the Phase II site investigation. The brownfield remediation process is typically performed by highly skilled environmental consulting agencies with experience in dealing with dangerous contaminants.

Typically, the brownfields redevelopment process begins with a Phase I site assessment. The site assessment process provides an initial screening to explore owner records and site history, extent of contamination, and possible legal and financial risks. If no apparent contamination and no significant health or environmental risks are revealed, redevelopment activities may begin immediately. If the site appears to contain unacceptably high levels of contamination, a reassessment of the project's viability may be necessary. Phase I site assessment also includes the performance of due diligence to look at "preliminary cost estimates for property purchase, engineering, taxation and risk management (EPA, 2002, pg 8)." Due diligence also involves a study of the market viability of the redevelopment project.

A phase II site investigation involves chemical sampling of the site in order to provide a comprehensive understanding of the contamination. If this investigation reveals no significant sources of contamination, redevelopment activities may commence immediately. If the phase II site investigation reveals a manageable level of contamination it is next possible to evaluate possible remedial alternatives. If no feasible remedial alternatives are found, the project viability must again be reassessed. Otherwise, the next step is to select an appropriate remedy and develop a remedy implementation plan. The discovery of additional contamination following remedy implementation would necessitate the reenactment of the remediation process.

Methodology

Scope and assumptions

Based on the literature outlined above, we began the process of constructing a model framework. At the core of the model, we wanted to represent the process of redevelopment as it

[2] This type of positive feedback has become prevalent in many cities such as East St. Louis, IL where negative perceptions surrounding crime and economic viability have caused an exodus of social and financial capital which, over time, has amplified negative perceptions of crime and economic hardship, leading to a further drain of capital (Reardon, 1998; Interdisciplinary Environmental Clinic, 2003).

occurs through different phases and delays. In addition to this core structure, which would reduce the stock of existing brownfields over time, it is important to capture some of the key barriers to redevelopment. We have identified funding for redevelopment, liability of redevelopment, and economic viability of the site as key factors influencing the probability of redevelopment for a given site. Moreover, redevelopment of brownfields at a given locale would in turn influence those factors for surrounding brownfields in the form of spatial feedback.

We chose to represent the brownfield redevelopment process at the aggregate level, utilizing data from a recent survey of over 200 cities across the nation (US Conference of Mayors, 2003). The city-specific estimates were treated as samples indicative of parameter distributions for average site size in acres, the fraction of redeveloping acres at a given point in time, and estimated tax and job benefits from redevelopment. While considering the aggregate representation of the process to be most appropriate, utilizing the distribution of data enables representation of site-specific processes.

We identified three primary research questions: What are the most important factors influencing brownfield redevelopment? What are the fundamental behavioral modes of brownfield redevelopment? How should we represent delays in the system? While the model inherently abstracts the redevelopment process as it takes place in reality, we believe that any dynamic model of brownfield redevelopment should attempt to answer these questions.

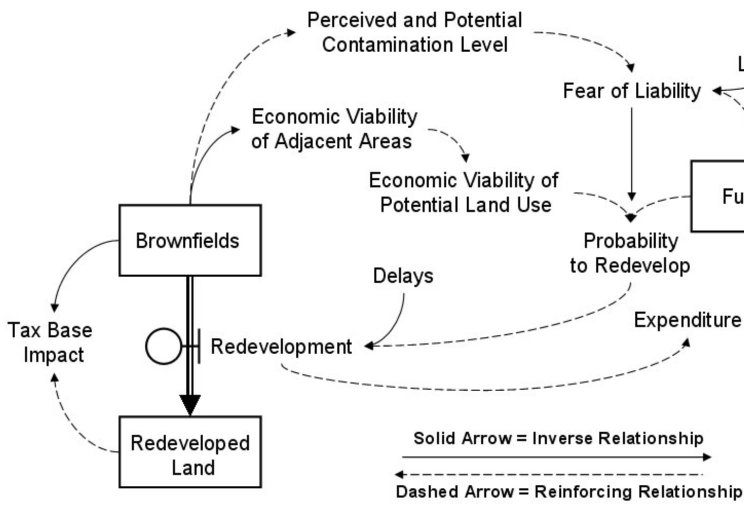
Modeling Techniques

Modeling brownfield redevelopment is complicated partly because the process simultaneously involves multiple system components such as site remediation, permitting, liability, funding, and economic viability. However, real complexity in this system emerges as system components dynamically interact and occur over time. In many systems where long-term studies or experimental manipulations are not possible, which is often the case in complex urban and economic systems, representative *models* have been shown to be helpful in filling knowledge gaps and assisting in decision-making and policy formation activities (Sterman, 2000). The extensive literature supporting system dynamics as an aid to cognitive processes and comprehension presents this methodology as an ideal technique for enhancing our conceptual understanding of the brownfield redevelopment process.

