Urban dynamics—The first fifty years

Louis Edward Alfeld

Twenty-five years have passed since the publication of Jay W. Forrester's *Urban Dynamics*. Any assessment of the condition of America's cities today raises the question of what might have been had the model and the methodology been accepted as a central urban planning and policy tool. Instead of looking backward at what might have been, however, it seems more useful to look ahead at what still may be. Urban dynamics still has a role to play in our urban future; this article provides a backdrop for how that role might best be shaped.

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This article recounts my own experience in five applications of urban dynamics. The first four applications occurred within a 40-mile radius of M.I.T. —Lowell, Boston, Concord and Marlborough, all in Massachusetts. The fifth transplanted the theory to the Atlantic beaches of Florida and a new community called Palm Coast.

All five applications differed from one another. In the first, Lowell, we demonstrated the importance of a limited land resource in shaping urban policy. In Boston, we underscored how urban aging widens the gap between the city's high-priced job base and its low-priced housing stock. Work in Concord employed simple models to capture the powerful feedback forces that drive migration and growth. Marlborough bypassed formal modeling, using the underlying theory to shape a verbal logic that supported political actions aimed at preserving the older inner neighborhoods in a dynamic equilibrium. Finally, a substantially revised model was constructed to guide the projected 80-year growth of Palm Coast, from a tiny community of 3000 to a new town of 224,000.

Lowell 1971

The publication of *Urban Dynamics* in 1969 generated intense controversy. To help assess the model's value, the then-new U.S. Department of Housing and Urban Development (HUD) provided a $210,000 research grant to support a two-year effort to validate the model. An advisory committee of urban experts drawn from academia and city government were to provide guidance and judge the results. At HUD's insistence, the committee included some of our harshest critics.

The committee experience

Although we attempted to engage the committee in a constructive dialogue concerning the model's utility, the members had neither the time nor the inclination to study system dynamics. Criticisms concerning data and validation techniques displaced issues of system structure and user needs. Neither side understood the other's point of view. For example, when we requested that the committee suggest alternative hypotheses for testing in the model, HUD responded by writing that:

> if we (the committee) feel that a specific hypothesis is incorrect or notably weak but don't correct the hypothesis, this isn't evidence that the hypothesis should stand. (Hoben 1973)

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Since the committee, trained in traditional econometric modeling, would not accept any of the model relationships without support from solid literature references or published data, they essentially rejected everything. In responding to HUD's criticisms of our efforts, Forrester wrote:

> It is unfortunate that you have not found it possible to spend more time with us in order to better understand system dynamics and its application to the dynamic modeling of social systems. Many of the issues you raise seem to rest on assumptions that reflect practices in other kinds of modeling but which do not apply in the same way to system dynamics models. In fact, the strength of system dynamics arises from these differences. (Forrester 1973)

In parallel to our work with the committee, we began the first practical application of urban dynamics in Lowell. Like many decaying New England towns, Lowell had ended a century of spectacular manufacturing growth with decades of crumbling old age. In contrast to the committee's criticism, the Lowell political leadership embraced the model as a means to address its persistent 12 per cent unemployment rate.

Resource constraints

Urban dynamics incorporates limited land availability as an explicit resource constraint. The "Land Fraction Occupied" hypothesis is embodied in a nonlinear table function that relates the rate of new construction to the fraction of land occupied by existing buildings. Early in its existence, city growth is hampered by a lack of supporting buildings and infrastructure. Too much open land holds risks for entrepreneurs. As the land is gradually developed, however, the pace of growth quickens. Each newly constructed building adds to the conviction of a prosperous future and so fuels more growth. Soon all of the best sites are taken and the price of the remaining land soars. The rate of new construction begins to slow. As the last buildable sites are developed, the lack of open land and high land prices deters further construction. Only demolition of existing structures can clear the way for further building. In equilibrium, construction balances demolition.

With nearly all of its land occupied by old mill buildings and aging factories, Lowell could not rebuild a new industrial base without first demolishing the empty hulks. New jobs required open land and, in Lowell, there wasn't any. Urban dynamics emphasized the need to make the most of every scrap of potential job-producing land. Lowell residents took that advice to heart.

