A Review of Social Force Modeling for Modeling Pedestrian Accessibility

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Introduction

Pedestrian infrastructure is not a high priority in American transportation planning and research, due to the over-emphasis of automobile infrastructure. Because of the lack of attention to pedestrians in a car-centric society, pedestrian needs are often overlooked which results in dangerous situations for both pedestrians and automobile drivers. While we understand basic principles of pedestrian movement, we have not applied that understanding to improving pedestrian infrastructure for greater pedestrian accessibility and movement.

Many of the pedestrians that are using less-than-great infrastructure are walking because they have no other choice. Often times pedestrians are vulnerable populations such as the disabled, the elderly, the young or the impoverished. Thus, addressing pedestrian needs is an issue of equity. Planning for the most vulnerable and developing solutions for the people with the most needs ensures that infrastructure is accessible,functional and comfortable for everyone.

In this project, pedestrian movement will be modeled as a context to understand where pedestrian infrastructure should be improved for greater accessibility. These measurements will be based off of pedestrian interactions to the context they move within, with greater focus on the contexts in which pedestrians choose to disregard pedestrian infrastructure. Such cases being instances of jaywalking, and the development of desire paths.

Typical pedestrian movement models can be grouped into three categories depending on what structure the model is based off. These include models based off of: Continuum Theory, Cellular Automata, and Newtonian Dynamics (Rainald, 2009). Models based in the Continuum Theory are “flow” based models describing human movement as a gas or liquid that moves through contexts that are solved using conservation law methods (Rainald, 2009). Cellular Automata models are designed based on pedestrians moving within a cartesian grid jumping from one cell to another at a time (Rainald, 2009). Finally, Newtonian Dynamic models define pedestrians in a more abstract mathematical approach, referring to pedestrians as responding to ‘social forces’ in a similar way to magnetic forces (Zeng, Nakamura, Chen, 2014). Other ways that pedestrian modeling has been grouped is based off of approaches to modeling including: simple statistical regression, spatial interaction theory, accessibility approach, fluid-flow analysis, queuing models and agent-based models (Editorial, 2001). Each type of modeling structure and approach have different strengths and weaknesses to how pedestrian movement is understood and how it impacts model outcomes, especially when it comes to measuring accessibility. There is no “one type” of modeling structure that best fits the approach for pedestrian accessibility and thus a great deal of this project has been evaluating different methods for their applications.

Pedestrian movement models can also be categorized based on what type of choice the pedestrian in the model is making. Such choices for pedestrian movement include: activity choice, destination choice, mode choice, route choice, the choice of next step, the choice of speed, and pedestrian interactions such as group behavior, collision avoidance, leader-follower and scene elements (Bierlaire and Robin, 2009). These choices and interactions are impacted by the environment and the infrastructure that the pedestrian is functioning within, so many of these questions of choice are related to this paper's topic and have influenced what approaches are taken.

This paper will review and discuss Social Force modeling approaches and will be evaluating the usefulness to the topic of pedestrian accessibility.

Model Description

Social Force Models take principles of Newton's Laws for modeling magnetic forces and apply them to human movement. Translating the magnetic forces into social forces to define and illustrate how humans react to their environment has been found to be very unique from previous modeling methods and informative for modeling pedestrian behavior.

It describes human interaction as something that is created from social "forces" not directly exerted by the environment but a measure of internal motivations (Helbing & Molnár, 1995). Examples of these forces would include the attractive force of the destination, or the repulsive effects of walls and surrounding pedestrians within the environment as a pedestrian doesn't want to collide with walls or interact with other people on the street (Helbing & Molnár, 1995). This is illustrated in Figure 1. Some pedestrians may have an attractive effect upon the pedestrian if they are friends, family or the related to destination of the pedestrian in question. The social force model also takes into account the differences between desired direction, and desired speed with actual direction and actual speed with measurements of desired velocity and actual velocity (Helbing & Molnár, 1995).

