Land Use Changes in Ciudad Juárez, Chihuahua: A Systems Dynamic Model

Sergio Peña* and César M. Fuentes**

Abstract. The objective of this article is to offer a model to simulate land use changes in Ciudad Juárez, Chihuahua, Mexico. The city faces serious challenges posed by accelerated demographic and urban growth. In its struggle to respond to urban land development pressures, governments, planning agencies and social civil organizations are overwhelmed by a multitude of concerns. The analysis of land use change revolves around two central and interrelated questions: What drives/causes land use change? What are the environmental and socio-demographic impacts of land change? The land use changes are approached as a complex system in which the elements that define the system and how these relate to each are identified. The development of dynamic simulation models that allow for the generation of different scenarios can be an important tool for urban planning. The software used to simulate the land uses changes is Stella®. The results of the model simulated the demand for land among different land uses (commercial, industrial and residential) in the next 10 or 20 years.
Key words: land use changes, system of dynamic model, Stella, Ciudad Juárez

Resumen. El objetivo de este artículo es ofrecer un modelo para simular los cambios de uso del suelo en Ciudad Juárez, Chihuahua. La ciudad enfrenta serios retos debido al rápido crecimiento demográfico y urbano que experimenta, lo cual ha preocupado a los gobiernos, las oficinas locales de planificación urbana y organizaciones de la sociedad civil (OSC). El análisis de los cambios en el uso del suelo se relaciona con dos preguntas centrales que se sobreponen: ¿Cuáles son las principales causas de cambios en el uso del suelo? y ¿Cuáles son los impactos del medio ambiente y las variables sociodemográficas en el cambio del uso del suelo? El cambio en el uso del suelo lo abordamos como un sistema complejo e identificamos los elementos que definen el sistema y cómo éste se relaciona en su conjunto. El desarrollo de un modelo de simulación dinámica que permite generar distintos escenarios puede ser una herramienta importante para la planificación urbana. El programa de cómputo usado para simular los cambios en el uso del suelo es Stella®. Los resultados del modelo permiten simular la demanda de suelos de los distintos usos (comercial, industrial y residencial) en los próximos 10 o 20 años.
Palabras clave: cambios en el uso del suelo, modelos de simulación dinámica, Stella, Ciudad Juárez

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Introduction

The objective of this study is to offer a model to forecast land use changes in Ciudad Juárez, Mexico. It is also our aim that this forecasting tool will be of use for local city planners to begin thinking about future policies regarding where to accommodate future growth and how to manage urban sprawl.

The analysis of land use change revolves around two central and interrelated questions: What drives/causes land use change? What are the environmental and socio-economic impacts of land change? The socio-economic drivers comprise demographic, social, economic, political and institutional factors and processes such as population and population change, property rights, etc. In this context, Ciudad Juárez faces serious challenges posed by faster demographic and economic growth. In its struggle to respond to urban land development pressures, local institutions, both public and private, are overwhelmed by a multitude of concerns.

The article analyzes the relationships among economic variables (US economy and industrial employment), demographics (population growth), and land uses (residential, industrial and commercial). A long-term analysis (to year 2020) will be offered. The results of the model show a reasonable fit between the predicted and the real data.

The article is organized as follows. The first part offers a historical overview of urbanization patterns in Ciudad Juarez to help put this study into perspective. The second part presents a discussion of the characteristics of a dynamic approach and how it differs from other approaches. The next section presents the conceptual model of land use changes. The fourth section presents the model developed in the Stella® software environment followed by an operationalization of the conceptual model in the programming algorithms of Stella® software. The fifth part discusses the results obtained with the simulation of the different scenarios. The sixth presents the conclusions where we emphasize the importance of this exercise for urban planning and policy issues.

Urbanization Patterns in Ciudad Juárez

After the Mexican Revolution of 1910, the city began to experience population pressures as a result of immigration flows from central Mexico. By 1921, the population of Ciudad Juárez was growing at an annual rate of 5.5% and reached a population of almost 20,000 inhabitants. In the next decade the population nearly doubled and the urban area encompassed 471 hectares.[1] During the 1930s the density fell from 482 to 85 inhabitants per hectare. In the 1940s, these indicators slowed their pace. Ciudad Juárez's population growth average annual rate was only 2.0% and the urban area increased only by an additional 92 hectares (Fuentes, 2000).

Beginning in the 1950s, the city embarked on a phase of spatial expansion. Ciudad Juárez experienced the highest rate of population growth in its history, mainly as a result of immigration flow due to the repatriation of Mexicans at the end of the *Bracero* program[2] in the US and settlement policies of the Mexican government to populate the almost empty northern part of the country through land reform and irrigation policies to expand agriculture. Population grew by 9.2% from year to year and its urban area expanded to encompass 800 hectares with a population density of 164 inhabitants per hectare. The city continued to grow at a high population rate of 7.2% in 1960 and its urban area reached 1,894 hectares (Table 1).

