Modeling The Effects of Oregon's Transportation Planning Rule on Land Use Development Patterns and Traffic Congestion

- An Agent-Based Simulation with NetLogo -

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Abstract

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We propose an agent-based simulation model to examine the effects of Oregon's Transportation Planning Rule (TPR) on land use development patterns and, in turn, the effect of those development patterns on traffic. The TPR is a statewide planning requirement that local governments must assess the traffic impacts of land use changes. To this end, we design an artificial city to simulate interactions between land use development and traffic. The simulated city has an environment of travel corridors and land uses. In addition, two types of agents move on the artificial city: Citizen and Developer agents. Citizen agents interact with the environment through activity of visiting land uses and collectively creating traffic on the corridors. Developer agents interact with the environment by converting vacant land to developed land based on local activity levels and/or development costs. We conclude that this agent based model demonstrates phenomenon described by planning professionals: when costs based on TPR performance metrics are imposed, development levels reduce and are deflected away from areas of high activity and traffic. While the model was able to show low-density development patterns caused by TPR performance metrics, there were insufficient interactions to cause higher trips distances by Citizen agents. We also found that the model was sensitive to the structure of decision-making by developers, suggesting that further exploration of realistic cost-benefit analysis of developers would improve the model's relevance.

주제어: 오레곤주 교통계획규칙, 에이전트 기반 시뮬레이션, 넷로고

Keywords: Oregon's Transportation Planning Rule, Agent-Based Simulation, NetLogo

I. Introduction

In 1991, Oregon adopted the Transportation Planning Rule (TPR), a policy that requires land use and transportation plans at all levels of the state be coordinated (Bianco and Adler, 2001). Specifically, this rule requires local jurisdictions to demonstrate that proposed changes in land use (for example, through comprehensive plan amendments or zoning modifications) will not impair the ability of transportation facilities to meet performance objectives outlined in adopted transportation system plans.

There also exist statewide land-use goals of discouraging sprawl through activities such as infill development (Weitz and Moore, 1998). However, most of the urban core areas where higher density is encouraged have transportation infrastructure that does not meet current performance criteria. Thus, new developments bear the burden of traffic mitigation costs in already well-developed areas. Often, these mitigation costs can be avoided by shifting development to areas of low-density. Low-density development, in turn, encourages more vehicle miles traveled (VMT) per person and increasing traffic. In essence, the TPR, which was initiated as a way to align transportation infrastructure investments and land use planning, has an unintended consequence of encouraging patterns that are at odds with official policy.

An additional level of complexity in this system is how development impacts on transportation infrastructure are measured and forecasted. A key performance criterion is the "Level of Service" which is calculated as the actual volume of cars on a road divided by the capacity of that road (Hanson and Giuliano, 2004). Under congestion situations, volume is often far greater than capacity. When forecasting impacts of a development, traditional traffic impact assessments use standardized linear models to calculate the number of additional car trips expected to a location based on development type and size. Reportedly, current practice in Oregon is to discount trip forecasts for developments in urban areas by 10%, but this is an arbitrary reduction (Bianco and Adler, 2001).

A primary question about this system is whether the TPR itself can be shown to be affecting spatial patterns of development. Can a pattern be replicated whereby the cost-benefit decisions of developers affect VMT by the population? Further, given that the TPR is an established law of the land, are there interventions in traffic impact forecasting or performance measurement which can correct for unintended consequences? For example, can we show that differences in traffic generation patterns between high and low density development that can give a rational basis to trip reduction credits?

Conceptually, the system in which the "TPR problem" exists can be considered from an agent-based perspective because the outcomes depend on individuals making personal decisions that are not coordinated by a hierarchical observer (Gilbert and Troitzsch, 2005). Further the system agents have a high degree of interaction with the environment. The TPR itself can be considered a special kind of environment in which decisions are made.

Agents in this system are both developers and the general citizens. Developer-agents interact with the environment directly through decisions about site location. The general citizens, in contrast, interact indirectly through their presence. Citizen-agents generate "traffic", too much of which triggers disincentives under the TPR. However, citizen-agents also generate "activity" which attract developers. In this simplified system looking at spatial patterns of development and travel, there are not direct interactions between agents of either type.

Ⅱ. Model Development

In this section, we describe in detail the components of the agent-based TPR model, implemented with NetLogo, and the model development process. The development of the TPR model started with defining the environment, then defining agents, then defining interactions. Initially there seemed to be similarities between the conceptualized TPR model and the classic "Ants" and "Traffic" example models. However, there were ultimately few procedures that were able to be repurposed from sample models and the TPR model used mostly original code.

1. Defining the Environment

An artificial city consisting of 55 x 57 patches is designed as shown in Figure 1. These 3,135 patches are broadly grouped into two types: "Corridor" and "Land Use" patches. The Corridor patches are drawn first as if transportation infrastructures are built on the empty land of a new city. Once the transportation network systems are ready, patches representing land use types of office, commercial, and residential are allocated on the remaining unoccupied patches.

