North Dakota State University
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Title

SMART CITY MODELING: USING GIS CAPABILITIES TO
SIMULATE URBAN AREAS AND EVENTS

By

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The Supervisory Committee certifies that this ***thesis*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF ARCHITECTURE

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SMART CITY MODELING: USING GIS CAPABILITIES TO SIMULATE URBAN AREAS AND EVENTS

A Thesis
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ABSTRACT

This research aims to show the capabilities of smart city modeling using GIS and other accessible information to provide accuracy and precision. Through this data collection, architects and urban planners can strategically alter urban areas to promote user experience and contentment. Current well-established cities can become known as smart cities, or cities that are data driven. This collection of data, such as traffic data, can be used to improve the user experience through efficiency and correct implementation. The idea of a “walkable city” is also reinforced as an important design solution that directly impacts the user experience in this urban environment. Through this technology, architects and urban planners may use this workflow in future design projects that focuses on user experience and engagement.

This exploration aims to provide possible simulation methods for current smart city implementations and improvements. The impact of this project is to find if computational simulations and modeling can improve the overall health and well-being of users in an urban environment. The area of focus in the downtown urban setting of Fargo, North Dakota. Key aspects of this research include generative modeling and simulation of traffic flows on roads, pathways, alleys, and sidewalks.

ACKNOWLEDGMENTS

I would like to thank the faculty of the Architecture department for providing feedback and critiques on my research. I would like to thank Fargo city officials Ryan Erikson, the Fire Marshal, and Hanna Anderson, with the Building Inspections Department, for providing relevant information of downtown building occupancy to begin to build the simulation models. Lastly, I would like to thank my thesis advisor, Dr. Ganapathy Mahalingam, for his support and continued feedback of my research and project development.

DEDICATION

I would like to thank my friends and family for their continued support through my education. Their guidance and support have helped me get so far in pursuing my interests and passion.

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LIST OF ABBREVIATIONS

GIS ....Geographic Information System.

BIM ....Building Information Modeling.

INTRODUCTION

As the world population increases, people migrate to urban areas with high density. As a result, inhabitants in an urban environment have lost a sense of their personal identity. Areas with high population density lose a sense of cultural identity and heritage through congestion and traffic. This research aims to promote the health and well-being of these users through computer simulations and modeling. To do this, user experience will be primarily focused. Through the data collection, architects and urban planners can strategically alter urban areas to promote user experience and contentment. Current well-established cities can become known as smart cities, or cities that are data driven. This collection of data, from pollutants levels and traffic control, can be used to improve the user experience through efficiency and correct implementation. To reduce the amount of manual input that is required, city modeling is tightly integrated with urban simulation (Aliaga, 2012). This means that current implementation could simulate future design choices in the urban environment. The idea of a "walkable city" is also reinforced as an important design solution that directly impacts the user experience in this urban environment. To do this, urban planners must use data from smart cities to make these decisions.

1.1. Overview

This proposal will outline the structure of the research to provide a clear and concise work schedule. Literature review will discuss past case studies in this area of interest to show the feasibility of this design research. Many research questions are provided and will be answered through the research process. Then, proposed outcomes will be compiled into the deliverables of the research and provide the overall impact the research contributes to the field of architecture. To do this, methodology will provide the process and approach of the project through data collection.

1.2. Mission Statement

The mission of this research is to establish that computational modeling and simulation can directly improve the overall health and well-being of inhabitants in an urban environment.

1.3. Research Questions

The following sections propose questions that will be answered through this research project. These questions directly correlate to the ideas to promote the wellness of users in an urban area with computational modeling and simulation. Areas of interest include the following:

1.3.1 The Urban Built Environment

- How do newer buildings in an urban area affect the built environment?
- How can computer modeling aid in overall health and accessibility of urban inhabitants?
- How have smart city systems improved the lives of people in those cities?