From 1960 to 1970, the population again almost doubled from 276,995 to 424,135, but the size of the urban area grew threefold. The urban area increased from 1,894 hectares in 1960 to 5,608 hectares in 1970, having an annual growth rate of 10.8%. The population density decreased from 146 inhabitants per hectare in 1960 to 75 inhabitants per hectare in 1970 (Fuentes, 2000). In others words, during this decade the city inaugurated a pattern of urban sprawl. Leap frog development,

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[1] 1 hectare = 2.47 acres

[2] The *bracero (arms)* program was implemented during World War II. Mexican workers were given permits to work in US agriculture to deal with the shortage of labor due to military duties. After the war Mexicans were repatriated to open up working options to the American soldiers returning from the war.

Table 1.
Historical Growth Ciudad Juárez,
Chihuahua (1990-2005)

Year	Population	Population Growth Rate Annual	Urban Area (hectares) (pop/ha)	Population Density
1900	8 218	3.5	61	134
1910	10 621	2.5	119	89
1921	19 457	5.5	N.D	N.D
1930	39 669	7.9	471	84
1940	48 881	2.0	563	87
1950	131 308	9.1	800	164
1960	276 995	7.2	1 894	146
1970	424 135	5.2	5 608	75
1980	567 365	4.4	9 395	60
1990	798 499	3.4	14 049	57
1995	1'011 786	4.3	19 177	53
2000	1'217 818	4.2	21 572	56
2005	1'313 338	1.5	31 246	42

Source: Own elaboration based on the Population Census (INEGI) 1980, 1990, 2000 and the Conteo de Población (INEGI), 2005.

development farther away from the center, and hillside squatter settlements lacking services contributed to the problem.

During the next decades the trend continued, the urban area growing at a faster rate than the population, therefore, density continued declining. The city population increased from 567,365 inhabitants in 1980 to 798,499 inhabitants in 1990. The urban land reached 9,395 hectares in 1990 and the population density continued declining to 57 inhabitants per hectare.

In 1995 the total urban area occupied 18,767 hectares of land. Residential uses consumed about 44% or about 8,416 hectares, industrial uses only 6% for a total of 1,209 hectares, commerce and services 1,075 hectares (5.7%), mixed use 617 hectares (3.3%). Open spaces 446 hectares (2.4%), internal roads 4,785 hectares (25.5%) and vacant urban land 2,219 hectares (11.9%). Residential uses and roads, which are

intrinsically linked, account for almost three quarters of the urban land use of the city. From 1995 to 2001 the annual growth rate of residential land was 3.4%, however, industrial and commercial land grew at a faster pace –8.4% and 8.2% respectively. In absolute terms, from 1995 to 2001 residential use increased 1,576 hectares, industrial use 635 hectares, commerce and service use 563 hectares, open spaces 159 hectares, roads 225 hectares and vacant land 281 hectares.

Table 2 shows that in relative terms the residential use of land has comprised a similar proportion since 1995. However, industrial land use has increased its proportion from 6.44% in 1995 to 8.34% in 2001; the commerce and service land area has increased from 5.7% to 7.40 percent.

Cities with significant population growth and housing demand require substantial quantities of land for development. Table 3 shows trends in the conversion of vacant land to residential, industrial and commercial uses. The data indicate that land conversion can be substantial. From 1995 to 2001, residential land use increased 262 hectares per annum, industrial land use 105, and commercial and services 93.5. Urban growth in Ciudad Juárez converts about 180 hectares of agricultural land per year, depending on the extent to which

Table 2.
Land Use in Ciudad Juárez (1995 and 2000)

Land Use	1995 Surface (hectares)	Percent	2000 Surface (hectares)	Percent
Residential	8 416	44.8	9 992	45.0
Industrial	1 209	6.4	1 844	8.3
Commercial	1 075	5.7	1 638	7.4
Mix	617	3.2	503	2.2
Open Spaces	446	2.3	605	2.7
Roads	4 785	25.5	5 040	22.7
Vacant Land Others	2 219	11.8	2 500	11.3
Total	18 767	100.0	22 122	100.0

Source: Plan Director de Desarrollo Urbano, IMIP, 1995, 2000.

Table 3.
Annual Urban Land Conversion in Ciudad Juárez

Land Use	Period	Hectares
Residential	1995-2001	262
Industrial	1995-2001	105
Commercial	1995-2001	93.5
Roads	1995-2001	42.5

Source: Own elaboration, based on Plan Director de Desarrollo Urbano, IMIP, 1995, 2001.

new population can be accommodated through redevelopment and densification.