In one case they refused to rezone industrial land for a much-needed new high school. Three years earlier a defense firm had built a factory on cleared land adjacent to a new highway. This was the first new industrial facility in Lowell in over two decades. A year later the government canceled the contract

and the company put the building up for sale. After it sat empty for a year, the company offered it to the school board, rent-free for a year. The company would add interior partitions to fit the school's needs. For a year Lowell teens attended "Factory High". At the end of the experiment, the company offered to sell the building to the school at a bargain price. The school board refused and moved the classes out, publicly justifying their actions by arguing that, if the school stayed, no new industry could ever use the building. Lowell needed jobs far more than cheap classrooms. Six months later Wang Industries bought the empty building and moved 1000 jobs into Lowell.

Following a wide range of urban dynamics suggestions, the Lowell City Council developed incentives to encourage existing industries to refurbish their buildings and expand their businesses. At the same time, Lowell took steps to slow the deterioration of its housing stock. The continued out-migration of the more affluent was emptying much of the central city housing, which was being refilled by a growing lower-income population. Strict enforcement of the building code forced some housing renovation and reinvestment and this helped to slow the pace of residential decay.

Achievements and frustrations

Although Lowell began to apply urban dynamics theory to practical policy decision-making, neither HUD nor our advisory committee found the experiment convincing. We had begun the project by altering a few of the model parameters to reproduce Lowell's historical growth curve. Except for the population census data and a few stories from the newspaper files, however, no hard data existed that could demonstrate that the model actually replicated Lowell's historical housing and employment conditions. To the committee's way of thinking, the fact that someone, somewhere wanted to use urban dynamics was not as important as first "proving" that the model was "correct". We had neither the time nor the resources to follow the Lowell experiment for long. Because so many outside factors also impacted Lowell's decision-making, no one could clearly separate urban dynamics from the rest. Did urban dynamics help or didn't it? We who worked there know that it did.

Clearly, Lowell wanted answers to pressing urban policy decisions and was not overly concerned with academic arguments over model validation issues. The model logic helped to create a consensus for action. The HUD committee, on the other hand, focused on the model data elements. Unfortunately, the mainframe technology of the time limited model accessibility to committee members. They could not test their own hypotheses and would not rely on us to interpret the model for them. The interface gap between model and critic contributed to the communication gap. In the final accounting, neither our

success in Lowell nor our outpouring of reports and papers could bridge that gap. HUD judged that we had nothing to offer and urban dynamics dropped out of academic sight, its potential contribution to resolving America's urban crisis ignored for the past quarter-century.

Boston 1974

In the fall of 1973 a $50,000 grant from The Kennedy Foundation provided the funds for what came to be called "The Boston Project". The project invited us to review the city's new ten-year plan, then under preparation by the city's planning agency, the Boston Redevelopment Authority (BRA). Several dozen business leaders, city officials, academics and planners were invited to a series of bi-weekly luncheons, each of which addressed a different facet of the city plan. Before each meeting, the BRA circulated a planning paper to which we attached a short urban dynamics "think piece" that probed the longer-term dynamic consequences of the BRA plans.

The exercise generated lively discussions, particularly around the issues of jobs and housing for Boston's lower-income residents. What was the relationship, we asked, between the observed growth in high-rise office construction and the increase in lower-income residents? Did one cause the other? If so, how?

Although the tone of the papers sought to remain objective, the conclusions were generally critical of the emerging plan and the questions usually posed politically difficult issues. For example, after describing the forces of neighborhood aging and quantifying the large flow of older housing that was filtering down to lower-income markets, one paper asked, "where will future residents of older neighborhoods work?". Another paper, examining the proposed high-rise construction goals for the city, concluded that, "planners are asking 'what can we get?' rather than 'what do we want?'"

Unlike our recent experience with the HUD project, the roles were now reversed. We unintentionally filled the role of critic and the BRA felt obligated to defend their traditional approach to city planning.