1.3.2 Smart Cities

- What makes a smart city smart?
- What data should be gathered to enable a smart city and its operations?
- How is the data collected by a smart city processed and analyzed?
- What should the data collected by a smart city be used for?

1.3.3 Data Collection

- How can the data collected by a smart city be used to better the lives of the urban inhabitants?
- How can we ensure that the benefits of smart city data are shared equitably among all city inhabitants?

- How can we ensure that the benefits of these technologies are realized while also protecting the privacy and security of citizens?
- How can we ensure that the development of smart cities is inclusive and beneficial for all residents?

1.4. Proposed Outcomes

The following section outlines deliverables for this research project. Additionally, the impact of this project will also be discussed, as to what this research project will have an impact on architectural practice, career field, and in a broader context.

1.5. Deliverables

The deliverables of this project include a data set of circulation patterns (that define a 15-minute city) in multiple urban design solutions. Moreover, a comparison of these design solutions will be included and heavily impact the final solution. The goal is to develop the solutions to find a more efficient and effective design to pedestrian wellness for walkability. Multiple circulation types such as walking, running, biking, and driving will be affected as a result. However, the concern of a walkable urban environment will be the major interest.

1.6. Impact

The impact of this project is to find that computational simulations and modeling can improve the overall health and well-being of users in an urban environment. Through this, architects and urban planners may use this workflow in future design projects that focuses on user experience and engagement. Rather than designing for the client, striving for user experience would change the design solution and result in better user wellness. Key players in urban planning are the inhabitants, who know the reality and the problems around them better than anyone else (Bugs et al, 2010). In a broader sense, the impact of designing for the user experience could develop a more sustainable environment in an urban area. Urban layouts have become more congested and focused on population density because of population growth. Urban layouts have also become more one-dimensional and plotted in a grid-like pattern. Through this design method, urban layouts could become more interesting regarding design choices to improve the health of the urban users. Planning authorities can implement urban renovation projects to enhance the quality of the streets in a logical order (Stefandisis, 2022). Moreover, this project is a direction towards a possible workflow of smart city implementation, prioritizing simulations to accurately model urban walkability and other means of transportation.

2. LITERATURE REVIEW

The following section reviews previous methods of research of computational modeling in an urban environment.

2.1. Integration of BIM and GIS in Smart Cities

In "Planning Utility Infrastructure Requirements for Smart Cities using the Integration between BIM and GIS," Marzouk and Othman discuss the benefits of the combination of BIM and GIS to plan infrastructure in smart cities (2020). For context, BIM (Building Information Modeling) is digital representation of physical models and GIS (Geographic Information System) is storage and analysis of geospatial data in each location. The integration between these two systems allows urban planning and development that is detailed comprehensively. Because of this, urban planners can easily find how infrastructure should be planned out in the most efficient and effective way.

Additional benefits of BIM and GIS integration include the improved understanding of infrastructure relationships, reduced costs in planning or construction, communication and collaboration of smart city developers, and precision in the smart city planning process. The authors argue that these benefits outweigh the challenges of this implementation, such as cost in data collection and constant data collection upgrades through new tools and technologies. Overall, Marzouk and Othman identified improvements of smart cities through BIM and GIS integration. In return, improvements in sustainable and data-driven cities are possible.

Although the integration of BIM and GIS is resourceful for the city developers, it is also important to consider the users and citizens of the urban area. The data collected is widely used regarding the users and should be distinctly analyzed to benefit them. Through additional research and analysis, the connection between BIM and GIS integration and boosting overall health and wellness of the users can be made.

2.2. Building Virtual Models for Smart Cities

Jovanović et. al propose the application of virtual modeling for urban design in "Building Virtual 3D City Model for Smart Cities Applications: A Case Study on Campus Area of the University of Novi Sad" (2020). Their case study focuses on a virtual city model of the campus of the University of Novi Sad in Serbia and made possible using geospatial data. Their workflow included data collection of the campus area, data processing on types of objects such as buildings and roads, model generation through aerial imagery, and model visualization through software applications. Urban planning is a potential future use, according to the author. This workflow can potentially simulate urban planning scenarios and present multiple design solutions. Lastly, navigation and pedestrian flow can be simulated and modeled to compare areas of congestion and easement.