Corridor Patches:

The artificial city is connected by two types of corridors in a grid form: major and minor corridors. Two major corridors are placed forming a central axis in the center of the city. Minor roads are placed at regular intervals away from the major corridors. The areas of patches bounded by corridors become "city blocks" of land uses. Corridors are placed close enough so that all Land Use patches are adjacent to a corridor. Intersection patches, those where corridors cross, are flagged with a special variable attribute; this is important because agents moving on the Corridor patches can change their direction toward their destination only at intersections.

Corridor patches have three key attributes: Capacity, Traffic, and LOS. The Capacity attribute is exogenously assigned via a chooser on the user interface. We assume that the major roads are capable of carrying two times more traffic volumes than the minor roads, so the Capacity on minor roads is ½ the slider value. On the other hand, the Traffic attribute is updated over time through the presence of citizen agents on the Corridor patches. These two Capacity and Traffic attributes of the Corridor patches are used to calculate the level of service (LOS) for each Corridor patch, described in the Interactions sub-section below.

Land Use patches:

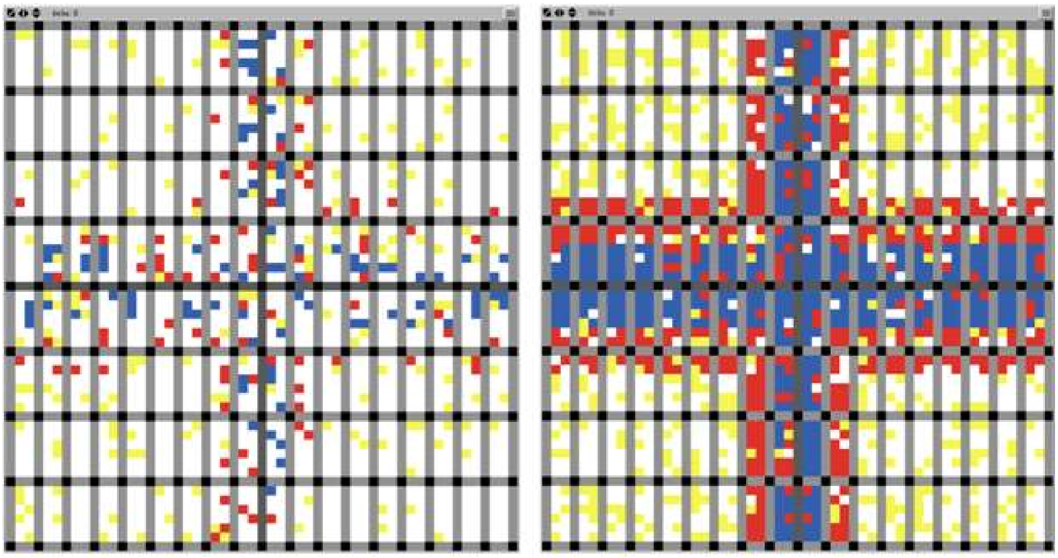
The Land Use patches fill up vacant patches between the Corridor patches with three different types of land-use. Sliders on the user interface allow for setting the amount of land assigned to specific uses at the beginning of the simulation. For our simulation testing we used 5 percent of the patches assigned to office use; 5 percent to commercial; and 10 percent to residential. The still remaining vacant patches can be thought of as potential sites for development. To create a natural land-use pattern of a city in the model, the office patches are randomly distributed within one building block of the two major corridors, and in turn the commercial patches are located randomly in two blocks of the major corridors. Lastly, the yellow colored residential patches are randomly distributed on remaining patches.

The Land Use patches have two important attributes: Activity and Cost. The Activity attribute is the count of visits by citizen-agents to the patch. Cost is calculated from the LOS attribute of neighboring corridors through the environment-environment interaction. We will describe these two types of interaction in detail in the Interactions sub-section.

Issues and Debugging:

Because patches, unlike turtle agents, do not have breeds, care had to be taken to define Boolean variables to differentiate the Corridor patches from the Land Use patches to prevent unexpected interaction calculations. Early in development, color was used to distinguish Corridors and Land Use types, however this proved problematic when different drawing schemes were introduced to the model which caused decisions based on color during the simulation to be unreliable.

Even though it is normal in an urban area to have a relatively low percentage of open or vacant space, having too little undefined land use patches in the model didn't allow for sufficient evolution of development. Setting the used land-types through the user interface allowed decisions about density to be deferred until after model behavior was better observed.



〈Figure 1〉 Environment Set-Up in the Model:

Corridor patches are shown in grey; intersections are shown in dark grey. Yellow patches are Residential land uses, red patches are Commercial land uses, and blue patches are Office land uses. White patches are unused land uses which are available for development. The left image shows the starting fill-level used in the TPR model of about 20% developed land. The right image shows a more realistic urban fill-level of 60%.

2. Defining the Agents

There are two types of agents in this system: "Citizen" and "Developer". First, a random number (between 0 to 9) of Citizen agents are sprouted from land-use patches with land use type "Residential." Second, a random number (between 0 and 2) of Developer agents are sprouted from office patches. During the simulation, agents are assigned goals that cause them to move through and interact with the city-space.