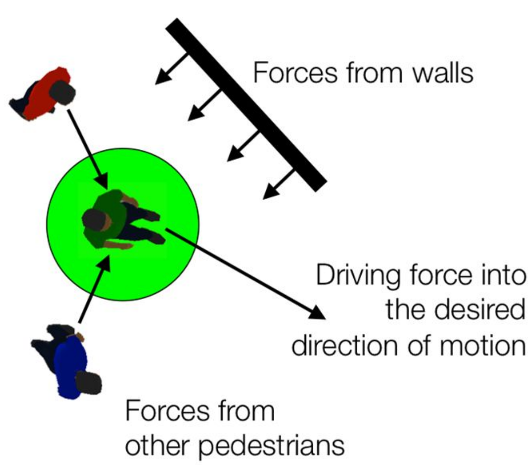

Figure 1: Basic Diagram of the Social Force Model

This approach to modeling pedestrian behavior works because humans walk so regularly that reactions to the environment are mostly automatic based off of previous experiences and do not go through an individual cognitive and psychological process to decide their response (Helbing & Molnár, 1995). Since the majority of pedestrians have similar automatic responses to the environment we can assume that these forces act equally upon each pedestrian.

The Social Force model was first introduced by Helbing and Molnár in 1995 in a paper titled: "Social force model for pedestrian dynamics". It has since seen a great deal of development as researchers have modified, adjusted and added to the basic principles of the model to greater reflect upon the detail in pedestrian movement being modeled or the specific context the model is applied to. That being said, the majority of the additions and adjustments made to the social force model have been very specific and unique to each context it is being applied to and isn't necessarily applicable to other modeling methods.

Applications

The Social Force Model has been used in numerous different applications and contexts including its original approach to modeling human movement at a micro-scale for architecture and design of human flow (Helbing & Molnár, 1995). Examples to the specific uses cases for this would be modeling movement in Museums, Churches, Malls, Downtowns, and Plazas. The Social Force model has also been used to model the movement of pedestrians at signalized crosswalks (Zeng, Nakamura and Chen, 2014), analyzing evacuation patterns and modeling escape panic (Helbing, Farkas and Visek, 2000), and modeling self-organizing pedestrian movement (Helbing, Molnar Frakas and Bolay, 2000). The Social Force model has been calibrated to maximum likelihood estimation, which evaluates individual trajectories rather than crowd dynamics (Ko, Kim and Sohn, 2013) along with modifying the model for more realistic pedestrian behavior and social evolution in crowds (Lakoba and Finkelstein, 2005). One of the strengths of the Social Force Model is its flexibility in adjusting the model for niche contexts and different scales of movement.

However, most of the Social Force Models found in literature have been applied specifically only for human systems (mainly pedestrians) due to the uniqueness of the model forces designed and being applied within the context of human reactions within the model.

Within the context of pedestrian accessibility research, Social Force Modeling may or may not have a huge influence within this project. The majority of Social Force Modeling has been in testing how human react within different contexts for uses in safety measurements and development of environments. The focus on accessibility and evaluating already existing networks is not as widely used for Social Force Modeling.

Discussion on Model Suitability (Strengths and Weaknesses)

As mentioned in the previous section, one of the greatest strengths of the Social Force model is its adaptability in applications. It is also well suited in creating models that are able to measure outcomes that are related to small social reactions that have big impacts on the modeling outcome.