The dynamics of aging

If any single issue pervaded the luncheon discussions, it was the growing mismatch between jobs and housing. Urban dynamics describes the aging of both housing and commercial structures. As the housing stock ages, it is successively occupied by residents of lower socio-economic status. On the average, older housing is less desirable and less expensive. Further, because

lower-income families cannot afford spacious residences, older housing tends to become more crowded, with more people occupying each structure. This phenomenon can be seen in the subdividing of large houses for smaller apartments and in the larger, extended families that often live together under cramped conditions. The gradual passage of housing from affluent to poor families is called "filter-down". Urban dynamics traces not only the change in housing occupancy but also the increase in population density. Older housing tends to shelter more people of lower income than does newer housing.

Parallel to residential filter-down, industrial and commercial buildings also age. Because older business structures generally command lower rents, they are usually occupied by less profitable enterprises. Lower rents also attract space-intensive businesses which require more floor space per employee. Urban dynamics follows the aging of industrial and commercial buildings as successive waves of tenants occupy them. Older buildings tend to contain fewer jobs and less profitable enterprises.

Urban aging creates two dynamically opposing forces. Residential structures fill with more people of lower income while jobs in commercial structures evaporate. Over time an imbalance appears—too many people and not enough jobs. Urban dynamics attacked this outcome by recognizing the need to demolish the excess housing to make way for new enterprise construction. Only by increasing the rate of land turnover could a city achieve a healthy balance between population and jobs.

Model application

Two of our papers, relying on census data, carefully charted the dynamics of housing aging. Boston has a large stock of older housing, firmly anchored in traditional ethnic neighborhoods. There was little prospect, therefore, of any significant clearance program that could slow the inevitable expansion of lower-income housing opportunities. Dynamically, two courses of action were required. First, the lower-income employment base needed to be stabilized and expanded (with a parallel emphasis on education). Second, the housing stock needed to be upgraded through an effective program of conservation and rehabilitation. Neither action appeared on the BRA agenda. 'What was the city going to do," we wrote, "about the growing gap between the low job skills of the residents and the high tech employment offered by the planned office towers?".

The overall conclusion of the project can be summarized in the title of the final report, *The Manhattanization of Boston*, not a very attractive prospect. Yet the BRA's plans unintentionally described the creation of a city with a high proportion of well-paid jobs for suburban commuters and a large pool of aging

housing for the underclasses trapped in the city without adequate education or employment. Sadly, twenty years later we see that this is exactly what has happened. Look beyond the glitter of high-rise wealth and discover the grime of South Boston's and Roxbury's poverty. Today, Boston is much like every other American city. But it could have been much better.

If the HUD project failed because of the gap between model and committee, the Boston project failed because we did not understand the importance of accommodating short-term political objectives within a set of larger, long-term goals. If we had been content merely to provide answers to start a small shift in the balance of forces, we might have had some impact on the planning and development of Boston. Instead, by attempting to rebalance all of the forces at a single stroke, we placed ourselves outside the bounds of political realism. Acceptable answers, alternative tradeoff options, and consensus-building (instead of criticism) could have produced a successful outcome.

Concord 1975

Concord is a small Massachusetts town with lots of history. Tourists come to see the 1776 birthplace of the American Revolution at Old North Bridge and to wander the shores of nearby Walden Pond in the footsteps of Henry David Thoreau. It is also quite an attractive, tree-lined bedroom community, less than 30 minutes from downtown Boston.

Concord also happened to be the home of Jay Forrester and, in the 1970s, was my home as well. In late 1972, several prominent residents approached Forrester to express their concern that continuing suburban growth would eventually destroy the unique pre-revolutionary character of the town. With a population of 15,000, Concord was already, in many minds, too big. They feared further growth would trade wooded expanses for garish commercialization and crowded apartments. "Can urban dynamics," they asked, "help us understand the growth process so that we might better control it?".

Forrester, already busy with the economics modeling project, suggested my participation instead. I agreed to join an informal "growth committee" and soon found myself leading bi-weekly urban dynamics discussions with a group of urban conservationists who wanted a tool to stop growth.

