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Agent-based Models in Supporting Pedestrian Transportation Planning and Design

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Abstract

Agent-based models offer a new approach to understanding human-urban interactions in transportation systems, allowing individual entities within a system to be characterized with cognitive and behavioral properties. This paper discussed the role of agent-based representations of pedestrian transportation systems, detailing the underlying assumptions and techniques behind different types of pedestrian models and illustrating the differences between aggregate and individual agent representations. It then turns attention to the case study and the development of a cognitive pedestrian model as a way to illustrate the spectrum of potential spatial behaviors that are enabled by material changes to the transportation network. The paper concludes with a discussion and specific frameworks for employing agent-based models to support transportation planning decisions.

Cities across the country are struggling with how to best address a network of street infrastructure that in many ways opposes shifting views of public health, urban transportation, and environmental sustainability. Many scholars advocate for a "complete street" design that enables safe access for all modes of transportation, maintaining that inclusive changes to street infrastructure can address the spatial mismatches in contemporary cities, while increasing the public safety and walkability of neighborhoods (Ewing et al. 2006; Schlossberg 2013). The design of walkable neighborhoods and pedestrian-oriented spaces are often portrayed as simple, solution-based approaches to redevelopment that can address myriad structural and social issues in the city (Speck 2012), and scholars emphasize deeper engagements between street infrastructure and human-scale pedestrian behaviors can form a strong theoretical foundation for more sustainable urban practices (Kenworthy 2006). As the public becomes increasingly aware of walkability as a measure of urban health, scholars and practitioners are beginning to focus more attention on both the structural elements of pedestrian-oriented design as well as the human experiences in practices of walking.

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Despite the need for pedestrian-oriented redevelopment, transforming existing street infrastructure is not a straightforward process, and the human responses to such changes are complex, dynamic, and plural. Modernist approaches to planning and design have embedded a set of automobile-oriented values into our collective urban imagination, bracketing our concept of streets and rendering alternative configurations and uses difficult to imagine (Forsyth and Southworth 2008). These embedded values often lead to confusions about the impacts of proposed changes among a variety of local stakeholders; thus, many redevelopment projects proposing to transform existing street infrastructure are met by the public with a great deal of confusion, often interrupting, delaying, or fostering resentment towards the proposed changes.

The paper will first discuss the history and context of agent-based models in pedestrian and human movement studies, with a particular focus on how different goal-oriented modeling frameworks have been implemented in the urban context and how these illustrate different types of movement scenarios. Next, a case study of a redevelopment project in the South Willamette Street corridor of Eugene, OR, will be introduced, highlighting both the need for changes to street infrastructure as well as alternative configurations to meet this need. Next, an agent-based model design is described using the ODD protocol (Grimm et al. 2010) that incorporates data-driven cognitive capabilities in pedestrian agents, interacting in a simulated environments matching the redevelopment proposals for South Willamette Street. The results of the model simulations illustrate the need for behavioral approaches to agent design, highlighting how the concept of individual cognitive capabilities can be incorporated into computational representations of transportation systems. Additionally, the results show how official assessments of redevelopment scenarios may be seriously limited in understanding the human impacts of changes in the built environment. The paper concludes with an extended discussion about agent-based modeling frameworks for supporting transportation planning and best practices for representing the individual spatial behaviors of pedestrians.

AGENT-BASED MODELS IN PEDESTRIAN STUDIES

Many sustainable transportation scholars advocate for the redesigning of city streets as a primary way to address issues from the local to the global scale, proposing that pedestrian-friendly configurations of street infrastructure can have a positive impact on issues ranging from citizen health to climate change (Forsyth and Southworth 2008; Speck 2012; Southworth 2014). Though pedestrian movement is a complex and difficult behavior to model (Whyte 1988), understanding how people move through space has important implications in practices of architecture, urban design, emergency management, and public safety. An agent-based modeling approach to investigate pedestrian movement often provides more flexibility, usability, and behavioral realism than traditional statistical or network optimization models (Torrens 2003). One unique benefit of an agent-based modeling platforms is the ability to understand how system-wide patterns emerge from a collection of individual behaviors and interactions, often producing results and insights that would be difficult to come by from the collection of the individual parts (Manson 2001; Bennett and McGinnis 2006).

Despite the ability to represent the heterogeneous behaviors of individuals, agent-based models are rarely employed in analysis and discussions about everyday individual pedestrian practice. This, in la is due in large part not to

exclusion by urban and transportation planners, but rather because the predominant way to represent pedestrian agents is rather narrow and limited. Many agent-based pedestrian models parameterize, or define agent behaviors, in collective rather than individualistic terms (Raubal 2001; Helbing et al. 2005; Bitgood and Dukes 2006; Torrens 2012). While collective representation may be best suited for planning issues at regional scales (Ligtenberg et al. 2004), aggregating individuals in pedestrian modeling often fails to capture the individual social motivations and cognitive processes of pedestrian behaviors. Thus, the use of generalizable agents is an appropriate representation for just two specific types of pedestrian behaviors: wayfinding models and evacuation models.