Goals for both breeds of agents are a randomly selected land use patch. Citizen agents are assigned a patch with a developed land-use type; developer agents are assigned patches with no land-use type. When a Citizen agent reaches their goal patch, the activity level on that patch is incremented by one, then the Citizen is assigned another goal. When a Developer agent reaches their goal, they may or may not change that patch to a specific land-use type based on the developers cost-benefit analysis (described in the Interactions sub-section below). After the development decision is made, Developer is randomly assigned another empty land-use patch, if available, as a goal.

Citizen agents are constrained to movement along corridor patches where their presence is counted in the patch's Traffic attribute. Developer agents do not contribute to traffic (in our model) and thus have unconstrained movement. Figure 2 shows an example of agent movement.

Issues and Debugging for Citizen-Agents:

The two primary development activities for modeling citizen agents were controlling the movement of agents along corridors, and giving the agents goals.

Controlling citizen-agent movement proved to be a more difficult and time consuming task than originally estimated. The two requirements for citizen movement were that they needed to move only along corridor patches towards their goal and that they needed to take a logical, short path to get there. (While the absolute shortest path was not required, completely random paths were deemed to be not useful for estimating traffic based on spatial distribution of development.) In order to debug agent movements, the "pen-down" feature was used to track the path of a randomly selected agent. Also, in early development cycles, agents would "hide" when they reached their goal that allowed better visualization of patterns in the path-finding algorithm. Success of the movement algorithm was defined by the number of ticks that it took until all agents found their goal (assigning new goals was not implemented until the movement algorithm was finalized). In poor performing versions of the model, this took over 13,000 ticks. At the final version of the model, agents take 100 or fewer ticks to find their goal.

Constraining agents to the corridor was easily accomplished by using the Corridor Boolean variable of the patches. Getting the agents to move towards their goal involved having the agent check their heading against the location of their goal. Because they are constrained to movement along the corridors, they cannot move strictly in the direction of the goal, but have to calculate the next best possible direction. At first, it was assumed that introducing random movements into this algorithm (similar to the Ants sample model) would be required. However, even though randomly moving agents could find their goals, the path was obviously not the shortest. Figure 2 shows a sample path in an early model using random path-finding.

Unfortunately, random path finding was more successful than early versions of logical "check-heading" methods as the logical methods would result in failure of agents to find the goal altogether. A difficulty during this part of the development was in interpreting how the heading reporters were being received by the agent. Assigning temporary variables to the citizen agents showing calculation results helped debug these problems. In the end, random movements are only introduced when forward movement by citizens is not possible, for example at the edges of the field. And finally, the best algorithm included only having agents check their headings at intersections, however this would sometimes lock agents one block away from their goal. A compromise to this problem was to have agents "jump" to their goal if they are two or less patches away. This allowed an efficiency of movement and calculation and allowed all agents to successfully reach their assigned goals.

Assigning citizen goals was fairly easy technically, but posed conceptual issues. The code used to give citizen goals was a simple variation on:

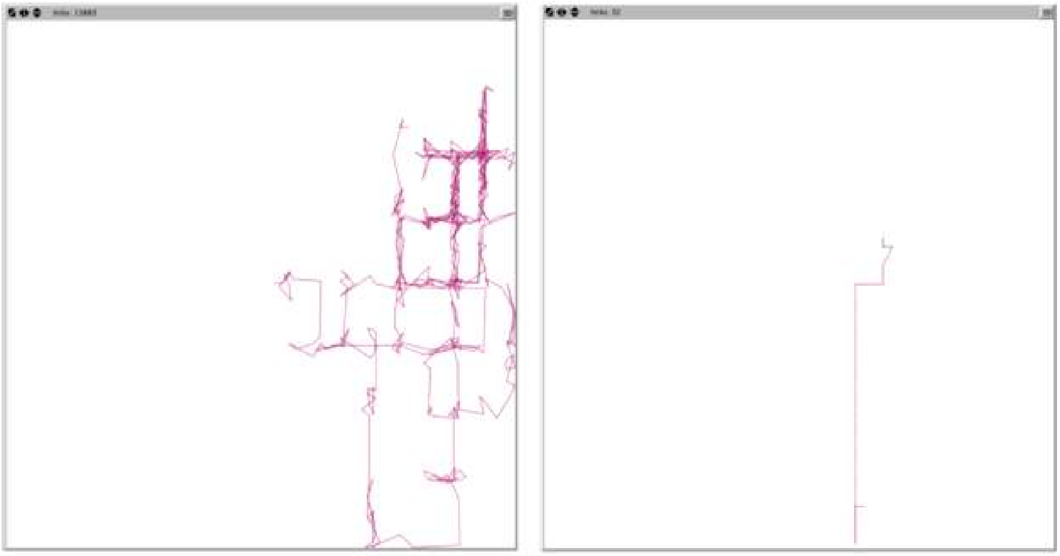
```
set CitizenTarget one-of patches with [LandUseType = "Office"]
```

where CitizenTarget is a Citizen breed variable which holds the patch coordinates for their assigned goal. The conceptual issues included determining which type of land use patch would be assigned and how to determine the radius of the agent search. While the original intention was to look to household travel survey information to get trip type and trip distance distributions to calibrate these concepts, it was determined that this may be unnecessary detail that did not contribute to the overall model.