1) Residential Land

Based on the previous discussion, the relationship between population and residential land was made clear. The demand for residential land expands due to increases in household formation and income. High population growth and household formation rates increase the demand for housing. Table 4 illustrates household formation and housing production trends in some Mexican cities. It shows the rapid increase in household formation that is common in fast-growth cities such as Ciudad Juárez. For example, annual rates of household formation range from 4 to 6% per year for the border cities. In non-border cities the annual rate of household formation ranges from 1 to 4% per year.

Fast-growing cities like Ciudad Juarez tend to consume more land through both outward expansion as well as using urban land more intensively through redevelopment. Population density gradients, which measure population density by distance, illustrate how these patterns change as a city grows. In most cities with well-functioning land markets, the intercept values (that is, the population density at the center of the city) decrease as commercial users take over these areas and residential development and households move to suburban areas. In Ciudad Juárez, population density of the center is the lowest, reaching

Table 4.
Households and Housing Production in Mexican Cities, 2000.

City	2000 House-holds	2000 Total Dwelling Units	Annual Household Formation (percent)	(a) Annual Average Household Increase	(b) Annual Average Dwelling Increase	(b)/(a)
Ciudad Juárez	279 874	293 752	6.0	10 954	12 316	1.12
Matamoros	103 696	103 009	5.0	3 649	3 610	0.98
Nuevo Laredo	74 389	73 744	6.0	2 879	2 850	0.98
Nogales	38 076	37 741	6.0	1 540	1 443	1.06
Piedras Negras	32 078	31 645	4.0	1 032	1 000	1.03
Monterrey	267 962	256 073	1.0	4 246	3 346	1.26
Guadalajara	388 751	369 894	1.0	5 618	4 233	0.75
Puebla	316 444	315 891	4.0	9 363	9 577	1.02
Distrito Federal	2'132 413	2 180 243	1.0	31 391.3	39 107	1.24

Source: Own elaboration, based on Population Census 2000.

Table 5.
Population Density Gradient (2000)

| Urban Hierarchy	Distance from the Center Sq. Meter	Population Density Inhabitants/Hectare
Center	0	44
Subcenter	50	53
Specialized Center	150	90
Neighborhood Center	200	71

Source: Fuentes, 2001.

44 persons per hectare. However, the population density of the suburban areas ranges from 70 to 90 persons per hectare (Table 5).

2) Industrial Land

As stated before, the adoption of the BIP program in the late 1960s was the inflection point towards a new economic regime in Ciudad Juárez. By the 1980s, Mexico shifted its development strategy from an import substitution model to an export led model where *maquiladoras* play a very important role. As a consequence of these economic policies, the city experienced broad-based industrial change as the number of *maquiladoras* expanded. Based on historical data, about 17 square meters of space are needed to accommodate each additional job in the *maquiladora* industry (AMPI, 2000). In Ciudad Juárez the real estate market for industrial facilities is estimated at about 4 million square meters of space, making of this city one of the largest markets of industrial facilities in the country (Figure 1).

The largest developers in this area are Intermex, Prologis (Formerly Security Capital), Cambridge, and Bermúdez. The Bermúdez Group owns and operates 4 industrial parks —Bermúdez, Río Bravo, Panamericano, and Los Aztecas in its current portfolio of 3.5 million square feet (about 325,000 square meters) of industrial space (Table 6). This is a family owned and operated business since 1954, and rated as one of the largest developers in northern Mexico. The Intermex Group is the

Figure 1.
Market Size of Industrial Facilities by Cities
(Million of ft²)
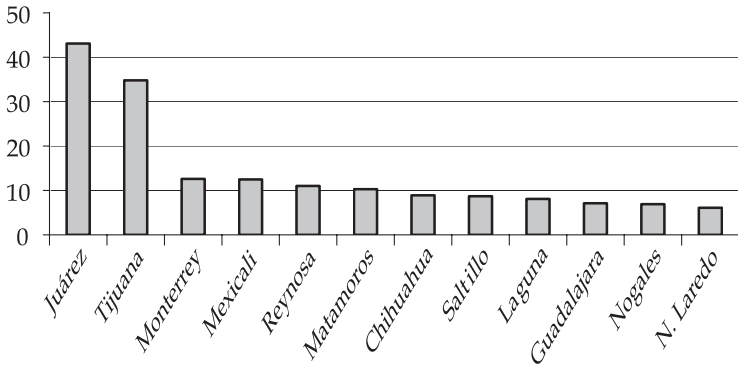
Source: Asociación Mexicana de Parques Industriales, 2000.

second in importance; it developed and owns three industrial parks —Gemma I, Gemma II, and Juárez. This industrial group developed 90 hectares since 1971. ProLogis group owns two industrial parks —Salvarcar and Southwest— the total square feet available is 76,115 (about 7000 square meters). Chihuahua's state government developed Complejo Industrial Aeropuerto (72 hectares) as a vehicle to attract maquiladoras.