Dynamic Model Structure

Before beginning the model-building process, we developed a representation of our dynamic hypothesis as a causal map of the major feedback loops, or circular chains of causation (Figure 1). Such feedback loops may be either reinforcing or balancing in nature, depending on whether a variable, if increased initially, will be further reinforced or balanced after the ripple effect of the other variables in the loop reaches it. This causal map hypothesis is a tool for conceptualizing the system. Only the key variable relationships are highlighted in this representation. Specifically, reinforcing dynamics of economic viability (or more precisely, the lack of viability) in areas proximate to brownfields are highlighted, as are the reinforcing effects of perceived contamination. Perceived contamination increases fear of liability, while funding alleviates it. These effects are combined in the presence of laws that may positively or negatively impact liability.

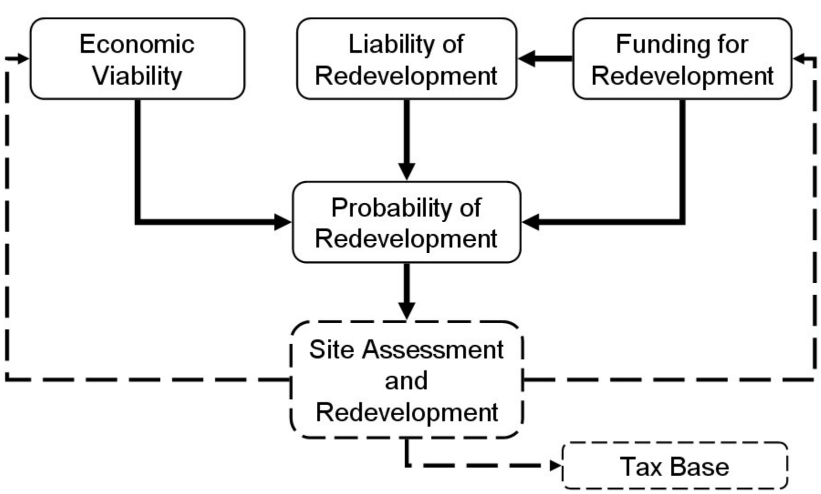
Figure 1. Dynamic Hypothesis



This dynamic hypothesis (Figure 1) illustrates state variables such as funding, brownfields, and redeveloped brownfields. For simplicity of illustration, details of the many system delays and the impact of brownfields on tax base are not shown in Figure 1. These are exposed in the sections that follow.

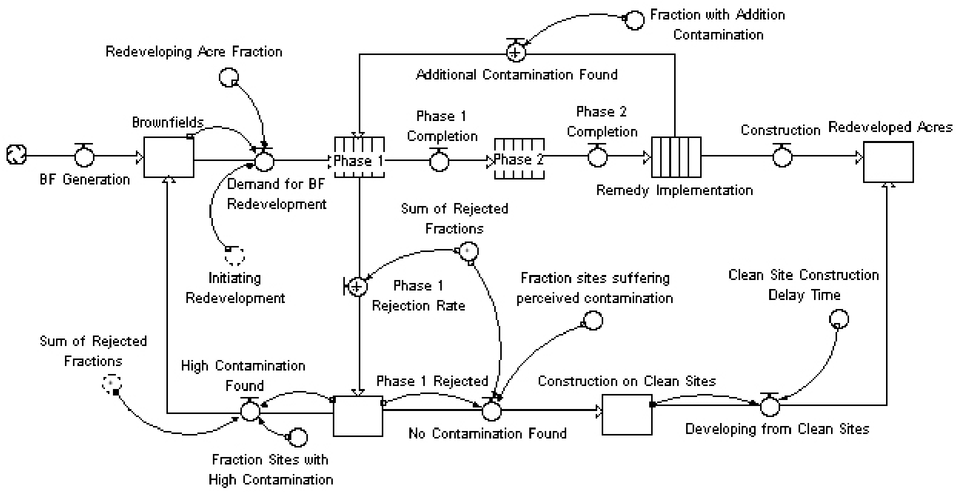
In contrast to the core dynamics described in Figure 1, an overview of the model structure is provided in Figure 2 to illustrate relationships among the major sub-sectors of the model. The three sectors of economic viability, liability, and funding all influence the probability of redevelopment, and funding in turn influences liability of redevelopment. The subsequent spatial relationship effects are illustrated with dotted lines in this diagram. The site assessment and redevelopment sector follows from the probability of redevelopment and in turn influences the economic viability and funding for redevelopment. Site assessment and redevelopment also influences the resultant tax base in terms of the jobs created from the redevelopment process.