This workflow shows the importance of accurately implementing smart city design through computational modeling. It also shows that developed and established cities are capable of smart city integration through aerial analysis rather than only newer, developing urban areas.

Similar workflows and the assistance of GIS are central to future implementation of data-driven design. Overall, the workflow presented by Jovanović et. al can directly impact the users through simulating design solutions and processes. This can be done by modeling pedestrian flows or sustainable practices. Additional ideas such as preservation of cultural sites and buildings can also be explored with the assistance of 3D modeling of urban settings.

2.3. Simulation of Urban Walkability

In "Urban Walkability Design Using Virtual Population Simulation," Mathew et. al presents an approach to design walkable urban environments (2019). The approach is to use procedural modeling where the environment, such as the buildings and circulation paths, alter to find the best solution for pedestrian behavior. To do this, the authors started with an urban layout and then simulated movement through the environment. From this, they analyzed the interactions and developed the model to produce a favorable outcome.

Even though this system is still under development, the system has been used in real-world applications. For example, the system was used to design a new pedestrian path in Venice, Italy. It has been shown that the crossing would reduce congestion and improve the safety of the users.

The application of the simulations shows the successful implementation of modeling around the pedestrians in an urban area. The study focuses on the importance of a walkable city which overall affects the health and wellness of the users, as a more walkable city can be more comfortable and safer. Other pedestrian transportation methods such as biking and vehicular traffic could also be explored, as well as proving the efficiency of the circulation path. This successful implementation could alter previous design solutions to become even more efficient or create new solutions to further enhance the urban environment.

2.4. Simulation of Transportation

In "A Simulation-Based Accessibility Modeling Approach to Evaluate Performance of Transportation Networks by using Directness Concept and GIS," Ertguay proposes a new simulation-based accessibility modeling approach that considers the directness of routes (2019). The approach uses a simulation-based model to generate direct routes between all pairs of origins and destinations in a network. These routes are then used to calculate a new accessibility measure that considers the directness of routes. The author argues that traditional accessibility measures do not adequately account for the directness of routes, which can lead to inaccurate interpretation of network performance. Ertguay applies their approach to a case study of the transportation network in cities of San Francisco, Paris, and Ankara. Through their assessment, the new approach produces a more accurate assessment of network performance than traditional accessibility measures. Areas such as urban planning, transportation engineering, and public policy may be directly improved according to the article. This approach has the potential to be used to improve transportation networks and make them more accessible for multiple users.

2.5. Modeling Walking Behavior

In "Modeling Walking Behavior in Cities Based on Street Network and Land-Use Characteristics: The Case of İstanbul," Ozbil investigates the relationship between street network design and pedestrian movement in İstanbul, Turkey (2013). Ozbil uses a variety of methods, like spatial analysis, statistical modeling, and pedestrian surveys, to study three different areas in the city. They find that street connectivity is a significant factor in determining where people walk, and areas with more connected street networks have higher pedestrian volumes. Land use mix is also important, as areas with more mixed land uses have higher pedestrian volumes. As such, urban areas such as downtown blocks are resourceful for diverse movement and activity.

Ozbil believes that their findings have important implications for urban planning, as they suggest that planners should focus on creating more connected street networks and promoting mixed land uses to encourage walking.

3. METHODOLOGY

Methodology will have three areas to define research ideas and outcomes. The following areas are as follows:

- Approach: Methods to gather data.
- Data Collection: Types of data that will be gathered.
- Analysis: The tools to analyze and organize data.