Pedestrian wayfinding models (see e.g., Raubal and Worboys 1999; Turner and Penn 2002; Antonini et al. 2006) typically use a stimuli-response framework to represent pedestrian movement, creating a set of causes and effects within the environment based on agent perceptual and physiological abilities. For example, an agent within the model environment perceives an environmental feature (e.g. a landmark) and responds with a specific behavior (e.g. turn right) in order to meet a defined goal. This approach focuses on the optimization of energy and spatially dependent variables as the catalyst for agent movement across the model landscape. In other words, agent perception of the environmental affords the planning and execution of rational, goal-driven actions (Torrens 2010). Portugali (2011) argues this approach to modeling pedestrian movement, while productive in certain scenarios, embeds agents with unrealistic motivations and abilities that lead to uniform and often inflexible representations of human behavior. While models with this design have been quite effective in representing pedestrian behavior in relatively static and single-purpose spaces, such as navigation through an airport terminal (Raubal 2001) or a shopping mall (Bitgood and Dukes 2006), they are limited in capturing broader and dynamic everyday pedestrian activities by assuming all agents to be rational, goal-oriented, and equal in abilities such as locating, encoding, and using salient environmental features in decision-making.

A second common type of pedestrian modeling using group-defined behaviors is extreme event or scenario-based models, such as emergency evacuation from a building or crowd flows at a festival (see e.g., Batty et al. 1998; Helbing et al. 2001; Shao and Terzopoulos 2005). Many scenario-based models are driven by agents perceiving and mimicking the movements of other agents, resulting in a sort of flocking behavior that creates an aggregated flow of people across space. This type of collective movement is typically referred to as a physics design (Helbing et al. 2005) in which individuals are treated as outwardly or physically reactive to environmental stimuli. As a result, computational resources focus primarily on physiological aspects of movement, such as steering, collision avoidance, and soft-body dynamics (Torrens 2012), producing realistic-looking but not necessarily realistic-behaving gamified pedestrian agents. Typically, these models represent agents homogenously in order to understand how crowds may react in certain situations or in response to different aspects of the built environment.

Homogenous agent design, however, limits the range of potential behavioral outputs that may prove more insightful both in understanding individual agency as well as the complexities of the whole system (Johansson and Kretz 2012). In moving towards expanding the role of agent-based modeling in support of urban and transportation planning, this paper advocates

for increased attention in representing humans as more than goal-oriented, rational, and reactive entities. To understand pedestrians beyond the limits of discrete and place-specific environments, we must work towards deeper representational frameworks that embody individual abilities and agencies rather than the collective representations common in many human-movement models. To explore this potential, I turn now to a case study of the South Willamette Street corridor in Eugene, Oregon, which is currently in the process of redevelopment with a particular focus on complete-street design to creates pedestrian friendly spaces and a walkable neighborhood.

STUDY AREA AND RESEARCH CONTEXT

South Willamette Street is typical of many streets in cities across the country—a car dominated arterial street intersecting a medium-density neighborhood with multiple modes of transportation competing in a limited space. In December 2013, the city of Eugene proposed the South Willamette Street Improvement Plan to improve an eight-block stretch of transportation infrastructure was in need of repair (Figure 1). The current configuration of a four-lane roadway with numerous driveways, obstructed and inaccessible sidewalks, and little bicycle or public transit facilities creates a relatively congested, disjointed, and, many argue, unsafe environment for pedestrian travel:

> "South Willamette Street is a multimodal corridor with a mixture of facilities to serve automobiles, bicycle, pedestrian, transit, and freight users. The challenge of providing mobility and accessibility to all users is managing various conflicts that arise, such as bikes and automobiles at driveways and turning trucks blocking travel lanes" (City of Eugene 2014).

In addition to addressing issues of multimodal interaction, redevelopment of South Willamette Street must meet the overlapping guidelines put in place by multiple agencies over the past two decades, including the Eugene Arterial and Collector Street Plan, the Eugene-Springfield Transportation Plan, and the Eugene Pedestrian and Bicycle Master Plan, resulting in a relatively unclear long-term vision for the space. Recognizing the need for redevelopment but without a clear framework of how to design, implement, and evaluate the impacts of the proposed changes on the transportation system in this short corridor, the city enlisted a private environmental consulting firm to assess the potential impacts of street improvement under a "triple-bottom-line approach to sustainability, providing for consideration of people, the planet, and prosperity" (City of Eugene 2014: V). Subsequent analysis proved inconclusive and city officials entered public meetings with a collection of alternative concepts for South Willamette Street and little insight into how the proposed changes may impact, among other things, pedestrian behavior. In order to better understand how pedestrians may be impacted by structural changes in the built environment, and specifically the impacts of each of the six conceptual alternatives, this paper introduces the design and analysis of an agent-based model to evaluate the relationship between redevelopment and everyday pedestrian behaviors.

METHODS

The purpose of the pedestrian and redevelopment (PAR) model is to represent a simple multi-agent pedestrian model street network to explore the effects of different municipal redevelopment plans in a simulated urban environment. Specifically, the PAR model explores the how six different conceptual alternatives

Figure 1. The South Willamette Street corridor, highlighting proposed changes between 24th and 32nd Ave. Pictures indicate the current state of the street infrastructure. Map: City of Eugene 2014. Photos: Julie Stringham 2016.

of the South Willamette Street corridor will impact a population of realistic pedestrian agents. The population of the PAR model is filled with agents who are parameterized with artificial different levels of spatial cognition, parameterized with data generated from a set of psychometric test. As cognitive variables are intangible constructs, they are difficult to directly measure. As such, psychometric test are commonly used to measure an individual's cognitive capabilities and preferences, strengths and weaknesses, and overall task completion strategies (Hegarty and Waller 2005).