Figure 2. Model Sector Overview



The detailed structure of the site assessment and redevelopment sector is illustrated in Figure 3 as composed in the STELLA modeling software. This sector provides the core of the model in the form of an aging chain structure. The process of brownfield redevelopment is depicted as flows between stocks from left to right, with the undeveloped stock of brownfields at the left-most side. This stock is increased in one of two ways. The first inflow is brownfield generation (in our base case this is zero, as we do not concentrate here on the dynamics of brownfield generation or classification). Another inflow is the recycling back of rejected brownfields from the phase I process, in the case that contamination is too high for the stakeholders to manage. Demand for brownfield redevelopment provides the outflow from the brownfields stock and is influenced by the stochastic parameter of initiating redevelopment, which can be zero or one. If this parameter is one, an amount will be extracted based on the existing brownfield stock in acres, multiplied by the redeveloping acre fraction.

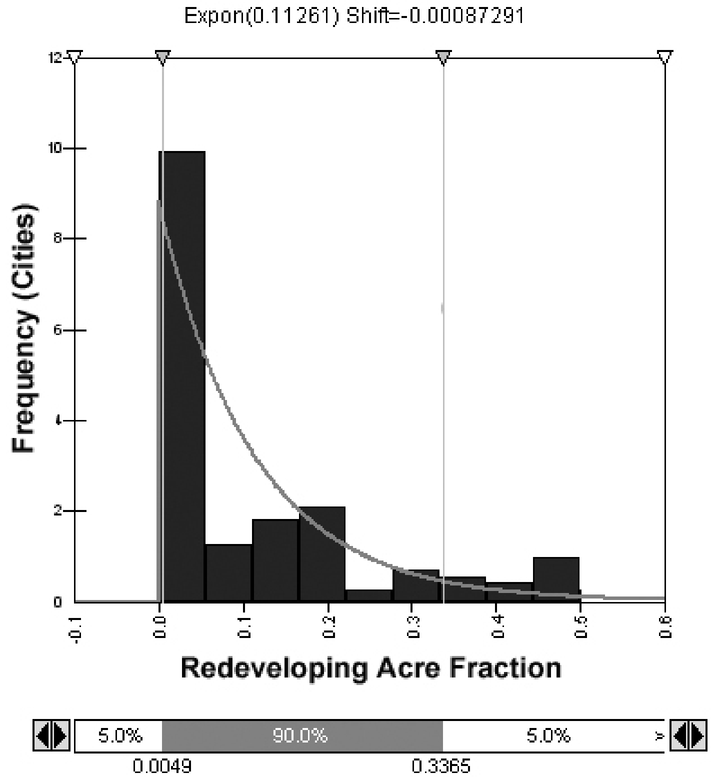
Figure 3. Site Assessment and Redevelopment Sector



The redeveloping acre fraction is a probabilistic exponential distribution based on the data from the 2003 US Conference of Mayors Survey. The form of this distribution was verified using the @RISK software (Figure 4)[3]. Including the zero fractions, beta (analogous to the mean) was close to 11% of total brownfields in redevelopment. We further accounted for the distribution of acres in redevelopment among the different phases, according to the expected delay times in each phase. We used a time unit of months for the model. As the average time to redevelopment is around 3.5 years, we divided the exponential distribution of redeveloping acre fraction by 42 months to convert it to units of acres per month (EPA, 2002).