3.1. Approach

To find the most effective solution to the urban design problem of pedestrian flow, multiple solutions will be explored. In this way, each solution will be compared distinctly to another solution to strengthen the result. Through this comparison, simulation and modeling will be valuable in comparing each solutions' features. The re-emergence of local transit strongly suggest the need for walkable spaces around stations as the means of access to the concentrated development (Barnett, 2016). As such, areas of analysis in the aspect of walkability and traffic efficiency are targeted to the user of the urban setting in order improve their health and wellness of their urban environment. Future solutions will be built upon these past design solutions moving forward.

More specifically, the focus will be on downtown urban settings in a Midwestern area like Fargo, North Dakota. This includes circulation through downtown and the efficiency of vacating the downtown area. As a result, users can circulate the urban area more efficiently. This will be conducted through a generative process. The final deliverable will be a simulation model using data collection from pedestrian simulation. After this process, lines can be drawn to multiple areas of interest to define the area as a "15-minute city." Through smart city models and data collection, a walkable city can be effectively defined.

Pedestrian mapping is a beneficial method to collect or simulate possible scenarios in established cities. Pedestrian mapping is primarily conducted in this research to simulate present transportation methods and find alternate solutions to urban transportation. These transportation methods include walking, biking, and public transportation, in which each method has distinct characteristics to examine.

3.1.1 Data Collection

Data collection will be conducted through established software platforms regularly used in the architectural field. Occupancy as well as human and vehicular circulation are key important data to help build the simulation as accurately as possible. Additionally, precedent studies from local governmental organizations such as Metro COG provide resourceful information regarding transportation patterns in the Fargo-Moorhead area.

3.1.2 Analysis

The following information will discuss the platform's overview and primary use for this project:

Adobe Illustrator is a graphic editor and design program. This program will be utilized to create the figure-ground maps needed for data analysis. Additionally, creating maps with lines that directly connect to areas of interest. In return, the downtown urban area can determine its walkability and accessibility.

AnyLogic is a general-purpose simulation software that uses agent-based modeling. Agent-based modeling is computational modeling used to simulate interactions of autonomous agents, such as people. As such, AnyLogic can simulate scenarios of pedestrian flows from different buildings and urban layouts to develop an efficient and effective outcome. From this data, urban planners can find an effective solution of urban planning primarily to the pedestrians' movement.

ArcGIS is a geographic information software used to complete mapping and analysis solutions. ArcGIS can provide exploration and visualization through smart mapping. Analysis of data includes locating prime locations, optimal routes, and patterns to make predictions. As a result, this tool can be used to discover optimal and strategic locations of interest through circulation studies. Additionally, ArcGIS can integrate with AnyLogic to provide an easier workflow within a single platform.

Lastly, Metro COG, or the Fargo-Moorhead (FM) Metropolitan Council of Governments, established in 1963, is a transportation policy-making organization made up of local government and transportation authorities in the FM-area. Metro COG's mission is to harmonize the activities of federal, state, and local agencies, render technical assistance, and encourage public participation in the development of the area. Metro COG functions as a resource of information on the numerous transportation activities in the FM-area to enhance and safety and experience of the cities of the area.

3.1.3 Conclusion

To review, the focus of this research project will be on downtown urban settings in a Midwestern area like Fargo, North Dakota. The primary analysis is to develop multiple designs to improve user circulation and traffic flow. This directly impacts the overall health and well-being of the users. Key aspects of this research include generative modeling and simulation of traffic flows like roads, pathways, alleys, and sidewalks.

Implementation of this idea is through smart cities, or cities that data driven that impact design choices and other decisions. BIM and GIS are useful in this idea to collect data and model specific urban settings. Feasibility studies have been shown through computational modeling and simulation in case studies. Lastly, additional resources such as the multiple software platforms will aid in research by generating design solutions and then reviewing and updating. This way, urban areas will become more efficient and directly impact the user experience.

3.2 Project Location (Larger Scale)

The project location of this project is the location of downtown Fargo. The downtown area is situated in the central area of the greater Fargo-Moorhead area and is active in terms of pedestrian movement. The location includes several means of transportation which will be useful in elaborating forward. Figure 1-2 outline the project location and the boundary at which the site is defined.