This study uses five distinct cognitive variable sto construct the agent spatial intelligence: spatial memory, non-metric location coding, metric

location coding, path integration, and spatial reference frame. Spatial memory is an agent's ability to remember the location of objects while moving through the environment (McNamara 2002) and is measured with a 15-question sense of direction psychometric test (Hegarty et al. 2002). The cognitive variable non-metric location coding is the agent's ability to use the egocentric, first person perspective to perform a piecemeal updating of the environmental frame of reference (Wang and Brockmole 2003) and is measured with a 14-question self-location psychometric test (Lobben 2004). The cognitive variable metric location coding is the agent's ability to use the allocentric perspective to perform global updating of the environmental frame of reference (Holden and Newcombe 2013) and is measured with a 12-question environmental perspective psychometric test (Lobben 2007). The cognitive variable path integration is the agent's ability to maintain a sense of place recognition and direction of movement within an environment to create efficient routes (Loomis et al. 1999) and is measured with a 65-question spatial engagement survey (Cherney and Voyer 2010). The cognitive variable spatial reference frame is an agent's ability to use move between an egocentric and an allocentric perspective when conceptualizing the environment (Taylor and Brunyé 2013) and is measured with a route-planning test (Lobben 2004).

The suite of cognitive test was administered to 42 participants in July 2015. Rather than using the direct scores to parameterize the agents in the model environment, participant data is reduced with a principal component analysis to find a new set of desirable variables that efficiently represent the information in the original participant dataset. The principal component analysis reduces the individual cognitive properties of the 42 participants down to 4 primary groups based on performance across the 5 psychometric tests.

Group 1 (54%) exhibits high scores in the spatial memory and metric location coding tests, indicating a strong ability to remember the location of objects in the environment and use an allocentric or top-down perspective. Group 1 is classified as *purposeful walkers* to represent objective-driven pedestrians in the model environment. Group 2 (26%) exhibits high scores in non-metric location coding and spatial reference frame, indicating a strong ability to use an egocentric or first person perspective. Group 2 is classified as *social walkers* to represent more-than objective-driven pedestrians. Group 3 (13%) exhibits strong performance in across all tests and is classified as *experiential walkers* to represent individuals who shift between objective-driven and more-than objective driven practices. Group 4 (7%) exhibits low scores across all tests as is classified as *wanderer walkers* to represent random pedestrian behaviors. Each pedestrian type uses a different submodel to direct individual movement in the model environment.

It should be noted the classification of agent types from cognitive data for this particular set of simulations is not to say participants classified a certain way will exhibit the associated capabilities, strategies, and behaviors during all pedestrian activities. Rather, cognitive performance at any given time relies on a multitude of factors, many of which are immeasurable with psychometric test. Rather the data indicates that during this discrete set of test, participants exhibited a set of cognitive capabilities across multiple measures, which can be classified into pedestrian types for the purpose of coding the model and making a more meaningful representation of a heterogeneous population within the model environment.

During model setup, agents are assigned one of the 4 pedestrian types based on the proportion of variance for each principal component. The cognitive capabilities of the agents for each

of the 5 cognitive variables are assigned using a random value within one standard deviation of the mean for each pedestrian type, allowing the population of the model environment to scale up from the number of participants while maintaining realistic human cognitive capabilities in the agents.

The PAR model environment is a horizontally oriented five-block by three-block urban streetscape populated with cognitive pedestrian agents, private automobiles, and bicycles. Automobiles and bicycles travel along the gridded road network at various rates of speed, stopping at traffic signals and operating unaware of the pedestrian agents. The spatial resolution of the PAR model is 1 pixel = 20 feet and the temporal resolution is 1 time step = 2 seconds. Each simulation runs for a total of 2500 steps. Grid cells are classified as street, sidewalk, crosswalk, or development, based on the spatial configurations of the various conceptual alternatives for redevelopment, and remain constant over the course of each simulation.