[3] @RISK is a risk analysis and simulation plug-in used in the Microsoft Excel spreadsheet software that specializes in modeling uncertainty through the use of sophisticated probability distribution functions (Palisade, 2004)

Figure 4. Distribution of Redeveloping Acre Fraction by City

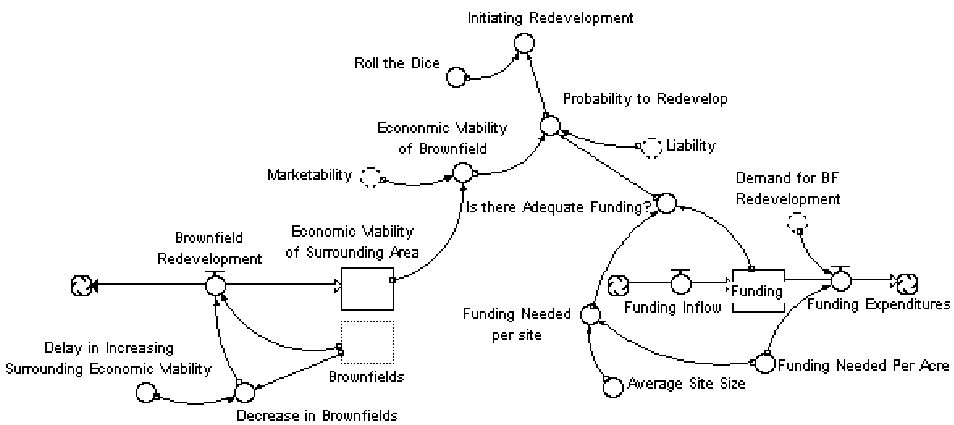


To keep the order of redeveloping sites consistent, we utilized the conveyor form of stock representation for each of the phases of redevelopment. Conveyor stocks allow for discrete accumulating and output, unlike normal reservoir-type stocks that assume continuous accumulating and output (which would imply that some small fraction of a site is being assessed at any given time). Here, the conveyor allows for a first in, first out (FIFO) behavior, with allowance for leakage and for probabilistic delay times. The duration in Phase I (site assessment) was assumed to be an exponential distribution of a delay time of 2 months. The initial acres in Phase I was also determined using the relative delay and the total redeveloping acres at the time of the 2003 US Conference of Mayors Survey. As the site assessment process is the initial introduction of uncertainty about potential contamination, we enabled a rejection rate for sites that were either too highly contaminated to address with the given resources, or for sites that were found to be uncontaminated and ready to redevelop. The bulk of the brownfield acres (90%) would continue on to phase II (site investigation), with an exponentially distributed delay time of 12 months, and then to the implementation of remedy (US EPA, 2002). This third phase is inclusive of the development of a remedy plan, remedy implementation, and redevelopment activities. We have assumed an exponentially distributed delay time of 30 months for the third phase, after is a stock of redeveloped acres (US EPA, 2002). Because the third phase includes so many activities, we also allow for 5% recycling back to phase one if additional contamination is found.

We have started with the overall process of redevelopment that is at the heart of this construction. The input to this sector that ties it in with other sectors is initiating redevelopment, the probabilistic parameter that could either be zero or one. The drivers of this parameter are outlined in Figure 5. At the top center of Figure 5 is the probability of redevelopment sector.

The initiating redevelopment parameter is influenced by the probability to redevelop and a "roll the dice" random parameter returning a value between zero and one. If the probability to redevelop is greater than this random number generator, then initiating redevelopment will be one. This construction is one way of explicitly representing stochasticity in the redevelopment process and has been applied to land-use models such as the Land-use Evolution and impact Assessment Model (LEAM) (Deal, 2001, Deal and Schunk, 2004).