Early versions of the model included a slider on the user interface that controlled the search radius of agent when being assigned a goal. With the search radius on, the average trip distance (the distance between an agent and its goal when first assigned) by agents always converged to about half the radius variable, regardless of the spatial pattern of land use developments. When the radius-constrained search was not used, the average trip distance responded to the development patterns. We did not explore multi-level decision making for agents (for example: search close first, if cannot find a goal then search farther), but this may be more realistic than the "search anywhere" algorithm that was finally implemented.

Similarly, after model development began, there seemed fewer compelling reasons to use empirical trip-type distributions to explore the defined model goals. While data on trip-type distributions is available, it was unclear how this would affect development. Model exploration did suggest that the distribution of land use type developments itself could be interesting fodder for future models - for example, in evaluating how land use type diversity versus uniformity in a neighborhood could affect trip distances. In such a case, using known distributions would be valuable.

However, in order to not introduce additional unfounded assumptions about development choices in this model, assignment of land use type by both citizen-agents and developer-agents were kept strictly random. Having more than one Land Use type in this model did prove to be important factor for agent movement. When agents were assigned only one type of land use, they tended to often stay on their own patch rather than be assigned a goal that required travel. Introducing goal variety induced agents to travel.



〈Figure 2〉 Citizen-Agent Movement:

Each picture shows the path one agent takes to find one goal captured with the “pen down” feature. The left picture shows an early development approach using random movement. The right picture is an agent path in the final algorithm, showing the agent taking a more direct route, but “jumping” to its goal diagonally when the goal is near.

Issues and Debugging for Developer-Agents:

There were few difficulties in implementation of developer agents other than the question of whether we needed developer agents at all. Because developer agents do not interact with other agents or the environment other than through the cost-benefit analysis decision of whether to convert an empty land use patch to a specific type, we surmised that they may not be necessary. Thus, in our early modeling efforts, the actions of developers were executed by NetLogo's “Observer”. Simply, at regular intervals (say every 20 ticks), the costs and benefits associated with development (described in the Interactions sub-section below) would be calculated and a random patch that met development criteria was converted to a designated use.

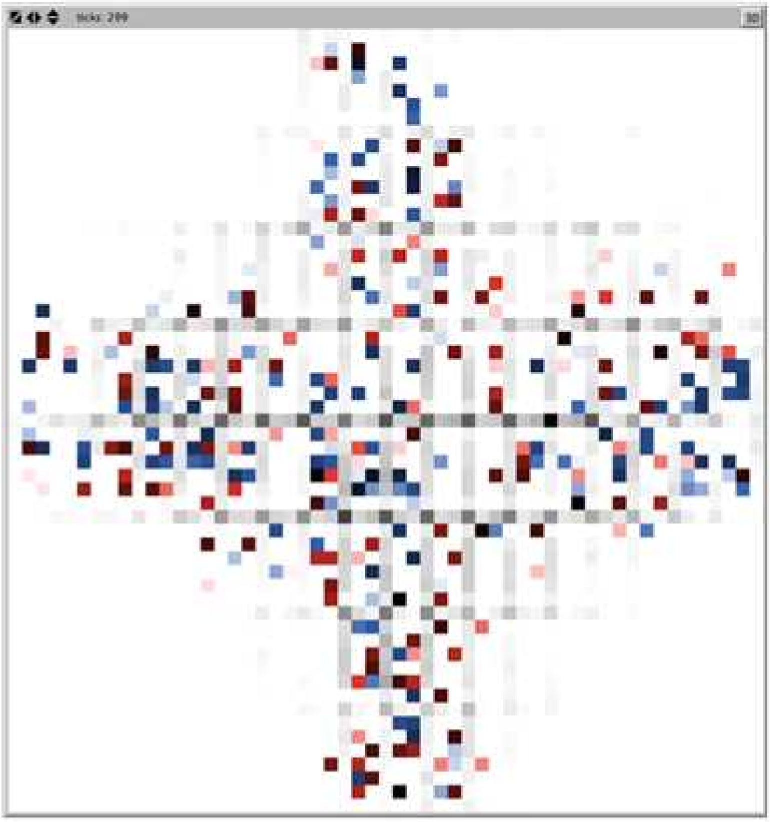
In practice, however, this caused the simulation to slow down noticeably every time the development cycle procedure was executed. When we implemented development through agents, we changed the cost-benefit calculation (e.g. determining LOS, Cost, and Potential Activity) to only be executed locally at the site where development may occur. There was no noticeable effect in the outcome of the pattern of development after this change, but the simulation did run much more smoothly and took less time. Qualitatively, this implementation felt more true to the "agent-based" paradigm as it imposed a number of factors including local rather than global knowledge and parallelism.