Relative attractiveness

We began by building some very simple, two-level models designed to explore the dynamic behavior between population growth and various aspects of community attractiveness. One of the principal assumptions behind urban dynamics

is the theory of relative attractiveness. The theory states that, given free migration, no place can long remain more attractive than any other place. A corollary of the theory suggests the existence of negative counterbalances. Population growth continues until negative pressures arise to counterbalance an area's underlying attractiveness. Perception delays can cause population to overshoot, thus exaggerating the negative impact of growth. Concord, with its many attractive qualities, would surely draw in more people than it could comfortably house and, in the process, erase its rural charm.

A second corollary of relative attractiveness is that no two communities need suffer the same set of negative counterbalances. All that is needed to bring a community into equilibrium with its surroundings is a set of pressures sufficient to deter further in-migration. Any mix of pressures will do so, as long as people outside the community perceive them as sufficiently negative. Yet residents may chose which pressures they prefer. People pick where to live on the basis of such tradeoffs. One community, quite distant from downtown and requiring a long and difficult commute, might offer picturesque countryside and reasonable housing prices. Another community, close by downtown, might trade lack of parking and higher housing costs for urban proximity. Concord was poised to offer something of everything to everyone. It was, in a word, attractive. We needed to discover what mix of negative counterpressures could offset this attractiveness.

Town goals and tradeoffs

The first models exhibited S-shaped growth patterns, with population equilibrium reached after exhausting whatever resource fueled community attractiveness. Instead of the "Land Fraction Occupied" hypothesis, we substituted housing costs, open space, schools, commuter access, town services and utility use as potential resource constraints. All proved initially attractive, only to ultimately turn negative when population grew to high levels. Little by little, the participants in the "Concord Project" recognized that they faced a very difficult choice: what to sacrifice and what to preserve?

In most communities, such tradeoffs go unrecognized, much less openly debated. Although the simple models did not pretend to forecast future growth, they did get across the point that growth was not inevitable. The town could control its own destiny. It had only to agree which problems to live with, which counterpressures to inflate, and it could lower its attractiveness as a target for developers and a magnet for regional population growth.

In a pluralistic society, such choices are virtually impossible to make. Each group, in seeking its own goals, unwittingly blocks others from achieving theirs. Parents support spending for educational improvements that attract

more families. Stores expand to feed and clothe the newcomers. Roads are widened to ease traffic congestion. Better automobile access opens more land for development. New houses require utility extensions, more school buses and a larger fire department. Taxes rise. Voters curtail teacher pay rises. Educational quality begins to decline and concerned parents relocate to new suburbs whose residents support spending for educational improvements. Multiply the feedback structure a hundred times to reflect the different goals and preferences of every group. A community that tries to solve every problem and meet every need eventually satisfies no one.

Concord residents were willing to live with narrow, poorly paved roads, congested shopping, limited utilities and negligible town services. But in exchange they wanted good schools, woodland vistas, reasonable taxes and affordable housing for their sons and daughters. Would the tradeoffs appease the model?

After mastering the dynamics of the simpler models, we plunged ahead with several larger models. One combined all of the attractiveness factors in order to examine their interrelationships. Another sought to disaggregate the single population level by age and income.

The models suggested that the tradeoffs would not be enough. The town could not supply affordable housing without fueling rapid growth. Nor could the town purchase sufficient open land for conservation without driving up the price of remaining land. High land prices coupled with restrictive zoning guaranteed high housing costs. Every option led back to the same conclusion: limiting the amount of housing effectively stopped further growth. Yet limiting the housing supply would drive prices sky-high.

Theory in action

Concord was a refreshing experience. Concord participants welcomed the insights into the long-term tradeoffs and negative counterbalances that would ultimately determine the character of their community. While most did not attempt to fathom the depths of urban dynamics theory, they did study the submodels well enough to master their workings and their implications for planning. Group discussions probed new issues with informed responses. Having learned from the HUD experience, I spent considerable time explaining system dynamics and offering local, common-sense examples of dynamic behavior.