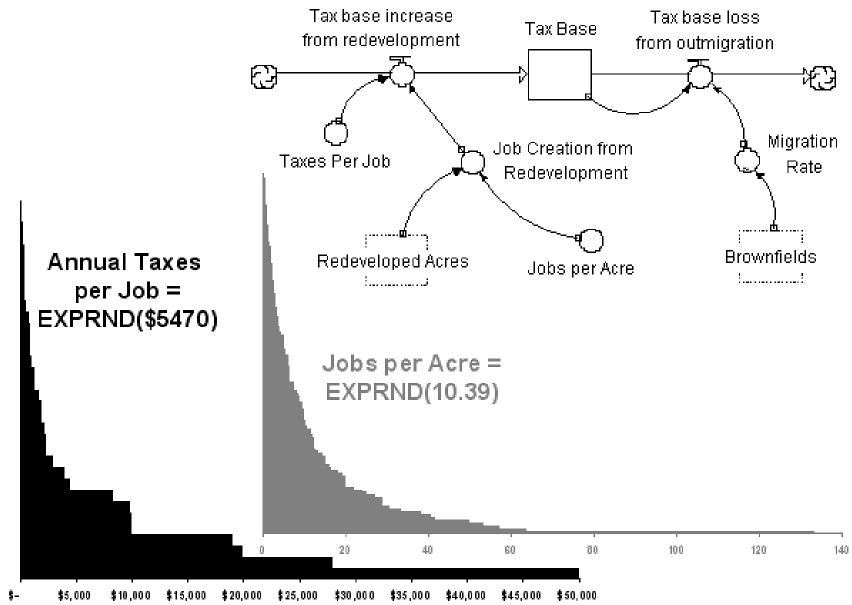
Figure 5. Drivers of Redevelopment



The probability to redevelop is not a true probability in the mathematical sense, but it is a measure of the likelihood of redevelopment. As mentioned before and illustrated in Figure 5, it is positively influenced by the availability of funding and the economic viability of the brownfield site, but is negatively influenced by liability. The funding sector is represented by a stock with inflow at $200 million over 12 months, as per the 2001 Brownfields Revitalization and Environmental Restoration Act. Funding expenditures are drawn down by calculated demand for brownfield redevelopment (acres/month) multiplied by the funding needed per acre. The average site size in acres is used in conjunction with this funding requirement to determine whether there is adequate funding to begin with. Average site size is an exponential distribution of 16.7 acres/site, also based on the US Conference of Mayors data.

The economic viability sector is also represented in Figure 5. As brownfields are redeveloped, a decrease in brownfield acreage is recognized after a delay. This proportionate decrease positively affects the economic viability of the surrounding area and combines with marketability of the site to affect the economic viability of further brownfield redevelopment.

Figure 6. Tax Base Impact of Redevelopment



With this understanding of the construction of redevelopment drivers, we now turn to the impact of redevelopment on the tax base. Figure 6 illustrates the tax base sector structure and the relevant parameters. Redeveloped acres translate to job creation through the jobs per acre parameter, derived from the US Conference of Mayors (2003) as an exponential distribution around 10.4 jobs per acre. The number of jobs created is translated into a tax base inflow through the parameter of annual taxes per job, exponentially distributed around $5470/job per 12 months. This inflow is integrated into the overall tax base, while accounting for the possibility of outflow if residents migrate due to the presence of brownfields in the area. Again, as brownfields decrease, the migration rate would decrease as well, further bolstering the tax base.

Results and Discussion

Because several of the parameters in our model construction were represented by probabilistic exponential distributions, the first step in our analysis of results was to repeat several model runs to gain a sense of the inherent uncertainty in the model. The results from this sensitivity analysis are illustrated in Figures 7 and 8 for redeveloped and remaining brownfields, respectively. For the redeveloped brownfields, we see at the outset that a very wide range of possible outcomes emerges. The average, maximum, and minimum redeveloped acreage for 25 stochastic scenarios at each point in time are measured along the left axis. The standard deviation of these scenarios is shown with a dotted line and measured on the right axis. The quantity of redeveloped brownfields begins at a value just above 10,000 acres, as initialized from the US Conference of Mayors (2003) data, and rises to a still increasing average in 2030 of around 20,000 acres, with a range from 16,000 acres to 22,000 acres. The standard deviation peaks shortly after the 5th year for this sample of runs, and then plateaus with a slight overall decline as the base of redeveloped brownfields increases. In contrast to the redeveloped brownfields, the same tests for remaining brownfields indicate an increase in the standard deviation over time as the base of remaining brownfields decreases (Figure 8). The quantity of remaining brownfields declines from the initial value of 425,000 to an average of 413,000 acres, with a range from 411,000 to 416,000 acres.