3) Commercial and Service Land

The commercial and services sectors, which traditionally constituted the urban center in the central business district, began a phase of expansion along the main roads that connected the historic downtown to the eastern part of the city. This resulted in the formation of a new central business district that is also located along the main roads (Fuentes, 2001). The new district was rooted in urban sprawl during the 1970s and 1980s. Industrial and residential growth toward the northeast also demanded a new central business district. Within this context, a new zone emerged with housing, large shopping centers

and restaurants. The appearance of this new zone reflects a change from activities surrounding tourism to those related to business. From 1995 to 2001, the land with commerce and service uses increased by 563 hectares.

The traditional pattern of centralization in commercial and service land use is modified as a result of four processes: 1) greater competition between regional, national, and international commercial corporations having as a result the southward relocation of warehouses near residential areas, 2) deficient public transportation, 3) substantial

Table 7.
Number of Maquiladora Industrial Parks by size
in Ciudad Juárez, 2000.

Industrial Park	Total Surface (hectares)	Surface Constructed (hectares)	Number of Industrial Plants
Antonio J. Bermúdez	174	139	51
Río Bravo-Beffer	77	65	16
Panamericano	31	19	8
Los Aztecas	36	29	9
Los Fuentes	57	23	10
Salvarcar	26	N.D	7
Zaragoza	99	31	24
Fernández	12	N.D	N.D
Gemma I	40	38	9
Gemma II	10	5	N.D
Juárez	40	N.D	15
Internacional Mexicano	81	20	8
Omega-Magnaplex	76	N.D	20
C. Ind. Aeropuerto	72	N.D	14
Aero-juárez	70	20	N.D
C. Ind. Médanos	468	0	N.D
Las Américas	23	6	1
El Dorado (Project)	19.5	0	0
Northgate (Project)	29	0	0
Total	1,440	394	192

Source: CIES, 2000.

investment in freeways, and 4) exhaustion of the agglomeration economies of the central business district (Fuentes, 2001).

As previously shown, demographic and economic factors drive urbanization; therefore, urban development policies to a great extent are mechanisms to allocate and accommodate a variety of urban activities such as residential, industrial, commercial, etc. In this context, the following sections deal with the development of a model to simulate future land developments.

System Dynamics Models

Modeling has been an endeavor that has caught the attention of social scientists. A classical definition of a model is the one put forward by Lowrey (1965), which defined a model as "a simplification" (cited in Batty, 2003). The objective is to take a given complex system and identify the elements that define the system and how these relate to each other. Furthermore, the objective of modeling must also be pedagogical in the sense that the modeler and users can learn about "actions, reactions, causes, and consequences" (Guhathakurta, 2003: 7). In sum, it is our intention to contribute to the understanding of the driving forces behind the growth and allocation of land.

The evolution and growth of systems models goes hand in hand with the advent of personal computers (PC). According to Gilbert and Troitzsch (2002: 17), most of the modeling prior to PCs was reduced to differential equations; simulation models are more concerned with understanding processes whereas statistical models, such as differential equations, focus on correlations. Systems models thus are preferable because they allow for theory testing and exploration. As PCs became more affordable and increased their processing power, efforts to develop more complex models increased and specialized software able to process a great deal of information, such as Stella®, became available.

According to Axelrod (1997) there exist two sets of models –rational-choice and agent-based models. A first set of models includes typical equilibrium models used in game theory and rational-choice which begin by "specifying a set of axioms and proving consequences

that can be derived from those assumptions" (Axelrod 1997: 3). These models assume that the actors behave rationally, choosing only strategies that would optimize outcomes. In contrast, agent-based models assume that the actors adapt their behavior instead of choosing optimal strategies; that is, the actors learn by doing.

Grant *et al*. (2001) point to different methods to identify the kind of "puzzle" that the researcher wants to solve. The method consists of identifying the components or variables that will be included in the model and the relation among the components. The researcher will try to solve puzzles. A first type is characterized by an unorganized complexity where several components exist and there is little understanding of how they relate. Another example is a system of organized complexity, where fewer components exist and there is a good understanding of how they relate to each other. In between these two methods exists organized complexity, where some understanding exists among the components and how they relate. Land use in Ciudad Juarez is a typical example of organized complexity where there is a good deal of understanding of the components (demographic and economic) and how they relate as the next section will show.

Conceptual Model of Land Use Change in Ciudad Juarez

In the modeling process, according to Gilbert and Troitzsch (2002), after the "puzzle" has been identified (what factors drive the urban growth process in Ciudad Juárez?), the next step will be to design a model. Ciudad Juárez has undergone enormous population and physical growth due to two interrelated factors –industrialization and population growth, mainly through migration. This is especially true since 1970, when the city experienced faster population growth than any other border city and became home to the second largest concentration of maquiladoras in the country (INEGI, 2000).