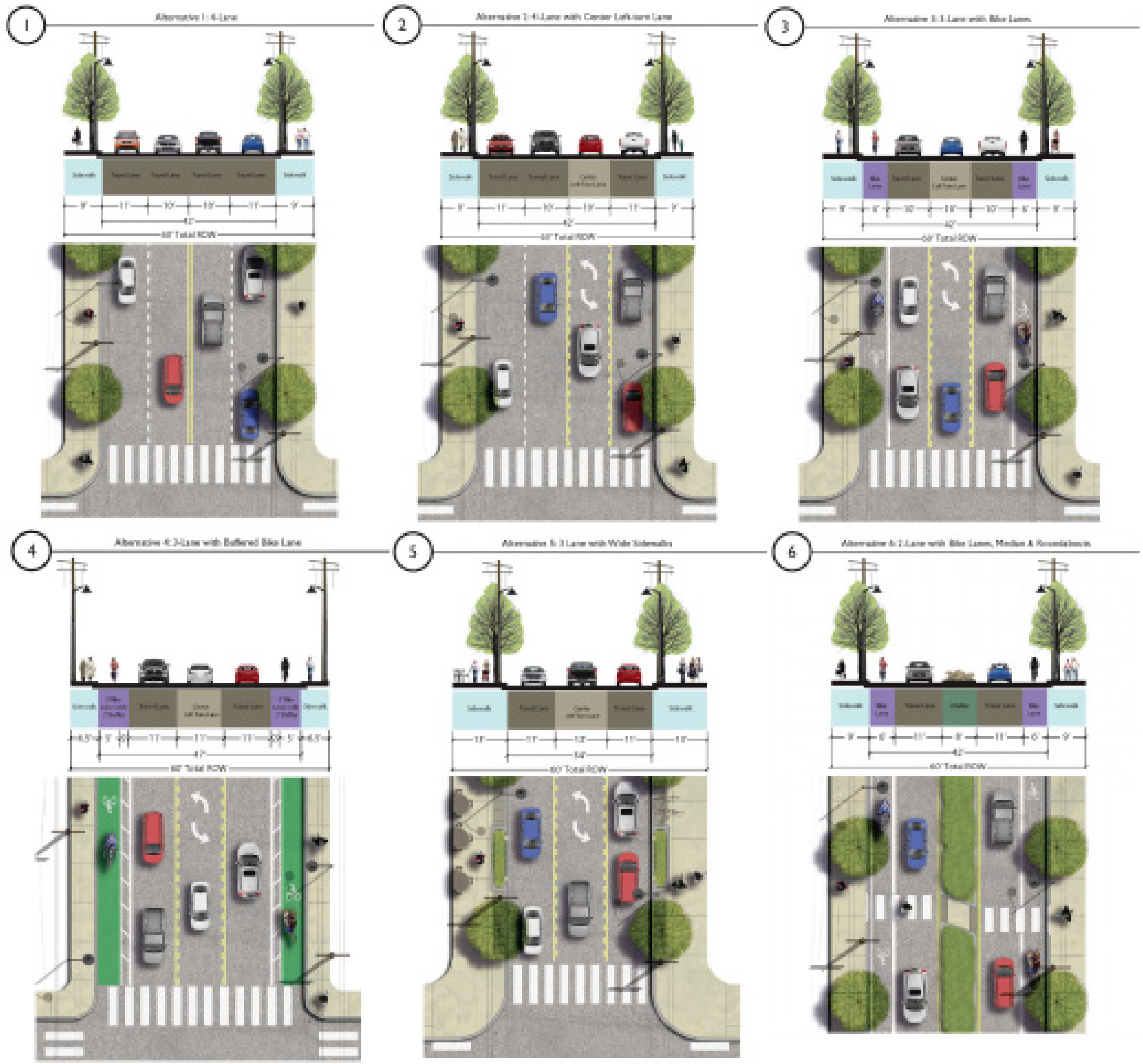
Process Overview and Scheduling

The PAR model measures how each agent moves through the environment and interacts with the different features of proposed redevelopment. Different rule-based spatial movement submodels for each pedestrian type drive this human-urban interaction and the model directly measures how the agents respond to structural change in the built environment. The model environment can be altered with four parameters highlighted by qualitatively coding the six conceptual alternatives for street redevelopment outlined in the proposed South Willamette Street Improvement Plan.

The South Willamette Street Improvement Plan is a redevelopment strategy to improve the eight-block stretch of transportation infrastructure in Eugene, Oregon. In November 2012, six conceptual alternative configurations (Figure 2) of South Willamette Street was introduced to the public to create a strategy by the second meeting to evaluate each of the alternative designs. During the second meeting, both the Eugene City Manager and the Transportation Community Resource Group endorsed a formal screening criterion to quantitatively evaluate the alternative concepts, focusing on social, environmental, and economic impacts of redevelopment.

The formal screening criteria calculated scores from the six conceptual alternatives on 23 different measures across eight categories—*Access and Mobility, Safety and Health, Social Equity, Economic Benefit, Cost Effectiveness, Climate and Energy, Ecological Function, and Community Context*; 18 of the identified measures received a score as part of the formal assessment (Table 1). The formal assessment used a quantitative assessment, coding values of -1 to indicate negative changes, 0 to indicate no change, and +1 to indicate positive change. The sums of scores across all 18 measures create an index to evaluate the impact of each alternative concept.

The primary concern with this assessment is the assumption all variables have equal impact on the system as a whole. Rather than follow assumptions of linearity and accept that all inputs have equal weight on the final output, the PAR model allows for a more in-depth and nuanced exploration into the various combinations as well as the nonlinear processes that may indicate the relative strength of different variables; how unique combinations or arrangements of redevelopment practices could produce unexpected outcomes to the pedestrian agents in the model. The model environment is parameterized by qualitatively coding the 18 established measures into four categories that reflect the type of structural change—dimensional changes,



Conceptual Alternatives (Tier 1)

Figure 2. The six alternative concepts proposed by the city of Eugene to redevelopment South Willamette Street between the 24th and 32nd Streets. Source: City of Eugene 2014.

public safety improvement, economic benefit, and community support. Classification of each of the six alternative concepts creates a set of environmental values that are coded directly into the PAR model environment based on the scores from the official assessment across the four coded categories, creating six model environments based on municipal plans. In additional to the six alternative concepts, a parameter sweep is run by iteratively changing each variable by .1 while keeping all other variables constant in order to understand how the pedestrian agents respond to each environmental parameter

A different movement submodel drives the behaviors for each agent type in the PAR model. *Purposeful walkers* use a wayfinding submodel in which each agent perceives discrete environmental features, such as a landmark or a specified

Table 1. Qualitative coding of the 18 measure assessment performed by the City of Eugene. Green indicates dimensional variables, yellow public improvement safety variables, blue economic benefit variables, and pink community support variables.

Design Concept		1	2	3	4	5	6
Access and Mobility	Neighborhood connectivity			1	1		1
	Motor vehicle travel time			-1	-1	-1	-1
	Active mode travel time			1	1		1
Safety and Health	Safety			1	1	1	1
	Security			1	1	1	1
	Emergency response			-1	-1	-1	-1
Social Equity	Equity			1	1	1	1
	Economic access			1	1	1	1
Economic Benefit	Freight mobility			-1	-1	-1	-1
	Walkable/bikeable			1	1	1	1
	Business vitality		1				-1
Cost Effectiveness	Fundability	1			-1	-1	-1
	Assett management	1	1	1	1	1	1
	Project benefits	1	1	1	1	1	1
Climate and Energy	Pedestrian facilities				-1	1	
	Bicycle facilities			1	1		1
	Transit facilities					1	
Community Context	Community vision				-1	1	
Total		3	3	7	4	6	5