That being said, the Social Force model does have some weaknesses, including the lack of decision making for pedestrians. This is good for simplistic, reactionary contexts however it isn't very good for evaluating complex situations. For example, the original Social Force model is not very good for modeling larger crowds for multiple reasons, one of them being the inability to have non-panicking and panicking pedestrians and another being the changes in pedestrian's tolerances within their territorial sphere as density increases (Helbing, Farkas and Visek, 2000). However, this weakness was addressed by modifying the original model to account for those changes with an additional algorithm when applicable (Helbing, Farkas and Visek, 2000). Another criticism of the Social Force model is the symmetry of social forces are inconsistent with human behavior (Löhner, 2008). In Löhner's article "on pedestrian motion" they point out that just because pedestrian 1 is trying to avoid pedestrian 2 does not imply that pedestrian 2 is trying to avoid pedestrian 1 (Löhner, 2008). They also go on to mention that we as humans tend to be only influenced by our nearest neighbors, particularly the ones that we can see, and not every pedestrian within the neighborhood as the model implies (Löhner, 2008). Dependent upon cultural setting, some pedestrians may avoid closeness to walls, while others prefer to walk rapidly close to walls, but this is an element that can be adjusted as needed in the original model.

Within the application of pedestrian accessibility to the Social Force model, there are different weaknesses apparent to the model that impact a smooth application for this context. Since the model is designed to evaluate changes in environment rather than evaluating entire networks, the scope of the project may be difficult to evaluate using the social force model. This model may not be suitable for modeling pedestrian accessibility unless it is able to be modified from its original design to be able to include network datasets or are combined with network based modeling structures. At this point in time, research has not been found that has combined these two modeling structures. That may be due to other restrictions and challenges in researching pedestrian networks that have slowed the research in combining these two models.

Network based models rely on underlying street network data of the segments of infrastructure that can be traversed to travel from point A to point B. Typically for pedestrians, network data can be at best: incomplete and at worst: segmented strips of sidewalk data, disconnected block from block. Most network datasets typically used in network based models are developed from street data for automobiles, where every street is connected to the rest of the road network (otherwise the street is useless for automobile travel). However, pedestrian infrastructure has a different reality where sidewalks can end abruptly and sidewalks around each block are disconnected from other blocks without assumed road crossing connections. Working with pedestrian network datasets in itself is a challenge due to the lack of data availability, and the inherent disconnection in pedestrian infrastructure (Holtzer, 2018). This could easily impact the lack of research in using the Social Force model on pedestrian's networks at this time.

However, evaluating and correcting pedestrian network connectivity is important for vulnerable users, such as the disabled, who require full functional sidewalk infrastructure to traverse across. It's important for safety for pedestrians, who may otherwise choose to walk along the road where sidewalks are not available. It's also important to provide safe, logical signalized crosswalks along busy roads so pedestrians do not have to resort to jaywalking to make it to their destination.

The possible solutions for this problem at this time is to create a model that is network-based that evaluates accessibility, connectivity and barriers through walkability surfaces, then consider applying the social force model as a secondary structure for this project.

In the future, improvements could be added to this review with further research on different subject matters and applications of the Social Force model, but particularly more research based on network modeling related to pedestrian accessibility and how that could be included to Social Force models.

References

Bierlaire, Michel and Thomas Robin (2009) "Chapter 1: Pedestrian Choices" *Pedestrian Behavior: Models, Data Collection and Application*. Emerald Publishing. pgs. 1-26.

This article reviews most of the lit around ped modeling and groups them based on elements of ped movement that is being addressed--particularly the choices that peds make when moving. Therefore this article is first off-- a resource for future readings and secondly-- a review and conclusion of the abstraction of ped movement in the pedestrian modeling literature. This will be helpful in my own research as I develop my own approach to what aspects on ped modeling I wish to include.

Zeng, Weiliang, Hiedek Nakamura, and Peng Chen (2014). "Modified Social Force Model for Pedestrian Behavior Simulation at Signalized Crosswalks" 9th International Conference on Traffic & Transportation Studies.

This is a detailed article of the social force model which is an approach to pedestrian movement based off of a magnetic-force model. It is heavily mathematical, calculus and physics based however the conceptualization of pedestrian movement is unique. It describes movement as something impacted by attractive, repulsive and driving forces of the environment, and that pedestrians respond to such forces very similarly to the way that magnets respond to forces.