Figure 7. Uncertainty in Redeveloped Brownfields

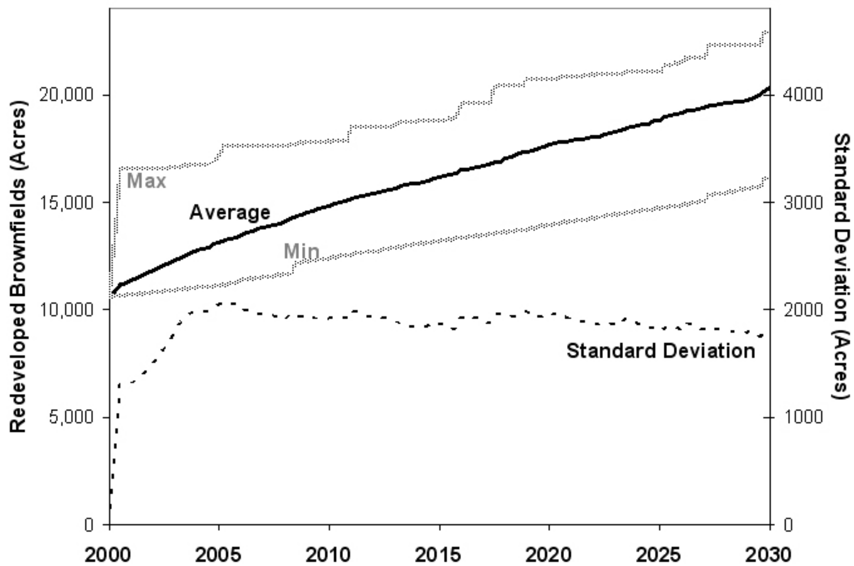
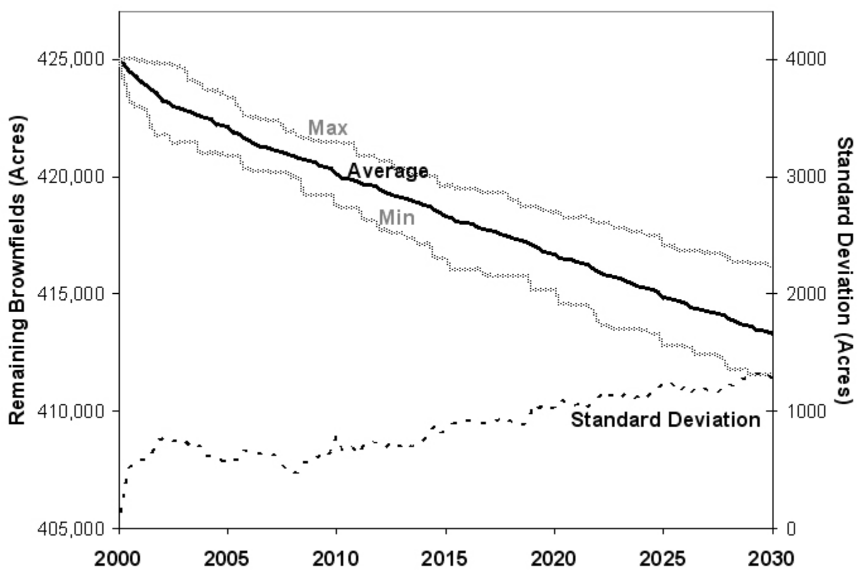
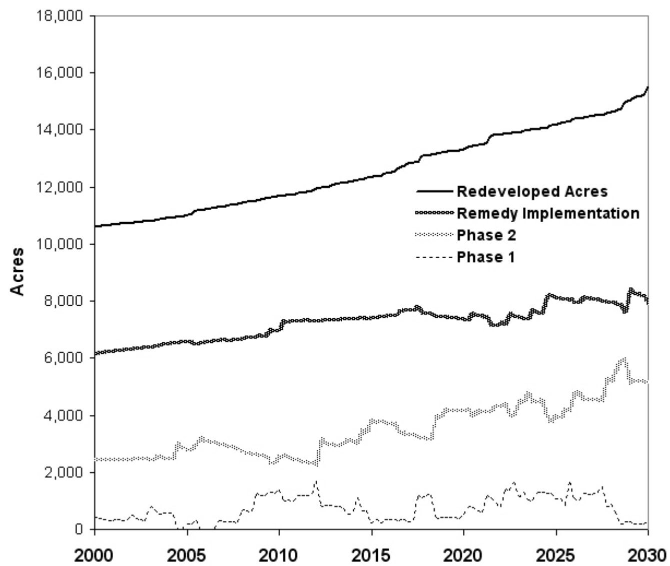