intersection, and responds with a behavior to meet a goal (see e.g., Raubal 2001; Turner and Penn 2002; Antonini et al. 2006). The wayfinding submodel represents individuals engaging in directed, purposeful walks between two points in the environment. *Social walkers* use an entity-interaction submodel in which local interactions with other *social walkers* is reinforced, causing small groupings of agents over time (Vicsek et al. 2008). The entity-interaction submodel represents individuals moving through the environment with intentions of being social with other individuals, rather than navigating to a specific location. *Experiential walkers* uses a localized search submodel (O'Sullivan and Unwin 2010) in which interactions with particular environmental features creates a positive feedback for the agents, motivating them to visit the location again during the model run. The localized search model represents individuals moving through and learning about desirable places in the environment to revisit for non goal-driven reasons, but rather because they are enjoyable or beneficial for whatever reason. *Wanderer walkers* use a random walk in which movement is not guided by anything but random decision-making, representing individuals who simply walk through the environment.

RESULTS AND DISCUSSION

Part 1: Representing Human Pedestrians

Due to the complexity and difficulty of modeling human movement, many computational pedestrian models strip away elements of individual agency, favoring the representation of human agents as responsive or reactive to external environmental variables. The PAR model uses a data-driven approach to code cognitive variables as means to represent individual agency in the model, aiming to achieve a deeper and more complete representation of human capabilities (O'Sullivan 2008). Parker et al. (2003) state, "the term cognition ranges in applicability to situations ranging from relatively simple stimulus-responses decision making to the point where actors are proactive, take initiative, and have larger intentions" (317). In the PAR model, cognition is conceived of as a high-level function, which guides the classification of the pedestrian type submodels and the individual level interactions between environmental features and agents. Model simulations under baseline conditions revel how the different data-driven pedestrian types respond and interact with different environmental variables through the course of pedestrian movement (Figure 3).

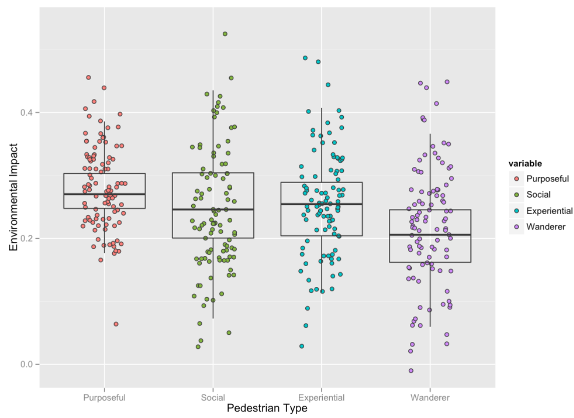


Figure 3. Impact of baseline environmental conditions across four walker types.

Incorporating a range of pedestrian cognitive capabilities into an agent-based modeling frameworks echoes the theoretical approaches of behavioral geographers, who argue that understanding different types of human decision-making processes and observable spatial movements in the environment is best known from the study of individual differences in the internal or cognitive processes (Golledge and Stimson 1997). Mark et al. (1999) provides a framework to understand how individuals perceive, cognitively transform, encode, and articulate the perceived external world. The first step in this theory of spatial knowledge acquisition is the sensory perception (sight, sound, touch, etc.) of the external environmental by an individual (this is the stage in which the majority of pedestrian models stop). The external perception of the world is then internally transformed into a mental representation of the environment. The quality, extent, and completeness of the transformation from external to internal varies from person to person based on a multitude of cognitive, sociocultural, biophysical, and spatiotemporal factors. The mental representation, or individually constructed knowledge of the environment, is then used in a decision-making process. Knowledge use again varies dramatically from person to person, ranging from subversive to goal-oriented motivations. Finally, spatial knowledge is articulated and communicated either through language, movement, or another type of spatial behavior. This framework provides a clear way to define the cognitive capabilities of each agent type in the model environment (Table 2).

An agent-based modeling platform provides the opportunity to explicitly model cognitive processes and to orient pedestrian representations towards more human-centered approaches. As opposed to generalizable representations of pedestrians, agent-based models allow for the investigation of pedestrian practices based on a

Table 2. Pedestrian types classified in a spatial knowledge acquisition framework.

Agent	Perception	Mental Representation	Knowledge Use	Communication
Purposeful	Vision	Rational	Optimization	Wayfinding Walk
Social	Vision	More-than-rational	Attraction and repulsion	Entity-interaction
Experiential	Vision	Cognitive map	Self constructed	Localized Search
Wanderer	Vision	Ephemeral	Impetuous	Random Walk

multitude of motivations, capabilities, emotional states, and past experiences. In this sense, agent-based modeling can help address the 'wicked' problem of transportation planning and, more specific to pedestrianism, of how to balance the technical and human components of a system.

Modeling pedestrian behavior from a human-centered perspective provides an entry point to understand and analyze the relationship between the conceptualized spaces of scientist, planners, and architects and the lived spaces or users and inhabitants (Lefebvre 1991). A human-centered approach is to embrace the individuality of the human subject, endowing the individual with agency as a way to link human and artificial representations in an analytical framework. Heterogeneous agent representations embrace the concepts of individual differences in cognitive capabilities and the myriad of social motivations inherent to human-centered planning practices. Alternatively, reducing human agency to the most technical and generalizable of terms, as is the case with the majority of pedestrian agent-based models, embraces a configurational planning approach (Sepe 2010) that focuses on the structural aspects of the environment, which, in most cases, is likely better represented by the more traditional statistical, site-suitability, or linear models. With elements such as memory, cognition, adaptation, mental maps, and changing motivations, human elements of everyday pedestrianism can easily be incorporated into an agent-based modeling framework.