Löhner, Rainald (2009). "On the Modeling of Pedestrian Motion" Applied Mathematical Modeling. Elsevier inc.

This is an overview article articulating the differences between different kinds of pedestrian movement modeling. The article categorizes different models based off of the structure the model is based off of (Continuum Theory, Cellular Automata, and Newtonian Dynamics). It covers multiple different types of pedestrian forces and circumstances and describes how they are represented in different models (internal forces, external forces and kinematic constraints). It reviews data structures for pedestrian models and provides examples of pedestrian models. This article has been critical in my own understanding of what pedestrian models can be found in literature.

Xiao, Yao, Ziyou Gao, Yunchao Qu, Xingang Li (2016). "A pedestrian flow model considering the impact of local density: Voronoi diagram based heuristics approach." Transportation Research Part C. Elsevier, Inc.

This article uses Voronoi diagrams to obtain useful information to pedestrian movement such as local density, safe distance and neighbors. Xiao and company argue in this article that pedestrian moving direction and velocity are determined by three factors: desire for fast walking, requirement for safe walking and the need for comfortable walking. The use of Voronoi cells in this article are unique because they are irregular, have no empty cells (unlike cellular automata) and define the spacing, density and types of interactions between pedestrians. This article creates a model of agents with movement settings that are put into multiple contexts to simulate pedestrian movement and compare how the Voronoi diagrams change depending upon context.

Dill, Jennifer (2004). "Measuring Network Connectivity for Bicycling and Walking" TRB 2004 Annual Meeting Paper Submittal.

This article is a collection of different types of measurement approaches to evaluating connectivity and accessibility in pedestrian and bicycle networks.Such measurements include block density, intersection density, street density, connected node ratio, link-node ratio, grid pattern, pedestrian route directness, and effective walking area. These measurements are helpful to evaluate networks within different models to have structural ways to create comparisons between contexts.

Flötteröd, Gunnar, Gregor Lämmel. (2014). "Bi-directional pedestrian fundamental diagram" Transportation Research Part B. Elsevier Inc.

This article is a review a Bi-directional pedestrian movement modeling within multiple model structures and design. It covers models structured in cellular automation, cell-transmission models and force-based models providing examples to the requirements, specification and properties each type of model would need to include in order to be considered a bi-directional pedestrian model. They use Voronoi cells to help compute flow statistics through the model by using the Voronoi cells to capture the specific density of pedestrian movement.

Editorial (2001). "Agent-based Pedestrian Modeling" Environment and Planning B: Planning and Design Volume 28, pages 321-326.

This article covers agent-based modeling and its place in developing models for modeling pedestrian movement. It covers previous modeling methods such as, simple statistical regression, spatial interaction theory, accessibility approach, fluid-flow analysis and queuing models. It then goes into detail about the uses and improvements that agent-based modeling has to offer for pedestrian movement describing and modeling.

Haklay, Mordechai, David O'Sullivan, Mark Thurstain-Goodwin. (2001). '"So go downtown": simulating pedestrian movement in town centres' Environment and Planning B: Planning and Design Volume 28, pages 343-359.

This article discusses and creates a model for pedestrian movement as both a process of the individual pedestrian choice movements and as a process evaluating the external networks and attraction locations as how pedestrians move according to the uses. The authors provide detailed information about the model and pay special attention to the agents themselves, given them unique behavioral characteristics and route-choice modules for the simulation.

Jiang, Bin, and Tao Jia (2009). "Agent-based Simulation of Human Movement Shaped by the Underlying Street Structure" IJGIS

This paper is arguing that random walkers in a street network would have the same movement pattern of a human pedestrian. They create an example model street networks for both London and a "Gavle" dataset to run their simulation in using NetLogo and ArcGIS. However they did not differentiate pedestrians and vehicles in this simulation, which concerns me on the relevance it has to pedestrian infrastructure (pedestrians cannot go on highways for example). They find that on a collective level, purpose-drive and random walkers do not differentiate in their movement patterns.