Figure 1. 3D view of site location.

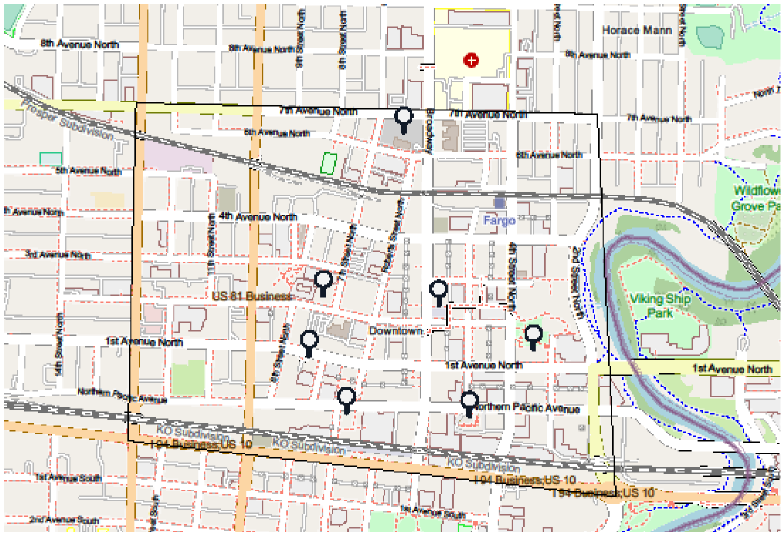

Figure 2. Site boundaries with key points of interest.

3.3 Project Location (Smaller Scale)

More specifically, this location is very important to the greater Fargo-Moorhead area. It holds many important government buildings as well as thriving businesses. Additionally, both day and night life are abundant in the location, as downtown Fargo holds many attractions, including restaurants, bars, and fine arts. To the south of the project location includes Island Park with is activate in outdoor events. Figure 3 highlights the primary and secondary roads through the location, as many primary roads connect the activity of the greater Fargo-Moorhead area, which includes Main Avenue, 10th Street, Broadway, NP Avenue, and University Drive. Figure 4 applies this information and presents it in AnyLogic digitally, which will be further discussed.

Figure 3. Figure-ground map of site location.

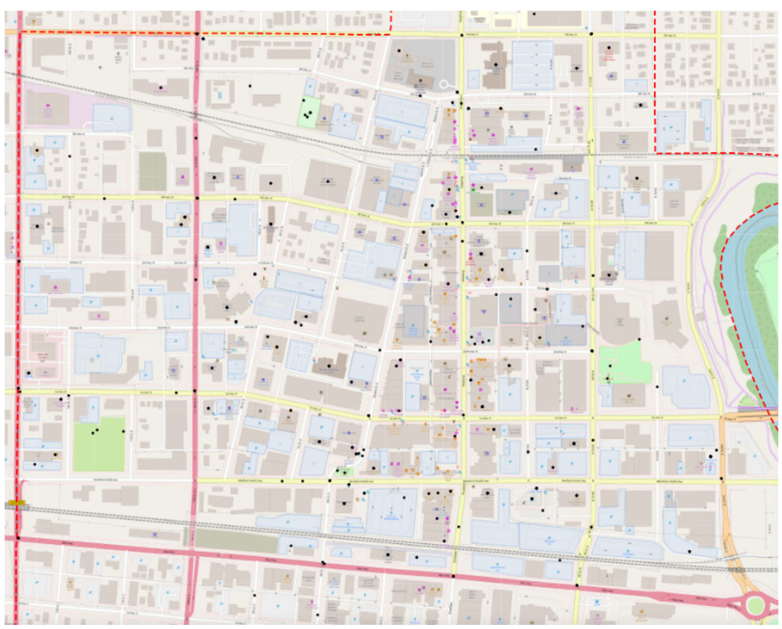

Figure 4. Site map currently in simulation.