Part 2: Impacts of Redevelopment on Pedestrians

In addition to illustrating differences in agent behavior, the PAR model is also able to explore the human impacts of different structural elements. The city identified 18 separate measures which were critical to evaluate to understand the impacts of the redevelopment, which, for the purpose of this analysis, were reduced to four primary categories that reflect the type of structural change: dimensional changes, public safety improvement, economic benefit, and community support. Dimensional changes include the variables of neighborhood connectivity, motor vehicle travel time, active mode travel time, and walkable/ bikeable business district. The defining feature of this classification is the effect of the change in configuration or dimensions of the material environment on different modes of movement. The results from the model indicate that iterative changes to the dimensions or configurations to the material environment has a positive impact on *purposeful walkers*, but has little to no effect on other types of pedestrian practices (Figure 4).

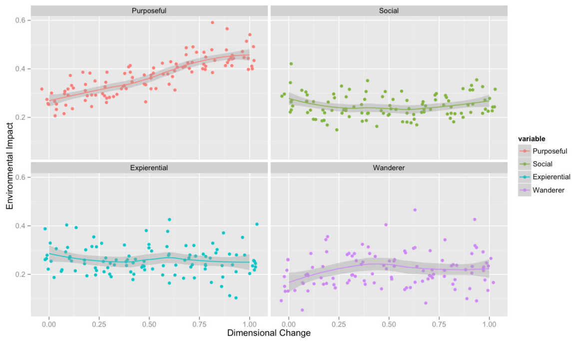


Figure 4. Impacts of dimensional changes on different pedestrian types.

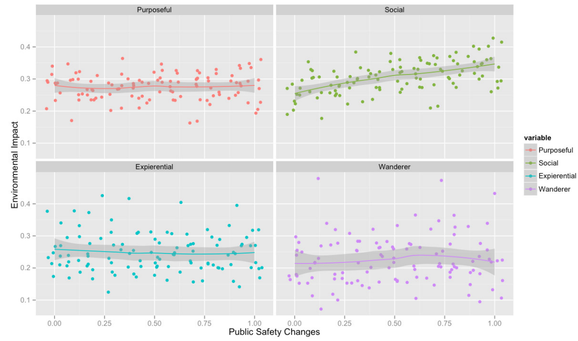


Figure 5. Impacts of public safety changes on different pedestrian types.

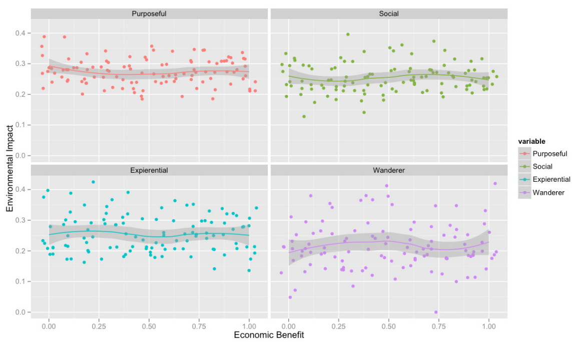


Figure 6. Impacts of economic benefit changes on different pedestrian types.

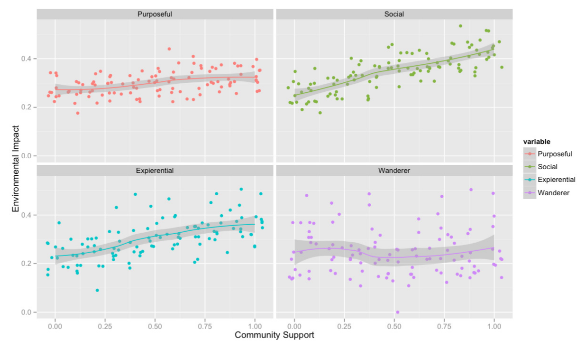


Figure 7. Impacts of community support changes on different pedestrian types.

The category 'public safety' improvements include the variables safety, security, and emergency response. Safety and security indicate the speed and proximity of private automobiles on the road network, whereas emergency response refers to the interactions of emergency service vehicles with other entities in the network. The results from the model indicate that iterative changes to the safety of the environment has a small positive impact on *social walkers*, but has little to no effect on other types of pedestrian practices (Figure 5).

The category 'economic benefits' includes the variables freight mobility, business vitality, fundability, asset management, and project benefits. These variables measure both the business related impacts as well as the financial burden on the city of redevelopment. The results from the model indicate that iterative changes to economic benefits, as measured by the official assessment, have little to no effect on any of the pedestrian types (Figure 6).

The category 'community support' includes the variables equality, economic access, pedestrian facilities, bicycle facilities, transit facilities, and community vision. These variables measure the ways in which redevelopment supports community goals and provides facilities and access across a wide range of citizens and individual practices. The results from the model indicate

Table 3. Weighting table for all variables and pedestrian types.

	Purposeful	Social	Experiential	Wanderer
Dimensional	3.3215	-0.01435	-0.6428	0.6251
Safety	0.259	3.4821	-0.3378	0.2984
Economic	-0.3202	0.3535	-0.1809	0.08159
Community	2.7184	3.1685	2.3398	-0.07749

that iterative changes to community support have a positive impact on *social walkers* and *experiential walkers*, a small positive impact on *purposeful walkers*, and little to no effect on *wanderer walkers* (Figure 7).

The analysis of this model most clearly reveals that the original assessment by the city of Eugene assumes all citizens will respond equally to changes, and the binary metrics used to evaluate the six conceptual alternatives in the official assessment misrepresents the impacts of each redevelopment variable on pedestrians. To correct this assumption, this paper uses a linear regression analysis between each redevelopment variable and each pedestrian type to create a weighting chart for a more detailed and refined assessment of the different conceptual alternatives (Table 3).