Employment is the indicator that best captures the close relationship between economic and demographic factors. Ciudad Juárez has more maquiladora employment than any other border city. The dramatic growth makes the maquiladora economy a prime catalyst for urban

change. The model presented here draws on the linkages between maquiladora employment and land use change.

In order to understand the dynamics of land use changes, it is important to take into account the interdependence among different urban land uses. Lowry's land allocation model (Lowry, 1964; Garin, 1966) provides an excellent conceptual framework for capturing these interdependencies because it describes how change in one land use precipitates change in other land uses — for instance, how employment growth affects residential land and how new developments, in turn, need commercial and services related functions.

In the contemporary context of Ciudad Juárez (1970 to present), maquiladora employment is the key force that induces change in the allocation of land within the city. Once maquiladoras arrived, the demand for industrial uses increased. Initially, the available local labor is employed but due to the rapid influx of maquiladora plants, each employing hundreds of workers (on average), additional "outside" labor is needed. This leads to migration and overall urban population growth. The inflow of labor increases the demand for residential land as workers and their families seek housing. Vacant housing units are initially filled, but the escalating number of immigrants leads to the development of new residential districts. Population growth also induces demand for commercial activities (defined broadly to include wholesale, retail and business/personal services). The demand for commercial activities leads to the expansion of commercial establishments already in place as well as the formation of new enterprises so that the amount of commercial land rises. The expansion of the commercial sector creates more employment and these employees require additional residential land (Figure 2). Finally, farm and desert land are the main suppliers of land to accommodate the urban growth.

Model Operationalization

Continuing with the Gilbert and Troitzsch (2002) methodology, once the model has been designed, the next step will be to build the model

Figure 2.
Model of Land Use Change in Ciudad Juárez
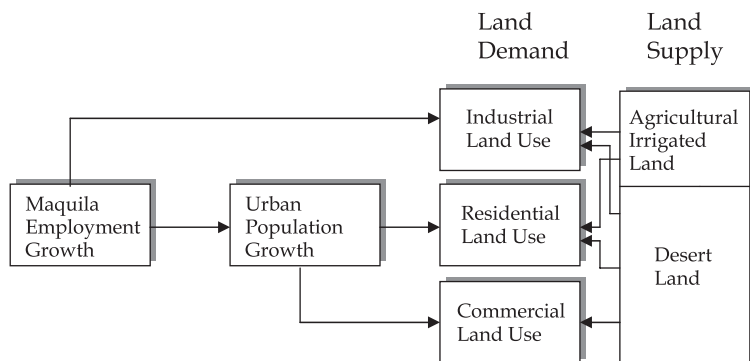
with the assistance of a computer program or software. The model in this article is operationalized using the Stella® software developed by High Performance Systems Corporation.

Stella® software employs only four types of states. The boxes represent stocks that increase or decrease. The stock increases as a result of an inflow or decreases as a result of an outflow; these are represented by the arrows with the knob icon where the flow is regulated. The clouds represent origin or destination of the flow that the model is not particularly interested in explaining. Finally, there exist converters represented by circles named converters, which are the ones that feed the inflows and outflows (Figure 3). The system

Figure 3.
Stella® algorithms
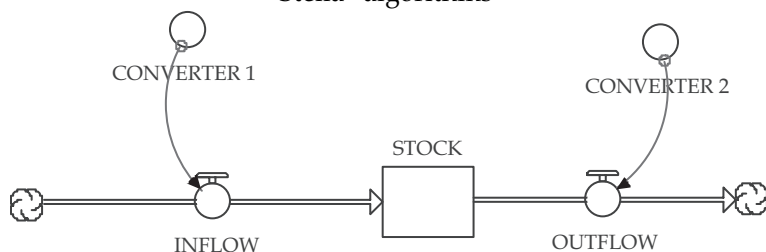
allows us to generate forecasts based upon a dynamic system so that once the user establishes the basic structure of the model, he or she can adjust the rates as sliders to explore different policy options. Among the many advantages of the use of Stella® is that behind the diagram of the model there exists a series of differential equations that the user can use to solve a complex system of equations without possessing extensive knowledge of statistics or mathematics.

In general terms, the land use model is divided basically into three linked sectors. The first sector focuses on modeling the economic sector in Ciudad Juárez (CJ) –specifically in forecasting the growth of industrial employment. The second sector deals with demographic changes. The third sector models urban land changes of industrial, commercial, and residential uses. Figure 4 shows the entire model which in the next paragraphs is explained in more detail.