4. RESULTS AND CONCLUSIONS

The section includes the overall process and iteration of creating a smart city model of downtown Fargo.

4.1 Final Project Description

At the beginning of the process, the following thesis questions were asked:

- What methods can well-established or newer cities use to become smart cities?
- How can the data collected by a smart city be used to better the lives of the urban inhabitants?
- How can computer modeling aid in overall wellness and accessibility of urban inhabitants?
- How can we ensure that the development of smart cities is inclusive and beneficial for all residents?

These questions followed throughout the design process and referenced the design choices of the simulation process. Figure 5 outlines the possible results of a smart city model to effectively collect data the guide design choices. Moving forward, Figure 6 establishes possible urban scenarios to be simulated in AnyLogic. The scenarios highlighted in blue were the focus of this design process. However, each scenario is possible and perhaps worth exploring in the future.

block_type	block	activity_type	mean (seconds)	total (seconds)	min (seconds)	max (seconds)	n_agents	mean (minutes)	total (minutes)	min (minutes)	max (minutes)
MoveTo	destination46NorthPints	MOVE	297.5417721	80331.362	100.687	738.711	270	0:04:58	22:18:51	0:01:41	0:12:19
MoveTo	destinationBarryHall	MOVE	420.9085148	113645.299	19.138	785.268	267	0:07:01	31:34:05	0:00:19	0:13:05
MoveTo	destinationBeerAndFishCompany	MOVE	289.120364	78640.739	4.465	707.876	271	0:04:49	21:50:41	0:00:04	0:11:48
MoveTo	destinationBernBaums	MOVE	318.4108971	77373.848	30.03	825.212	240	0:05:18	21:29:34	0:00:30	0:13:45
MoveTo	destinationBismarckTavern	MOVE	436.4888793	105630.333	35.763	957.324	236	0:07:16	29:20:30	0:00:36	0:15:57
MoveTo	destinationBlackBirdWoodFirePizza	MOVE	264.9847107	74195.719	17.512	801	276	0:04:25	20:36:36	0:00:18	0:13:21
MoveTo	destinationBlackCoffeeAndWaffleBar	MOVE	565.7107647	153873.328	8.716	1161.479	270	0:09:26	42:44:33	0:00:09	0:19:21
MoveTo	destinationBossPizzaAndChicken	MOVE	309.5659216	94727.172	6.751	719.05	303	0:05:10	26:18:47	0:00:07	0:11:59
MoveTo	destinationChubsPub	MOVE	796.4397574	216631.614	200.025	1186.227	271	0:13:16	60:10:32	0:03:20	0:19:46
MoveTo	destinationCowboyJacks	MOVE	379.8855667	102569.103	35.763	921.561	267	0:06:20	28:29:29	0:00:36	0:15:22
MoveTo	destinationDempseys	MOVE	275.6015285	72483.202	5.21	712.299	261	0:04:36	20:08:03	0:00:05	0:11:52
MoveTo	destinationDistrict64	MOVE	346.5014167	83160.34	31.118	923.767	239	0:05:47	23:06:00	0:00:31	0:15:24
MoveTo	destinationDrunkenNoodle	MOVE	346.5342227	88712.761	3.508	857.422	253	0:05:47	24:38:33	0:00:04	0:14:17
MoveTo	destinationEmpireTavern	MOVE	340.02925	88407.605	1.422	874.166	260	0:05:40	24:33:28	0:00:01	0:14:34