The weighting table is combined with the formal assessment by the city of Eugene and the distribution of people from the principal component analysis of pedestrian types to evaluate the impact of each redevelopment on a heterogeneous population of pedestrian citizens. With this approach, the impact of each conceptual alternative is measured in human-centered terms, giving considerably more attention to the range of pedestrian practices and being inclusive of individual differences within the population (Table 4).

The results of the model find two important considerations not calculated in the official assessment of South Willamette Street. First, not all variables are equal when considering the range of pedestrian practices within the redevelopment space; the variables of community support and dimensional changes have a much more significant influence on pedestrians in the system than the variables of public safety and economic benefit. The model analysis also reveals that in the redevelopment of pedestrian spaces, design practices focusing on network connectivity, non-automobile facilities, and inclusive or evenly distributed development are essential changes. Often the issues of public safety and business

Figure 8. Example of economic benefit and public safety being linked in opposition to redevelopment. Photo by Author.

Table 4. Human-centered assessment of alternative redevelopment concepts. Green indicates dimensional variables, yellow public improvement safety variables, blue economic benefit variables, and pink community support variables.

Alternative		1	2	3	4	5	6
Access and Mobility	Neighborhood connectivity			1.770	1.770		1.770
	Motor vehicle travel time			-1.872	-1.872	-1.872	-1.872
	Active mode travel time			1.770	1.770		1.770
Safety and Health	Safety			0.854	0.854	0.854	0.854
	Security			0.854	0.854	0.854	0.854
	Emergency response			-0.570	-0.570	-0.570	-0.570
Social Equity	Equity			2.614	2.614	2.614	2.614
	Economic access			2.614	2.614	2.614	2.614
Economic Benefit	Freight mobility			-0.248	-0.248	-0.248	-0.248
	Walkable/bikeable			1.770	1.770	1.770	1.770
	Business vitality		0.313				-0.248
Cost Effectiveness	Fundability	0.313			-0.248	-0.248	-0.248
	Assett management	0.313	0.313	0.313	0.313	0.313	0.313
	Project benefits	0.313	0.313	0.313	0.313	0.313	0.313
Climate and Energy	Pedestrian facilities				-0.367	2.614	
	Bicycle facilities			2.614	2.614		2.614
	Transit facilities					2.614	
Community Context	Community vision				-0.367	2.614	
Total		**0.939**	**0.939**	**12.795**	**11.813**	**14.234**	**12.300**

vitality are linked together and serve as the main focus of discussion, both in arguments supporting and opposing larger redevelopment projects. The analysis shows arguments within this framing likely fail to capture the actual impacts on pedestrian movement within redevelopment spaces (Figure 8).

Additionally, the new assessment illustrates the impact of each conceptual alternative on pedestrians are not even across all types of walkers, and assumptions of homogenous or uniform impacts from the identified redevelopment variables neglects many of the individual and human-centered elements of pedestrian practices. The results from the official assessment of the conceptual alternatives ranked option three highest, and the redevelopment of South Willamette Street to meet these specifications is set to begin in Summer 2016. While there are multiple variables and modes of transportation to consider when evaluating the redevelopment of South Willamette Street as a whole, the results from this analysis ranks option five as the highest (Figure 9).

This analysis does not suggest option five is superior to option three, nor is it meant to predict how a broader sense of walkability will change from these different structural arrangements. Rather, the analysis of the PAR model shows the strengths and weaknesses of the