3. Defining the Interactions

There are three primary interactions in the TPR model. First Citizen agents interact with the environment through their presence and movement. Second, Corridor and Land Use patches interact based on TPR rules. And third, Land Use and Developer agents interact through development.

Citizen-Patch Interaction:

When Citizens pass over a Corridor patch on their way to a goal, the Traffic variable on that patch is incremented by 1. However, the Traffic variable also evaporates over time so that the measure more closely resembles activity at a given moment and does not hold cumulative information. When Citizens reach their goal, the Activity variable on that Land Use patch is incremented by 1. Unlike the Traffic variable, the Activity variable is cumulative. Figure 3 shows the simulated city colored by the values of the Traffic and Activity variables.



〈Figure 3〉 Traffic and Activity:

In this image, patches are drawn according to the values of their Traffic and Activity variables. Land use patches with dark blues and reds have higher activity levels. Corridor patches with higher traffic values are shown in darker grays.

Patch-Patch Interaction:

As described earlier, the user interface to the simulation includes a "capacity" selector which exogenously assigns the Capacity value of the Corridor patches. If Traffic on the patch exceeds the Capacity, that patch is calculated to have a low "Level of Service" (LOS). In turn, the LOS value is used to calculate Costs of nearby Land Use patches. Similarly, the Activity variable of Land Use patches are used to calculate Activity Potential of nearby empty Land Use patches. Calculation of LOS, Cost and Activity Potential occur when a developer is executing the decision as to whether to develop an empty patch or not. The value of these variables are stored as discrete "high", "medium" or "low" values.

Developer-Patch Interaction:

Developers use the Cost and Activity Potential variables in a cost-benefit calculus when deciding whether to convert a Land Use. Here, the Cost variable is the cost of development and the Activity Potential is the benefit. Developers only convert a Land Use if the Activity Potential is greater than or equal to the Cost on the patch. For example, they only convert patches with a "high" Cost if the Activity Potential is also "high." Once a patch has been developed, it is available to be assigned as a goal to Citizen-agents, thus potentially influencing the travel patterns of the Citizen-agents.

Issues and Debugging:

Because the interactions between agents could not be observed directly, we extensive employed color and inspection to determine if the interactions were behaving as expected. During the model development, there was a great deal of evolution in the structure and calculations of the interactions. The greatest modification was in implementing the Activity Potential variable. Early in development, this was thought to be unnecessary and the "benefit" was calculated from the Traffic level of the Corridors adjacent to the Land Use patches. After several simulations which yielded no interesting results, we determined that we needed a measure that was more independent of the Traffic and LOS variables. While the Activity variable is highly correlated with Traffic, it is calculated independently and thus seemed to be the best alternative for estimating Developer benefit in the existing framework of the model.

Ⅲ. Model Testing

In order to test how the interactions in the model affected the model outcomes, we compared simulations in which we isolated the benefit and cost decisions of the developers.

Testing Set-Up:

We defined global variables that allowed us to turn on and off the cost and benefit analysis decisions of developers. We were able to control these variables through switches on the user interface, but relied used the NetLogo Behavior Space feature to better control the simulations (e.g. run for specific time period and keep other parameters constant). The four simulations are summarized in Table 1. The results of the simulation were reviewed based on 1) spatial distribution of development, 2) mean trip distance of the agents, 3) development rate, and 4) traffic levels. Each simulation was run for 1,000 ticks. The Capacity constraint was set to 6, a value which was just under the generally observed maximum Traffic values during testing. This Capacity level would allow at least some patches to have poor-performing LOS and thus the simulations would include imposition of development costs.

〈Table 1〉 Simulation Set-Up for Interactions Testing

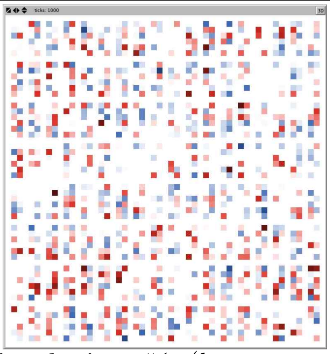
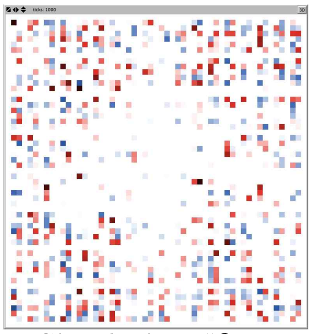
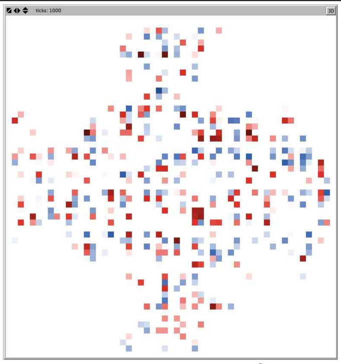
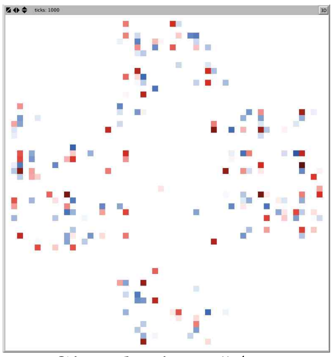
		TPR (Costs)	
		On	OFF
Activity Potential (Benefits)	On	Simulation #1 (base case) Developers use neither Cost nor Activity Potential in development decision	Simulation #2 Developers use only Cost, but not Activity Potential in development decisions. Land uses with “High” costs are not developed.
	Off	Simulation #3 Developers use only Activity Potential but not Cost in development decisions. Land uses with “Low” Activity Potential are not developed.	Simulation #4 Developers use both Cost and Activity Potential in development decisions. Land Use Activity Potential must be higher or equal to Cost in order to be developed.