Figure 8. Uncertainty in Remaining Brownfields



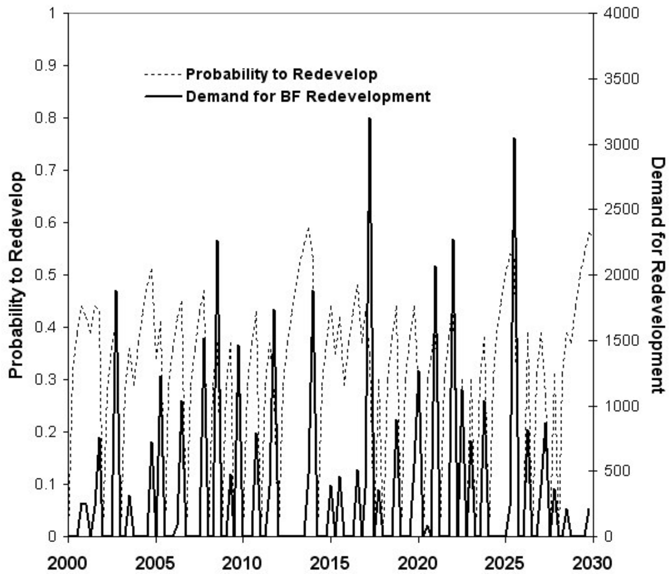
While the range of uncertainty is substantial, the direction of the progress made is consistent. Moreover, given that the model scope encompasses the nationwide stock of brownfields, we had no reason to suppress the compounding stochasticity of this system. With this grounding in the probabilistic nature of our model as it represents what we hold to be a probabilistic real-world system, we proceeded to test other aspects of the model by assigning seed values to each random element. The seed values enable reproducibility of simulation runs while retaining the random variable representation. Figures 9 through 12 represent relevant variable results for a single run using the same set of seed values for each figure. The variables charted in Figure 9 represent the acres in each phase of redevelopment. The stock of brownfields decreases with increasing redeveloped acres in this single run similar to the multiple runs described above. The acres in the different phases of redevelopment show less directionality, with phase I acres not accumulating much with its short delay time. The subsequent phases reveal the effect of uncertainty as it compounds through the system, with increased variability of acreage levels at later stages in the run.

Figure 9. Phases of Brownfield Redevelopment



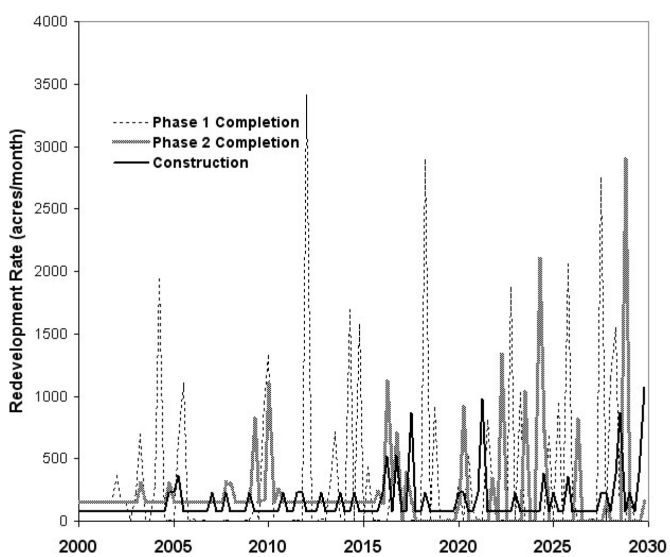
Working upstream through the system, Figure 10 displays the probability of redevelopment and the subsequent demand for redevelopment. Again, the actual *demand for redevelopment* is mediated by the intervening variable of *initiating redevelopment* as the roll of the virtual dice. Moreover, its magnitude also varies with the exponential distribution of the *redeveloping acre fraction*. We see that the interaction of these two variables is such that the probability remains non-zero for several dice rolls until demand for redevelopment is initiated, at which point the available funding for further redevelopment is likely to be insufficient in the near-term and so the probability drops to zero until funding is restored. These interactions produce highly variable or “jagged” results when considered on the scale of a month-to-month basis, but represent the real constraint of funding availability and the uneven nature of project starts.