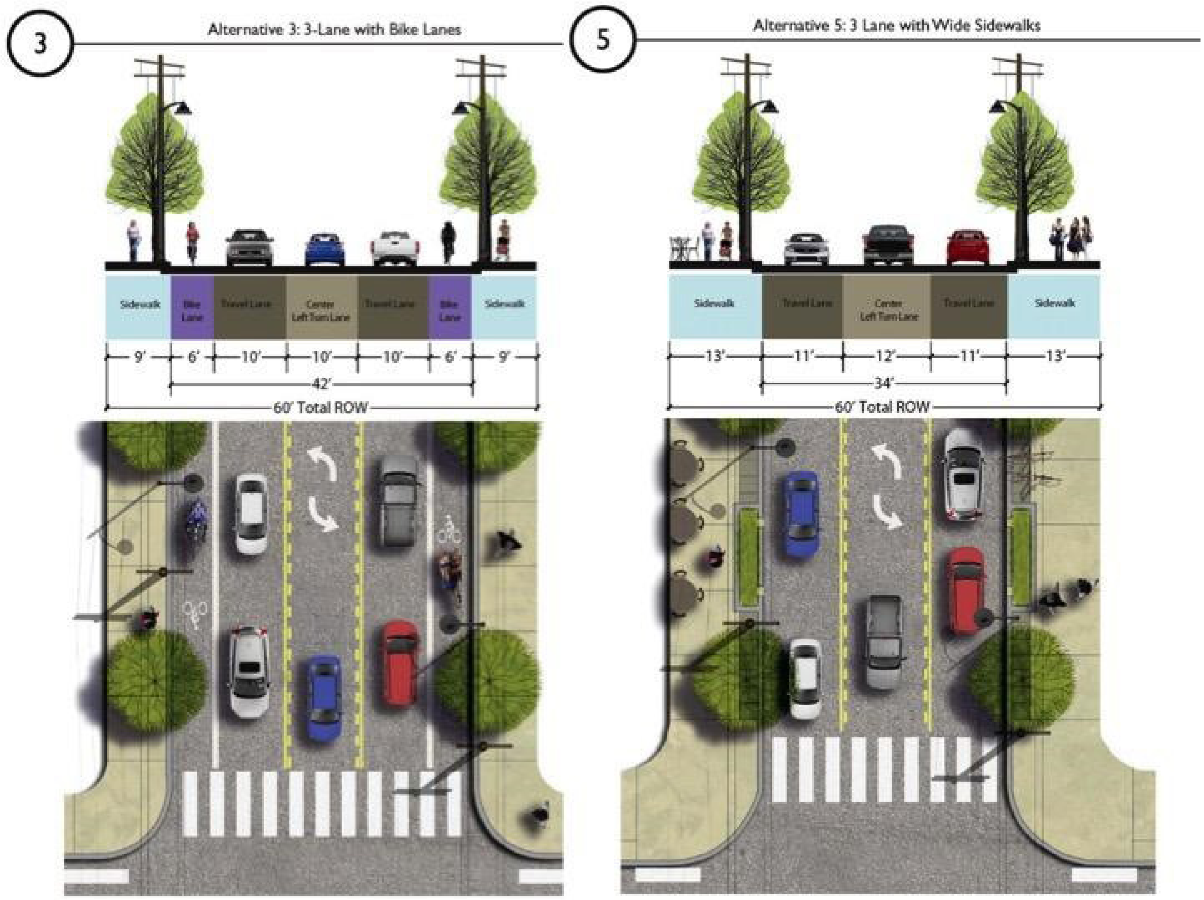


Figure 9. Side by side comparison of alternative concept three and five for the redevelopment of South Willamette Street. Source: City of Eugene 2014.

alternative concepts in a more nuanced and thoughtful way, disrupting assumptions about the impact of different environmental variables on a representative population of individual pedestrians and providing clues pertaining to the most important variables to consider when designing pedestrian-friendly spaces in multimodal corridors. While options three and five appear quite similar, small differences between the two provide clues into features most desirable to pedestrians.

First, the sidewalk dimensions of option five create more space for multiple types of pedestrian practices and accommodate features such as sidewalk furniture, public art, and social spaces. Option five also provides more room in the road network, creating more space for cars to operate. Option three does have bike lanes where five does not, creating both a buffer for pedestrians and access for another mode of transportation. Both alternatives illustrate the difficulties in supporting multiple modes of transportation within 60 feet of right of way, and regardless of the configuration certain modes will be privileged while others disadvantaged. The PAR model serves to remind us how a human-centered evaluation of such projects provides can highlight specific features that are pedestrian friendly and illustrate how the range of pedestrian experiences respond to different environmental features.

CONCLUSION

Literatures on the everyday experiences of walking in the city (see e.g. Lynch 1960; Jacobs 1961; Whyte 1988; Solnit 2000) all place a heavy emphasis on the more subjective variables in understanding pedestrian practices. Many existing pedestrian models are embedded with reductive ontologies (O'Sullivan and Hakley 2000), framing the pedestrian as a rational transportation unit optimizing resources or reacting to other agents across the model environment. While wayfinding and evacuation approaches to pedestrian movement have proven effective for discrete purpose or event-based phenomena, other aspects of pedestrian movement such as communication with other agents, cognition and emotion, uneven internal representation of perceived spaces, and multiple agent motivations need to be incorporated into the agent-based framework to understand more everyday human pedestrian behaviors.

Despite the communication barriers embedded in process-driven analysis, agent-based modeling remains a powerful and innovative way to understand the relationships between changing spaces and individual behaviors, serving to highlight many unexpected facets of both individuals and the system in which they are embedded. The PAR model described in this paper incorporates a data-driven representation of cognition into agents as a way to explore the implications of different types of redevelopment and design on realistic pedestrian types. The results indicate the design variables of dimensional changes and community support has a stronger influence on a heterogeneous population of pedestrians than the design variables of public safety and economic benefits classifications. The model also introduces a weighted interaction scheme highlighting flaws in the official assessment administered by the city of Eugene. In doing so, the PAR model provides insight that would be hard or impossible to obtain with traditional statistical models.

Due to the immense potential of agent-based models to shed light on pressing issues in land-use, urban growth, and especially transportation planning practices, it is critically important that research on agent-based models, both from modelers and from planners, continues to focus not only on design and evaluation metrics, but on the discursive dimensions of the knowledge produced by models and the role of that knowledge in policy debates. This is especially true for pedestrian modeling applications, as pedestrian-oriented development has great potential to radically transform urban transportation spaces and address pressing global issues with localized sustainable practices. In the context of increasingly urgent social and environmental issues, there is a pressing need to understand how people move through everyday spaces, how various human subjectivities play into pedestrian decision-making, and how to best design and communicate model results to support municipal planning and development.

Agent-based models provide a relatively new scientific tool to integrate human-centered and configurational approaches to urban and transportation planning. A computational approach to represent human-centered and everyday pedestrian behaviors has significant methodological contributions in the field of planning and elicits strong insight to address many community-based goals of livability, safety, and environmental sustainability. Thoughtful pedestrian representations in agent-based models aligns with emerging municipal goals of data-driven smart city design initiatives (Townsend 2013), while drawing linkages between individual representations of space and the concrete elements of the city, informing a deeper understanding of

pedestrian behaviors and transportation choices. Additionally, an agent-based modeling approach allows for different design variables, infrastructure configurations, and social conditions to be systematically simulated in a model environment, fostering a broader understanding of how real-world behaviors are influenced by material changes in the environment. While there are still many issues in design protocols, validation techniques, and communication frameworks that require continued attention, agent-based modeling can serve as a powerful and low-cost computational platform to learn about urban and transportation systems in supporting planning practices.

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