Figure 4.
CJ Operational Land Use Model
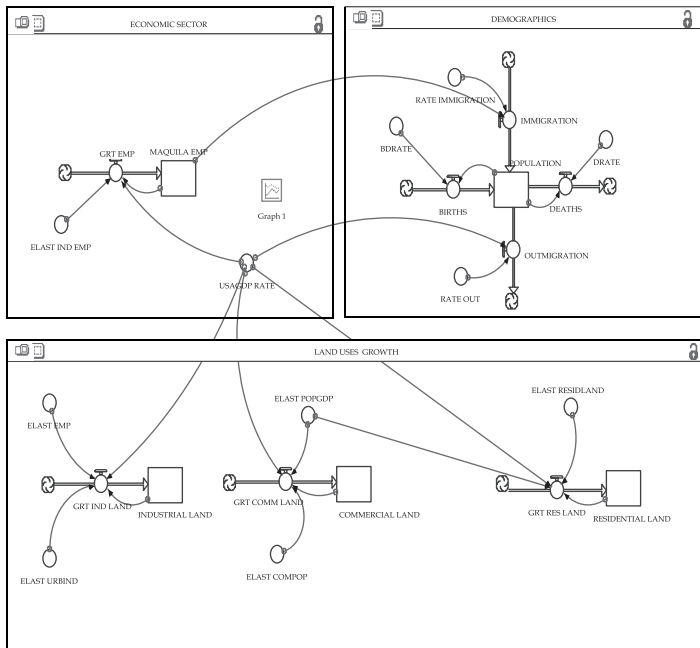
The economic model contains a stock variable that attempts to model the growth of industrial employment (MAQUILA EMP) as a function of the growth of the US economy (USA GDP). The variable ELAST IND EMP (2.774) is a factor that converts the USA GDP into maquiladora employment, measured in the form of elasticity. In other words, if USA GDP increases by 1%, the maquiladora employment will increase by 2.7%. It is important to clarify that this parameter was estimated based on historical data from 1980 to 2000.

The demographic sector models the population growth (POP). Population growth is driven by natural factors, such as births and deaths, and by socioeconomic factors such as immigration and out-migration. Immigration and out-migration are a function of maquiladora employment. It is assumed that for each additional job in the maquiladora industry there is a 5% probability of a worker migrating; that is, for every 20 new jobs in the maquila, one new migrant arrives to the city. The probability of outmigration is set to 2.5%, which means that if there is a loss of 40 jobs, then one worker leaves the city. The probabilities were calculated through a process known as history matching until parameters are found through different rounds calibrating the model.

The third sector in the model deals with land. The model focuses only on three types of land uses considered to be the most important –industrial, residential and commercial. The model was set in such a way that industrial land use is closely linked to employment in the maquiladora industry which, in turn, is a function of the US economy. The growth of land is the product of the elasticity of industrial employment (ELAST IND EMP) with respect to the US economy and the elasticity of the industrial land with respect to changes in the urban area (ELAST URBIND).

The growth of residential land depends to a great extent on population. It is important to keep in mind that a significant force behind population growth in CJ is the US economy. The growth of residential land is the product of the growth rate of the US economy (USAGDP RATE) and the rate of change in the population induced by the US economy measured as elasticity (ELAST POPDGP) and the elasticity of residential growth with respect to the urban area (ELAST RESID LAND).

As in the case of residential land, the growth of commercial land depends on demographic and economic forces. This relationship reflects what was explained previously –that as new neighborhoods emerge, people demand certain goods and services, such as groceries, furniture, construction materials, etc., this in turn will create the opportunity to expand and create new business that the new residential centers and population demand, measured as elasticity(ELAST COMPOP). The other factor is the US economy and its effect on population growth (ELAST POPGDP). All the equations and values are given in the appendix.

Validation of the model

The model was validated against real data from 1980 to 2000. The results are presented in Table 8, where the real and estimated data are shown for the five key variables in the model –population, maquiladora employment, and industrial, residential, and commercial land uses.

Table 8 shows the evaluation of the results of the estimated model against the real data. The three variables that presented the biggest margin of error (percent being underestimated or overestimated) are commercial land (9.04%), employment (-8.02%) and population (-7.38%). The variables with the minimum margin of error are residential land (4.58) and industrial land (3.74%).

The explanation for the errors in the model is that the US GDP was assumed as a constant (3.5%) as were the industrial land elasticities. However, it is clear that by 2000 the rate of economic growth in the US has slowed. Furthermore, authors such as Carillo and Hualde (1996) had pointed out that the maquildora industry has shifted from highly labor intensive industries, such as textiles, to less labor intensive industries, such as auto design. In other words, the productivity of the labor force has increased, which means fewer people producing more output and, consequently, the demand for industrial land should decline as well.