The growing wisdom of a small group of influential citizens manifested itself in several town actions. The two most successful—using town funds to purchase developable lots fronting on scenic roads and limiting the expansion of the utility system—worked together to limit housing growth. Limited new housing, of course, drove up the prices of the existing housing stock, thus

further limiting the influx of new residents. A three-bedroom home on a quarter-acre lot that sold for $42,500 in 1970 was worth over $300,000 in 1990. Residents found that a return on their housing investments of 11 per cent per year for twenty years is not too high a price to stop growth, particularly when only the newcomers paid it.

From 15,000 in 1970, Concord's population increased to only 16,500 in 1990, an annual rate of growth of just one-half of one per cent. The number of homes, however, increased twice as fast, rising from 4000 to 4800, an annual rate of growth of one per cent. In the process, however, the average number of residents per dwelling unit dropped from 3.75 to 3.45 persons. This drop reflects the fact that few new families could afford to move in, while many "empty nest" families (whose children had grown and left home) remained. In limiting growth, Concord turned gray. No longer does the town lure young families with small children from the city to the suburbs. Most of those families cannot afford it.

All in all, Concord managed very successfully to pick and choose its way through a series of difficult tradeoffs and seemingly incompatible town goals. It did not want to grow. And it was willing to act to stop growth. Urban dynamics provided the necessary logic upon which to build an effective coalition for action. The urban dynamics of Concord, however, was quite unlike the urban dynamics of Lowell or Boston. Lowell wanted the revival promised by Forrester's book. Boston wanted a painless growth, free of difficult tradeoffs. Concord, wanting just to be left alone, interpreted the urban dynmics theory to fit its needs, discarding the inapplicable notions of job loss and housing obsolescence, while expanding upon the insightful migration and attractiveness elements.

The emphasis on finding practical answers to real town policy questions made urban dynamics a credible tool. In addition, the interface was a personal one, represented by myself at countless meetings. The models were accessible to the participants because they took the time to understand them and examine the results. Emphasizing answers and interface worked for Concord.

Marlborough 1976

Late in 1975 I left M.I.T. to become the first director of the newly created Department of Planning and Community Development of Marlborough, a city of 30,000 located 30 miles west of Boston. Marlborough suffered many of the same aging problems that had characterized Lowell—except that Marlborough had plenty of unused land. Older buildings crowded the central district, many empty and awaiting demolition under an earlier urban renewal program that

had become bogged down in local politics. Random scatterings of new subdivisions were replacing the surrounding woodlands and grim new apartment projects were sprouting alongside the roadways. Marlborough's residents were struggling against their own economic decline while, at the same time, promoting uncontrolled housing development for newcomers. In a classic example of counterproductive behavior, Marlborough's short-term pursuit of residential growth was sapping the long-term capacity of the city to provide the services, housing, education and employment so desperately needed by its lower-middle class residents.

Planning for equilibrium

Urban dynamics traces how persistent unemployment arises as a natural consequence of urban aging. Marlborough faced just such a future. Decaying homes and deteriorating neighborhoods ringed the crumbling Main Street commercial center. An ambitious urban renewal project had succeeded in demolishing several older structures for a new by-pass road, but had failed to attract any new development to fill the voids. Jobs were scarce, particularly entry-level jobs for local high-school graduates. In ignorance, new apartment clusters along the highways and new, inexpensive homes along the wooded back roads were taken as a sign of progress.

With the close co-operation of elected officials, citizen's groups and business associations, we gradually evolved a plan that reflected nearly every aspect of the urban dynamics revival scenario. Yet never once did I mention urban dynamics or simulation modeling.

With the logic of urban dynamics behind it, even the highly partisan city council agreed that the emerging city plan made sense. Every citizens' group endorsed it. The Chamber of Commerce, the League of Women Voters, the Arts Council and both local newspapers backed it. The plan clearly explained the dynamic consequences of the current shortsighted policies. Trading what little remained of its declining economic base for new apartments could only lead to more people, increased traffic, higher unemployment and more problems. Instead, the plan offered a series of interlinked programs that promised to move the city toward a long-term balance between population and employment.