Result 1) Spatial Distribution

The spatial distribution of development is shown in Table 2. Here, only the Land Use patches which were assigned by Developer agents are shown.

In the base case, development is random throughout the field as expected. When the TPR imposed Cost is used, development is deflected away from the central axis where activity and traffic is pre-existing. In contrast, when the Activity Potential is used in decision making, development concentrates where activity and traffic are pre-existing. With both costs and benefits included in development decision making, development occurs along the fringes of pre-exiting activity.

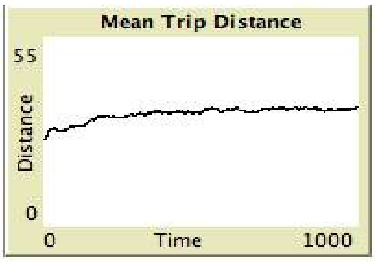
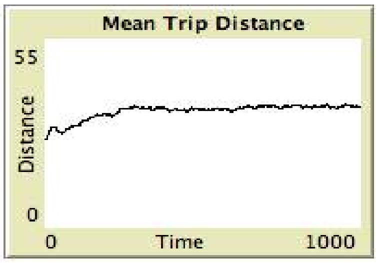
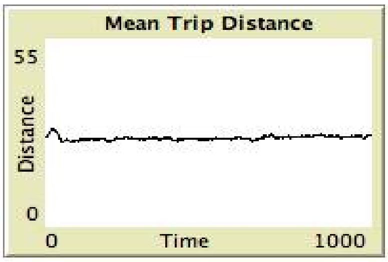
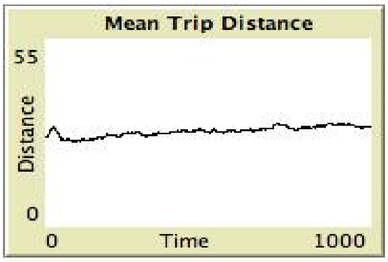
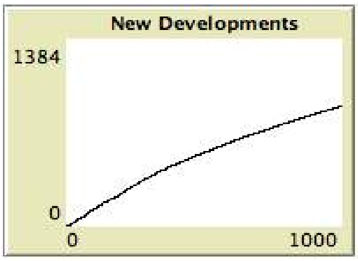
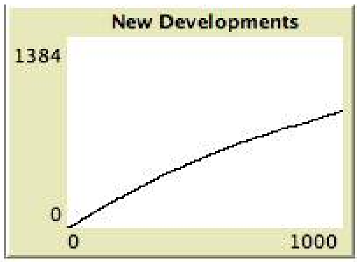
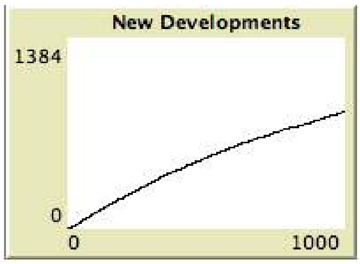
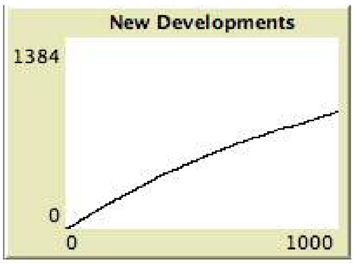
〈Table 2〉 Spatial Distribution of Development

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">TPR (Costs)</th></tr>
<tr><th>On</th><th>OFF</th></tr>
<tr><td rowspan="2">Activity Potential (Benefits)</td><td>On</td><td>
Simulation #1 (base case)</td><td>
Simulation #2</td></tr>
<tr><td>Off</td><td>
Simulation #3</td><td>
Simulation #4</td></tr>
</table>

Result 2) Mean Trip Distance

In this model, Trip Distance is the distance between an agent and its goal at the time the goal is assigned. The mean trip distance of citizen agents over the simulation time is shown in Table 3. The simulations with greater dispersion of development (#1 and #2) did lead to slightly greater trip distances by agents. However, the difference between TPR on and off only appears to have a small impact on increasing trip distance.