Özbil, Ayse, and John Peponis (2007). "Modeling Street Connectivity and Pedestrian Movement According to Standard GIS Street Network Representations" Proceedings, 6th International Space Syntax Symposium.

This article hopes to explore measurements for pedestrian accessibility and connectivity using pedestrian movement data, creating a model of the distribution of pedestrian movement according to the configuration of streets.However, the research is still ongoing and isn't conclusive. They have found that road segments that take fewer turns to get everywhere draws greater volumes of pedestrians. The data collection of pedestrian movement that they took on wasn't detailed enough for further analysis.

Zielstra, Dennis and Hartwig H. Hochmair (2010). "A comparative study of pedestrian accessibility to Transit Stations Using Free and Proprietary Network Data"

This article has two objectives, one to compare pedestrian segment data to street data for levels of completion and coverage, second to analyze which extent the integration of pedestrian-only segment datasets affects the size of service areas generated around bus and metro stations. This article uses OpenStreetMap data and uses ArcGIS Desktop for its analysis. It provides methods for analysis pedestrian-only infrastructure data. It was found that Open Street Map usually had better Pedestrian path data then Proprietary data, outside of select conditions that involved previous projects. It was found that light rail and metro stations benefit more from the integration of pedestrian-only segments than accessibility to bus stops.

Holzer, Ricky (2018). "Measuring Pedestrian Accessibility in QGIS" Minnesota Department of Transportation State Agency Lunch 'n' Learn, March 7th.

Talk attended on March 7th about pedestrian accessibility and measurement using QGIS software. Discussion based on what accessibility and mobility is and different measurements related to each. Measurement types covered: opportunity base measures, separation based measures and gravity base measures. Arguments were made to why the measurements applied for car accessibility is not applicable to pedestrian accessibility due to larger scale analysis, specialized infrastructure, less focus on work commute movements and the distance decay function. Example application of measurements were provided with methods using QGIS and OpenStreetMap data.

Helbing & Molnár, 1995 "social force model for pedestrian dynamics" Physical Review E Volume 51, Number 5. May.

This is the original published article that introduced Social force modeling for pedestrian dynamics. It has since seen a great deal of growth in the modeling structure as researchers have modified and adjusted the basic principles of the model to greater reflect upon the detail in pedestrian movement modeling or the specific context the model is applied to. As is with most "new idea" articles, the majority of it defends the model to the public and provides arguments and examples to why the idea works, rather than providing a complete breakdown and analysis of the model itself, which it does briefly.

Helbing, Dirk, Illes Farkas and Tamas Visek (2000). "Simulating Dynamical Features of Escape Panic"

Helbing, Dirk, Peter Molnar, Illes Frakas, and Kai Bolay (2000). "Self-organizing pedestrian movement" Environment and Planning B: Planning and Design Volume 28, pages 361-383.

Ko, Moonsoo, Taewan Kim and Keemin Sohn (2013). "Calibrating a social-force-based pedestrian walking model based on maximum likelihood estimation." Transportation 10.91-107

Lakoba, Tara and Neal Finkelstein (2005) "Modifications of the Helbing- Molnar- Farkas-Vicsek Social Force Model for Pedestrian Evolution" Simulation Volume 81, Issue 5 May. The Society for Modeling and Simulation INternational.

Bonabeau, Eric (2002). "Agent-based modeling: Methods and techniques for simulating human systems" PNAS May 14, 2009. Vol. 99 suppl. 3

Kneidl, A., D. Hartmann, A. Borrmann (2013). "A hybrid multi-scale approach for simulation of pedestrian dynamics" Transportation Research Part C. Elsevier.

Figure Sources:

Figure 1: FuturICT Blog: "Social Forces" http://futurict.blogspot.com/2014/12/social-forces-revealing-causes-of.html