High-leverage actions

The Marlborough plan contained five major action areas. First, an ambitious program of street and sidewalk repaving, housing repair, code inspections and tree planting aimed at arresting further neighborhood decline. Second, acquisition and demolition of structures too far gone to save created much-needed

residential mini-parks and off-street parking areas. Third, construction of small parking lots bolstered the marginal commercial zones and a new large parking lot adjacent to the city's second largest employer, an aging boot factory, convinced the company not to relocate but to expand its local operations instead. Fourth, the planning department purchased an old, empty church in the center of the aging neighborhoods and converted it from an eyesore into a landmark, restoring its formal gardens and installing a day-care center, community meeting rooms and the offices of the planning department. Lastly, the city purchased hundreds of woodland acres to land bank, thereby slowing some of the random, outlying residential development and preserving a critical watershed area.

Taken individually, none of the actions sounds controversial. And none were. Taken together they created pressures within the urban system that tended to conserve the existing housing stock and employment base from further erosion. The city's investment in its neighborhoods also encouraged private re-investment, which, in turn, helped to stabilize both the population turnover and the property tax base. Growth was not a goal; sustainable equilibrium was. Planning sought to equalize the rates of change, balancing housing and commercial renovation against the ravages of age and obsolescence.

Positive results

The plan worked well. Within a few years most of the inner neighborhoods showed visible signs of improvement. Residents and homeowners no longer feared that they would have to move, forced out by falling property values and displaced by lower-income strangers in search of housing bargains. Unlike Lowell, Marlborough sat within commuting distance of Boston and the metropolitan job market and so did not suffer the same unemployment problems. Marlborough needed care and conservation, not rebuilding.

Marlborough proved that urban dynamics theory can translate into successful practice. It proved that long-term logic can prevail over short-term political pressures. But it also revealed the incredible difficulty of creating a coherent and acceptable plan of city action without direct access to urban dynamics theory. Marlborough presents the perfect argument for repackaging urban dynamics into an interactive, desktop learning program. Such a program, combining answer-oriented analysis with an easy-to-use interface, could give urban officials a firm grasp of long-term dynamic principles, sufficient to offset some of the short-term political expediency that dominates urban decision-making today.

Palm Coast 1980

Palm Coast is the largest planned new community in the United States. It covers 42,000 acres along the Atlantic coast of north Florida, half-way between St. Augustine and Daytona Beach. ITT Community Development Corporation (ICDC), a subsidiary of ITT, plans and directs its continuing growth.

ICDC believed that a simulation model could provide an underlying logic to the projected growth curves. In particular, the model could help convince Florida officials that sufficient affordable housing would result from the filter-down of the housing stock over the fifty-year development period. Not all of the affordable housing need be constructed at the beginning. If the mandated percentage of affordable housing was built each year, by the time the community completed its long growth period, on-going filter-down processes would insure that the community would become predominately lower-income. If Palm Coast followed Florida guidelines for smaller communities, ICDC argued, the result would be the largest slum north of Miami. The model would help to make this point clear.

Palm Coast modeling efforts continued for nearly a decade, with periods of intense activity in preparation for hearings, followed by lulls once the desired building permits had been granted. Over that time the model naturally evolved, from a straightforward adaptation of Forrester's model to the eventual development of entirely new models, first on mainframe computers and later on the Apple Macintosh. In between, I created perhaps a half-dozen distinct models, each exploring in greater detail one or more aspects of the urban growth process.

For example, an early disaggregation of population into two distinct sectors —families and retirees—examined the impact of each group upon the other. Each group was attracted by different amenities. Retirees wanted recreational facilities (particularly golf courses), modern hospitals and isolation from noise, traffic and commercial enterprise. Families, on the other hand, desired affordable housing, good schools and close proximity to jobs and shopping. Families also shunned "old age" developments, for they knew that their preferences would be ignored in favor of retirees. ICDC planned to sell sufficient homes to retirees (a very lucrative market) to generate cash flow while still attracting families who would form the backbone of the projected growth wave. The marketing people were sales oriented and that meant tapping the rich southward flow of the nation's retirees. The planners held them back, forcing a more balanced sales effort. Without the model to back their logic, the planners would undoubtedly have lost the battle and Palm Coast might have tipped irreversibly toward becoming a retirement community.