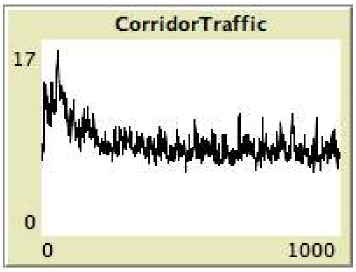
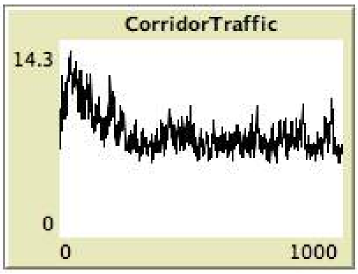
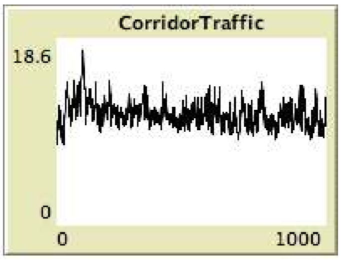
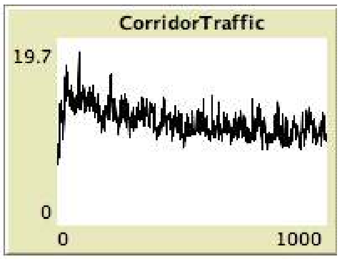
〈Table 3〉 Mean Trip Distance

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">TPR (Costs)</td></tr>
<tr><td>On</td><td>OFF</td></tr>
<tr><td rowspan="4">Activity Potential (Benefits)</td><td>On</td><td>Simulation #1 (base case)
Final Distance: 34.5

</td><td>Simulation #2
Final Distance: 35.0

</td></tr>
<tr><td>Off</td><td>Simulation #3
Final Distance: 26.6

</td><td>Simulation #4
Final Distance: 29.1

</td></tr>
<tr><td>On</td><td>Simulation #1 (base case)
New Developments: 886

</td><td>Simulation #2
New Developments: 843

</td></tr>
<tr><td>Off</td><td>Simulation #3
New Developments: 373

</td><td>Simulation #4
New Developments: 207

</td></tr>
</table>

Result 3) Development Rate

Table 4 shows the rate at which new development occurred in the testing simulations. Predictably, as increasing constraints are imposed in the decision making process, development happens more slowly and fewer patches are developed. Similar to the trip distance finding is that the difference when turning the Activity Potential calculus on and off has a much greater impact on the development rate than does turning TPR rule on and off.

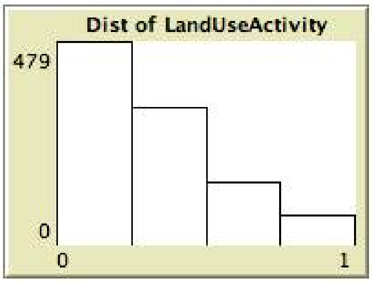
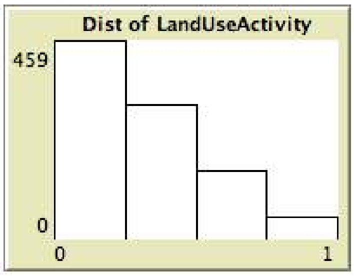
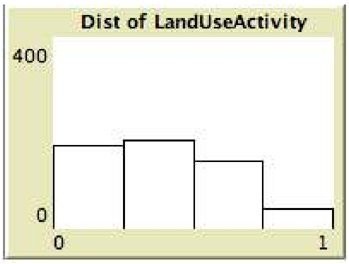
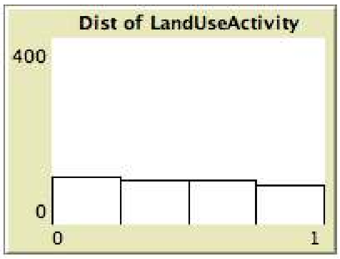
〈Table 4〉 Development Rate

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">TPR (Costs)</th></tr>
<tr><th>On</th><th>OFF</th></tr>
<tr><td rowspan="2">Activity Potential (Benefits)</td><td>On</td><td>Simulation #1 (base case)
Average Max Traffic: 8

</td><td>Simulation #2
Average Max Traffic: 8

</td></tr>
<tr><td>Off</td><td>Simulation #3
Average Max Traffic: 11

</td><td>Simulation #4
Average Max Traffic: 11

</td></tr>
</table>

Result 4) Traffic Levels

Figure 5 shows the maximum Traffic value for Corridor patches during the simulation. (We exclude Intersection patches because they have much greater Traffic values than normal Corridor patches.) In the simulations that have greater dispersal of new developments (Simulations #1 and #2), the maximum Traffic value decreases over time. This is expected because when Citizens spread out to reach goals over more space, traffic is less concentrated on specific corridors. In contrast, in the simulations without dispersed development (#3 and #4) have higher and more stable Traffic values over time because as agent goals are concentrated in a smaller area.