An advantage that the Stella® software offers is that the parameters can be adjusted to explore different scenarios. A future scenario for 2020 was forecast, changing some of the assumptions and parameters. It is assumed that the pace of the US economy will be slower. Random

Table 8.
Model Validation

Year	Population	POP EST	MAQ_EMP	EMP EST	INDLAND	IND EST	COMMLAND	COM EST	RESIDLAND	RES EST
1980	567 365	567 365	39 402	39 402	378	378	688	688	6 061	6 061
1981	586 987	582 299	43 994	43 228	433	415	709	718	6 153	6 220
1982	607 288	597 766	42 695	47 425	495	455	731	748	6 246	6 383
1983	628 291	613 796	54 073	52 029	567	499	753	781	6 340	6 551
1984	650 020	630 423	72 495	57 080	649	548	776	814	6 484	6 723
1985	672 500	647 682	77 592	62 622	689	601	799	849	6 632	6 900
1986	695 759	665 613	86 526	68 702	731	659	824	886	6 783	7 081
1987	719 821	684 257	97 800	75 373	777	723	849	924	6 937	7 267
1988	744 716	703 661	107 315	82 691	825	793	875	963	7 095	7 457
1989	770 472	723 875	124 386	90 719	876	870	901	1 005	7 256	7 653
1990	798 499	744 951	130 000	99 527	930	955	929	1 048	7 421	7 854
1991	831 086	766 950	134 838	109 190	987	1 048	957	1 093	7 590	8 060
1992	865 004	789 934	129 146	119 791	1 048	1 149	986	1 140	7 763	8 272
1993	900 305	813 973	132 046	131 422	1 113	1 261	1 016	1 189	7 940	8 489
1994	937 047	839 144	140 405	144 182	1 182	1 383	1 047	1 240	8 120	8 712
1995	975 289	865 527	153 322	158 180	1 274	1 517	1 079	1 293	8 368	8 941
1996	1 015 091	893 214	177 914	173 538	1 373	1 665	1 169	1 349	8 622	9 175
1997	1 056 518	922 300	196 095	190 387	1 480	1 826	1 266	1 407	8 885	9 416
1998	1 099 635	952 894	201 926	208 871	1 595	2 004	1 372	1 467	9 156	9 663
1999	1 144 512	985 111	217 155	229 151	1 720	2 198	1 486	1 530	9 435	9 917
2000	1 217 818	1 019 079	249 509	251 399	1 854	2 412	1 610	1 596	9 722	10 177
ERROR		-7.38%		-8.02%		3.74%		9.04%		4.58%

growth between 0% and 3% was used given the fact that the historical growth of developed economies in average is about 3%. Also, it is assumed that the maquiladora industry will continue to shift towards less intensive industries, therefore the employment elasticity was changed from 2.74 to 1.5, which means that if the us gdp grows by 1%, the level of employment will increase by only 1.5% instead of the original 2.74 percent.

Table 9 shows the forecast results for the period 2000-2020 for Ciudad Juárez. The model forecast a population of 2 275 059 which is about a 5% underestimate than the one by Peach and Williams (2000) in their medium case population forecast of 2 395 024. The maquiladora employment is estimated to create an additional 111 718 jobs in 20 years, reaching a total of 361 227.

In regard to the land use forecast, as expected, residential land will experience the biggest increase overall. According to the model, 1990 additional acres (805 hectares) will be needed to accommodate the population increase. Commercial land will need 571 additional acres (12.1 hectares) to take care of the new residential growth. Finally, as was expected, the growth of industrial land will require only 830 additional acres (37.1 hectares).

Conclusions

This study has shown that the economic boom of Ciudad Juárez has been related to the maquiladora industry, which at the same time is a reflection of the industrial reorganization of the US economy from *fordists* into flexible production systems. During two decades beginning in the 1980s, Ciudad Juárez experienced an economic boom that transcended into other social and demographic variables. The urban area of the city expanded from almost 9 000 hectares to 22 000 and its population grew from almost .5 to 1.2 million in two decades.

In the same way as booms, economic downturns of the us economy have also contributed to the economic uncertainty of Ciudad Juárez. The 2000 recession in the USA translated in the lost 65 000 industrial jobs in the city because the engine of growth of the city is an