The Palm Coast modeling experience was unique in that the client's planning team took the time to learn what urban dynamics was all about. We engaged

in lengthy discussions concerning the possible impact of alternative assumptions, tracing their consequences around the tangled feedback webs with increasing clarity. The models served as sounding boards for new ideas, not as revelations of ultimate truth. The result was that the methodology facilitated learning and communication; the planning process benefited tremendously by relying on an underlying discipline to assure that all elements of the plan mutually reinforced each other toward common goals. In 1992 Palm Coast housed 24,900 residents, right on the growth targets for the year 2030.

Again, the two rules worked to create a successful application. We focused on providing answers to immediate planning questions, not on trying to provide a proven "valid" model. The analytical methodology, rather than any single model, proved most valuable. It was at this time that the interface began to take on increased importance. For the first time, a modeling language (STELLA™) that the planners could use became available on a desktop computer. The ability to try many different data assumptions and to compare many different scenarios turned the model from an abstraction into an everyday planning tool.

Conclusion

The past twenty-five years have not treated urban dynamics kindly. Had HUD initially endorsed it, urban dynamics might have become the institutional foundation for the training of a new generation of urban leadership. Instead, it has become a curiosity, a relic of the past that few have heard of and most dismiss. But it is too early, I think, to write it off, to consign urban dynamics to the archives of academia. Although I mourn its history, I firmly believe in its future. It is, after all, perhaps the most insightful system dynamics application ever developed. Urban dynamics only awaits the right change for its revival and the right inspiration for its reinterpretation.

To encourage that urban dynamics renewal, I offer a few conclusions based on my experience.

Guiding principles

If experience is any guide, then two central rules ought to guide any future application of urban dynamics:

- emphasize answers, not models, and
- emphasize interface, not data.

ANSWERS. The first rule cautions model-builders to present their work in terms

of answers that urban decision-makers need rather than models of urban problems. These answers must be responsive in three areas of decision support:

- how to maximize the leverage of existing programs by highlighting some aspects while downplaying others,
- how to quantify the tradeoffs among competing programs in terms of budget, performance and time, and
- how to use the model logic to create a consensus to support needed change.

INTERFACE. The rapid evolution of graphical interface techniques for desktop computer simulations now makes the second rule possible. Giving a model user the ability to easily create alternative scenarios and test "what if?" assumptions lessens a model's dependence upon a fixed database. When the model user controls the data inputs, the model becomes a tool for organizing information and clarifying logic, rather than a single conclusion to be either accepted or rejected. New graphical interfaces can also help to turn future models into learning tools that encourage users to explore the logic of urban dynamics principles and their application to policy design.

In addition to applying the two rules, any future urban dynamics work must help urban decision-makers grasp four interconnected principles that control urban behavior:

- resource constraints,
- urban aging,
- relative attractiveness, and
- growth vs. equilibrium.

These four principles are still the fundamental forces driving city evolution today and an understanding of how they combine to determine the impact of urban programs is essential to effective decision-making. In describing the five urban dynamics applications, I have attempted to show how one or more of these four principles provided a major theme for the work.

In addition to guiding principles, the next wave of urban dynamics work should seek to overcome past weaknesses while building solidly upon past strengths.

Overcoming shortcomings

Urban dynamics suffers from two shortcomings—limited detail and limited resources. Both, I believe, can be overcome by new hardware and software technology. Limited detail refers to the model's apparent inability to touch

directly upon the everyday administrative decisions that determine a city's fate. Where, for example, does one discover what to do with a request for a zoning variance? Or which street to repave and which to leave alone? Further, which goals should apply and how can they be distinguished, articulated and accepted so as to become guidelines for interpreting system behavior?