〈Table 5〉 Maximum Traffic Levels

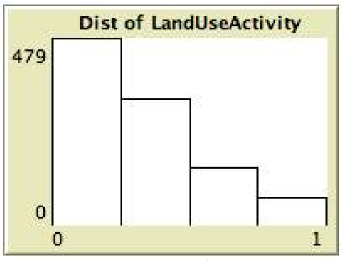
<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">TPR (Costs)</td></tr>
<tr><td>On</td><td>OFF</td></tr>
<tr><td rowspan="2">Activity Potential (Benefits)</td><td>On</td><td>Simulation #1 (base case)

</td><td>Simulation #2

</td></tr>
<tr><td>Off</td><td>Simulation #3

</td><td>Simulation #4

</td></tr>
</table>

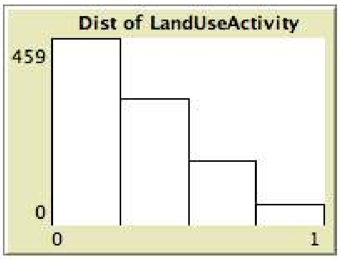
Result 5) Land Use Utilization

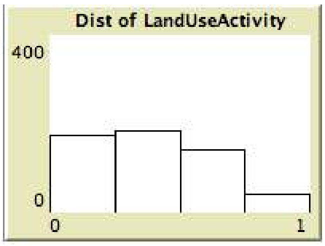
Land use utilization was not a pre-defined performance metric for the simulation tests. This metric was captured as part of debugging how the Activity variable for Land Use patches may be influencing the system. It turned out to be an interesting measure, and thus we include it in our results. For this measure, the Activity variable is converted to a 0 to 1 scale with zero being no activity levels and 1 being patches with the highest activity levels. The distributions of this measure for developed Land Use patches are shown in Table 6.

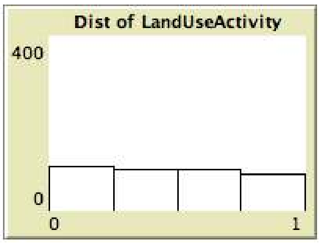
We see that in the simulations with higher development rates and greater dispersion of development (#1 and #2), there are a small number of patches with very high activity counts and a great deal of patches with very low activity counts. These simulations have low efficiency of land use utilization. In contrast, the simulations with lower development rates and less dispersion do not have a large share of developed-but-not-visited land use patches. The concentrated development pattern leads to more efficient use of developed land.

〈Table 6〉 Land Use Utilization

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">TPR (Costs)</td></tr>
<tr><td>On</td><td>OFF</td></tr>
<tr><td rowspan="2">Activity Potential (Benefits)</td><td>On</td><td>

Simulation #1 (base case)</td><td>

Simulation #2</td></tr>
<tr><td>Off</td><td>

Simulation #3</td><td>

Simulation #4</td></tr>
</table>

Ⅳ. Conclusion

The impact of the TPR on development in Oregon is widely debated. Our real-world evidence that the TPR yields lower development rates and discourages infill development comes anecdotally from discussions with professional and academic planners in the region. Quantitative evidence of development failure due to TPR constraints is not available. Our model may exhibit behavior of the TPR producing lower development rates and development deflected away from existing high-activity patterns per our qualitative information.

However, the interaction rules to generate this behavior include gross assumptions and do not feel sufficiently interesting to generate new insights about the processes involved. Instead, the model seems useful as a starting point from which to experiment with more nuanced interaction rules. For example, the model makes clear that the benefits of a cost-benefit analysis are potentially more important than the costs. We assume that developers are attracted to potentially high activity levels, but do not understand how behavior such as speculation or response to incentives may work. Similarly, both the goal-assignment of citizen agents and their path-finding may benefit from using multi-criteria decision making, congestion-avoidance, and mode-choice to show behavior with greater applicability to real-world situations. And finally, it is obvious that the size of the 55x57 simulated city is not large enough to capture diversity of neighborhood-level versus regional-level interactions.

Agent-based models (ABMs) for travel demand analysis has emerged since 2000. In particular, as a paradigm of travel demand modeling shifts from trip-based models to activity-based models, ABMs will be a promising approach because of their ability to explicitly capture interactions of person-to-person, person-to-environment, and environment-to-environment (Pinjari and Bhat, 2010). For example, in the context of the activity-based approach to travel demand, intra-household interactions are one of the most important modeling components. Individual members of a same household share its resources such as vehicles; they allocate their own time to household maintenance activities such as grocery shopping; they escort children or the elderly in the houseold; and they jointly participate in out-of-home activities. Another example of the person-to-person interactions is a social network analysis, which is an emerging research area. Existing travel demand models do represent social and leisure activities that individuals undertake, and joint activities within households are also captured. However, there is no activity-based model taking an individual's social network into account, even if the social network influences several aspects of activity and travel patterns, for example, activity generation and scheduling, destination and route choice, etc. (Pinjari and Bhat, 2011).

Further, transportation modelers seek to "truly" integrate transportation and land use models. There are some operating land use models based on agent-based simulation, such as UrbanSim (Waddell, 2002). However, existing travel demand models take socioeconomic and spatial data from such agent-based land use models into an exogenous input; that is, there is no interaction between land use inputs and transportation outputs. In this sense, it is possible, and widely expected, that ABMs carry the potential to improve the integration of land use and transportation through their explicit modeling of the person-to-environment interactions.

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