Table 9.
Forecast 2020*

Year	Population	Employment	Commercial Land	Industrial Land	Residential Land
2000	1 217 818	249 509	1 610	1 854	9 722
2001	1 258 121	249 563	1 610	1 854	9 723
2002	1 299 347	251 104	1 618	1 866	9 753
2003	1 341 592	259 800	1 664	1 930	9 922
2004	1 385 237	262 718	1 680	1 952	9 978
2005	1 430 026	268 240	1 708	1 993	10 083
2006	1 476 114	268 988	1 712	1 999	10 097
2007	1 523 293	269 500	1 715	2 003	10 106
2008	1 571 575	280 114	1 770	2 081	10 305
2009	1 621 491	285 442	1 798	2 121	10 403
2010	1 672 814	295 841	1 852	2 198	10 593
2011	1 725 830	296 697	1 856	2 205	10 608
2012	1 780 100	308 228	1 915	2 290	10 814
2013	1 836 187	315 970	1 954	2 348	10 950
2014	1 893 942	321 284	1 981	2 387	11 042
2015	1 953 283	327 979	2 015	2 437	11 157
2016	2 014 315	329 611	2 023	2 449	11 185
2017	2 076 822	337 584	2 063	2 508	11 320
2018	2 141 157	343 114	2 091	2 550	11 413
2019	2 207 238	347 705	2 114	2 584	11 490
2020	2 275 059	361 227	2 181	2 684	11 713
Net change	1 057 241	111 718	571	830	1 991
Acres (Hectares)			(231)	(335)	(805)

* Assumption: USA GDP (0%–3%) Industrial employment elasticity (1.5).

exogenous force –i.e. the US economy. The development of system dynamic models and the simulation of different scenarios can be an important tool for urban planning. An advantage of systems dynamics, such as the one presented here, is that it allows us to develop other types of scenarios, such as a best case scenario where we could assume that the US economy will go back to a high growth path and, therefore, Ciudad Juárez can continue its economic boom, or a worst case scenario, where the US economy stagnates in the next 20 years.

This paper has contributed to developing a model that forecasts key variables in a long-term scenario into 2020. Incorporating systems dynamic is important to guide policy making; the system would allow the policymaker to explore different case scenarios and to observe the result of his/her actions. Furthermore, the policymaker can experiment with different policy options and simulate results by changing the parameters in the model, for instance, the effect of increasing population density on the demand for residential land.

In sum, the model developed here can help planners and policymakers to forecast the demand for land among different land uses in the next 10 or 20 years. As previously stated, the model could help to determine how much land is needed and allocated to the different uses but the locational decision is up to the land use planners or the market. There exist other modeling techniques, such as a cellular automata (CA) or agent based models, that can be used to explore the spatial impacts and the form of the city under the current rules of development and how the city would grow if the rules were changed (Batty, 2003). CA models deal with the geography of development whereas dynamic system models focus on estimating parameters and quantity. So a combination of a dynamic system, such as the one presented here, and a CA model dealing with the geography of development can be the best option as some studies have shown (Batty, 2003).

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Appendix (Stella® Algorithms)

DEMOGRAPHICS

POPULATION(T) = POPULATION$(T - DT)$ + $($BIRTHS + IMMIGRATION - OUTMIGRATION - DEATHS$)$ * DT

INIT POPULATION = 567365

INFLOWS:

BIRTHS = POPULATION*BDRATE

IMMIGRATION = MAQUILA_EMP*RATE_IMMIGRATION

OUTFLOWS:

OUTMIGRATION = IF$($USAGDP_RATE$<=0)$ THEN RATE_OUT=.025 ELSE 0

DEATHS = POPULATION*DRATE

BDRATE = 28.3/1000

DRATE = 5.45/1000

RATE_IMMIGRATION = .05

RATE_OUT = .025

ECONOMIC SECTOR

MAQUILA_EMP(T) = MAQUILA_EMP$(T - DT)$ + $($GRT_EMP$)$ * DT

INIT MAQUILA_EMP = 39402

INFLOWS:

GRT_EMP = MAQUILA_EMP*ELAST_IND_EMP*USAGDP_RATE

ELAST_IND_EMP = 2.774

USAGDP_RATE = .035

LAND USE SECTORS

LAND USES GROWTH

COMMERCIAL_LAND(T) = COMMERCIAL_LAND$(T - DT)$ + $($GRT_COMM_LAND$)$ * DT

INIT COMMERCIAL_LAND = 688

INFLOWS:

GRT_COMM_LAND =

 COMMERCIAL_LAND*ELAST_COMPOP*ELAST_POPGDP*USAGDP_RATE

INDUSTRIAL_LAND(T) = INDUSTRIAL_LAND(T - DT) + (GRT_IND_LAND) * DT

INIT INDUSTRIAL_LAND = 378

INFLOWS:

GRT_IND_LAND =

 INDUSTRIAL_LAND*ELAST_IND_EMP*ELAST_URBIND*USAGDP_RATE

RESIDENTIAL_LAND(T) = RESIDENTIAL_LAND(T - DT) + (GRT_RES_LAND) * DT

INIT RESIDENTIAL_LAND = 6061

INFLOWS:

GRT_RES_LAND =

 RESIDENTIAL_LAND*ELAST_POPGDP*ELAST_RESIDLAND*USAGDP_RATE

ELAST_COMPOP = 1.036

ELAST_POPGDP = 1.185

ELAST_RESIDLAND = .633

ELAST_URBIND = 1