Figure 10. Probability Driver and Subsequent Demand for Redevelopment



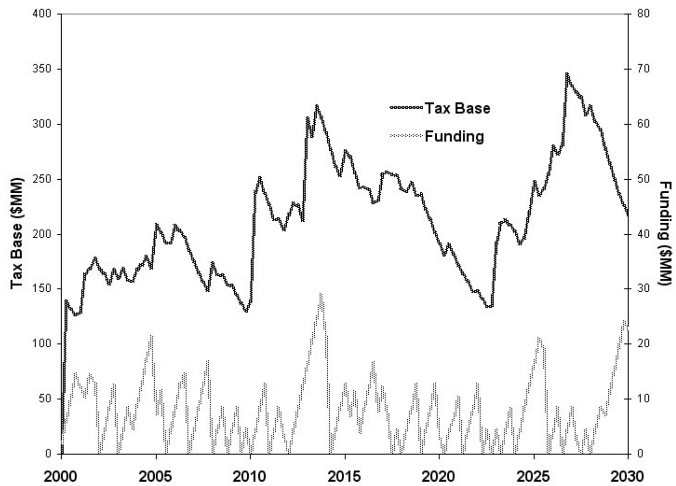
The erratic nature of demand for redevelopment can be seen rippling through the phases of the system in terms of completion rates. Unlike the stocks, which accumulate net flows, the completion rates are flows themselves and are represented with probabilistic exponential distributions of delay times. Figure 11 illustrates the completion rates for phase I and phase II, as well as the construction rate corresponding with the final phase of redevelopment. The phase I completion rate is the input to the subsequent phases. While there is some evidence of the ripple of a spike in acreage, it is difficult to pinpoint due to leakage, the longer delays of subsequent phases, and the inherent randomness of the system.

Figure 11. Completion Rates for the Redevelopment Phases



Finally, we examine the impact of the redevelopment process on the tax base sector and funding level (Figure 12). The funding periodically runs out as recognized above after expenditures on redevelopment. The tax base increases over the long run, with substantial variability due to its occurrence at the end of compounded uncertainties, as well as the uncertainty in the two key parameters of *jobs per acre* and *tax base per job* as described earlier.

Figure 12. Impact of Redevelopment on Tax Base and Funding



In summary, the results have demonstrated that the uncertainty we aimed to represent is adequately represented. There is an intuitive nature to this model. The brownfield redevelopment process decreases the stock of brownfields, increasing redeveloped area, which in turn increases the tax base in the model by both bringing in jobs to the site, and slowing the exodus of people away from the area that surrounded the former brownfield.

In this model, we are able to observe the interaction of uncertain elements over time in order to see the ripple effect for downstream phases in the process. Regarding the relevant factors in redevelopment, we are able to model the fact that funding is a key factor, as it periodically constrains development activities. Here, our objective was to create a framework into which greater exploration of specific issues such as liability and land-valuation can be placed.

There are opportunities for further scenario testing with this model, as there are many more aspects of the system to digest. Moreover, we want to be sure that the random element of redevelopment probability represents the real discrete project-based development activity and is not outweighing other factors.

Conclusions and Implications for Further Research

Many of the conclusions we can draw from the literature involve the need for shifting redevelopment incentives away from greenfields and towards urban core brownfields. However, the connection of brownfield redevelopment to broader community goals that is needed in order for this to be realized is difficult because it involves non-economic factors that can be difficult to quantify for the type of cost-benefit analysis often utilized for planning purposes. The social costs and benefits of brownfield redevelopment relate to issues of environmental justice, environmental quality and regional land use, issues that local governments cannot completely control. Overall, brownfield redevelopment is a regional endeavor to ameliorate historical problems that have plagued inner cities for decades. By classifying brownfield redevelopment as part of smart growth initiatives and other planning issues current in the spotlight, funding for such revitalization purposes may become more readily available.

The implications of further research on this model are wide ranging. Using this type of model as a framework for policy analysis may hold the key to many promising avenues of research and policy ideas.[4] Furthermore, explicit quantification of various aspects of economic viability, marketability and liability (especially as discussed in Tam and Byer, 2002) as they implicitly occur in public and private cost-benefit analyses of redevelopment projects is an important step in more accurately theorizing a general process by which redevelopment occurs.

This model looks at brownfield redevelopment without spatial context. Further work on this topic must look at the spatial extension of this model to real urban areas. This aspect would allow for the full implementation of the feedback loop in Figure 1 involving the relationship between economic viability and surrounding brownfields. The dashed line in Figure 2 also represents the important role that spatial feedback plays in this system. Furthermore, additional research could determine the efficacy in extending this type of model using agent-based simulation techniques in which individual brownfield sites could be tracked through the redevelopment process. By studying the spatial configuration and effects of brownfields and redevelopment activities alongside the view of brownfields as agents in the larger urban system, the ability to add functional knowledge to the debate on policies for brownfield redevelopment may be increased, thus bringing us closer to an overarching goal of improving our urban spaces.

[4] Examples of these include the implementation of a municipally controlled land bank that would initiate brownfield redevelopment soon after a property underwent tax foreclosure (see Betancur, et. al. (1995) and Leigh (2000) for more information).

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