Limited resources refers to the larger national (and global) setting, of which urban dynamics is only a part. The classic urban dynamics revival policies of creating jobs assumes that cities can be restored to the dynamic conditions of their past, functioning as great engines of individual economic advancement. By strictly limiting their population through carefully controlled housing policies, cities can draw in large numbers of poor, provide them with skills and income, and disgorge them into the hinterland in order to make room for more newcomers. As Forrester himself noted, this is the America of the nineteenth century, when second-generation immigrants still had a frontier to settle and resources were plentiful. Late twentieth century America no longer has any place left to go to. Every place is already settled, already overfilled with people eager to go elsewhere. Urban revival may well be a dream, for the country now operates under such resource constraints and tradeoffs that it may not be able to support the urban "golden age" even if we attempted to create one.

The solutions to both weaknesses lies in the development of new interface technologies that can help users establish goals, specify alternative actions and compare results. Many alternative urban goals, other than growth, are possible. Concord and Marlborough are evidence that not every model application need create an urban revival. Experience has shown that model extensions can expand model detail beyond the original Forrester model. Graphical interfaces and more powerful computers can help reach further into the detail of urban decision-making, perhaps by allowing users to geographically disaggregate their models and selectively to expand the level of detail according to their immediate needs.

Extending strengths

Urban dynamics contains far more than meets the eye. It is a theory of the forces that shape human settlements which, in turn, shape human history. The theory is rich with subtle nuances which deserve a vigorous reinterpretation, a reinterpretation suited for no less a purpose than the political management of the people and resources of every nation on Earth.

Urban dynamics shows us the folly of traditional thinking, both for our cities and for our world. Human systems are too complicated for intuitive solutions. Traditional cause-and-effect thinking does not work. Feedback, nonlinearities and hidden delays defeat most conventional policies. Eventually we must shift

the paradigm away from traditional analytical methods to the urban dynamics viewpoint—conserve what we already have and reinforce the counterbalances we prefer. It is the mentality of the great cities of Europe and it is the mentality of the well-preserved American suburb. It works there and it can work worldwide.

Within American cities, four directions for new work seem obvious. Although all four are interrelated, each forms a definable subject for future modeling extensions.

URBAN POVERTY. Elements of the urban poverty cycle, particularly the fragmentation of families and transmission of values, are well-documented but have not yet been subjected to rigorous dynamic analysis. Models may help public policy to better address issues of inner city educational shortcomings, high rates of illegitimacy and persistent unemployment.

URBAN VIOLENCE. Drugs and immature value systems contribute to violence, while current law enforcement and judicial systems provide ineffective counterbalances. Understanding the feedback linkages that nurture a violent subculture could uncover high leverage intervention points for public action.

URBAN POPULATION. Age, sex, race and ethnic origin can be as important a determinant of urban migration and settlement patterns as economic status. How do the dynamics of urban aging and rebuilding either interrupt or reinforce the creation and isolation of homogeneous, segregated communities?

URBAN ECONOMICS. Innovations in high-rise construction and transportation access gave cities the ability to support the continued economic growth of face-to-face businesses. Changing communications technologies and changing economic needs are producing pressures to alter the historical course of urban evolution. How can public leadership best manage this transition?

These four subjects hardly exhaust the possibilities for further urban dynamics work. They do illustrate, however, the rich possibilities of soaring structure that could be supported by the solid foundation that already exists.

Urban dynamics represents a triumph of human reason, extending our capacity to see and shape our future. Bogged down in political squabbles, we cannot envision how different the world might be if urban dynamics theory became a global household word. The next twenty-five years are crucial for the promotion of a dynamic viewpoint. Global population, pollution and resource usage are all following dangerous trends. Urban dynamics has much to contribute to both the well-being of urban residents and the well-being of our world. It is not too late to begin.

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EDITOR'S NOTE: Given the historical review nature of this article, the author has grouped all references by project, along with the other bibliographic material. All D-prefixed references are Sloan School Working Papers, available from the Sloan School of Management, Massachusetts Institute of Technology, 50 Memorial Drive, Cambridge MA 02139, U.S.A.

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