MoveTo	destinationFargoCivicCenter	MOVE	418.129412	111640.553	19.994	1010.397	264	0:06:58	31:00:41	0:00:20	0:16:50
MoveTo	destinationFargoTheatre	MOVE	323.5175146	88643.799	17.139	768.1	270	0:05:24	24:37:24	0:00:17	0:12:48
MoveTo	destinationFirstLutheranChurch	MOVE	608.2205365	141715.385	9.531	1144.5	232	0:10:08	39:21:55	0:00:10	0:19:05
MoveTo	destinationFortNoks	MOVE	364.4290077	94751.542	13.663	1016.956	259	0:06:04	26:19:12	0:00:14	0:16:57
MoveTo	destinationHavocHouse	MOVE	295.9765394	75178.041	4.465	712.341	251	0:04:56	20:52:58	0:00:04	0:11:52
MoveTo	destinationKaiHall	MOVE	372.168354	101974.129	40.57	682.674	269	0:06:12	28:19:34	0:00:41	0:11:23
MoveTo	destinationLittleBrother	MOVE	597.584415	158359.877	0.598	1186.227	265	0:09:58	43:59:20	0:00:01	0:19:46
MoveTo	destinationMezzaluna	MOVE	297.9132992	75669.978	17.139	750.961	252	0:04:58	21:01:10	0:00:17	0:12:31
MoveTo	destinationNoBullSmokehouse	MOVE	362.2146846	101057.897	19.815	979.267	277	0:06:02	28:04:18	0:00:20	0:16:19
MoveTo	destinationOldBroadway	MOVE	379.2595692	98607.488	13.684	1006.214	258	0:06:19	27:23:27	0:00:14	0:16:46
MoveTo	destinationParadoxEventCenter	MOVE	448.2753077	116551.58	112.201	838.899	259	0:07:28	32:22:32	0:01:52	0:13:59
MoveTo	destinationPhoDLicious	MOVE	387.1195986	113813.162	19.816	959.451	291	0:06:27	31:36:53	0:00:20	0:15:59
MoveTo	destinationPixelatedBrewing	MOVE	637.0976681	145885.366	15.12	1088.997	229	0:10:37	40:31:35	0:00:15	0:18:09
MoveTo	destinationPlainsArtMuseum	MOVE	368.0887796	90181.751	91.76	772.193	242	0:06:08	25:03:02	0:01:32	0:12:52
MoveTo	destinationPokeBowl	MOVE	590.9709158	168426.711	8.716	1170.196	284	0:09:51	46:47:07	0:00:09	0:19:30
MoveTo	destinationPounds	MOVE	434.2408962	112902.633	12.395	1084.935	259	0:07:14	31:21:43	0:00:12	0:18:05
MoveTo	destinationProofArtisanDistillers	MOVE	288.7442459	70453.596	16.717	766.77	242	0:04:49	19:34:14	0:00:17	0:12:47
MoveTo	destinationRenaissanceHall	MOVE	416.4233745	104522.267	123.741	888.286	250	0:06:56	29:02:02	0:02:04	0:14:48
MoveTo	destinationRootersBar	MOVE	292.3111786	73662.417	59.215	885.111	250	0:04:52	20:27:42	0:00:59	0:14:45
MoveTo	destinationRoughCutSocial	MOVE	611.5793295	161456.943	15.12	1073.877	260	0:10:12	44:50:57	0:00:15	0:17:54
MoveTo	destinationSanctuaryEventsCenter	MOVE	379.5882069	99072.522	172.452	711.813	256	0:06:20	27:31:13	0:02:52	0:11:52
MoveTo	destinationSidestreetBarAndGrill	MOVE	396.4210579	102673.054	8.608	964.972	256	0:06:36	28:31:13	0:00:09	0:16:05
MoveTo	destinationSonsOfNorway	MOVE	385.5069756	94834.716	19.83	723.243	246	0:06:26	26:20:35	0:00:20	0:12:03
MoveTo	destinationSpicyPie	MOVE	314.5451978	87443.565	30.03	828.389	275	0:05:15	24:17:24	0:00:30	0:13:48
MoveTo	destinationSportsBar	MOVE	330.4140696	75995.236	31.118	906.355	229	0:05:30	21:06:35	0:00:31	0:15:06
MoveTo	destinationStoneEventCenter	MOVE	294.6526708	71600.599	38.836	838.576	241	0:04:55	19:53:21	0:00:39	0:13:59
MoveTo	destinationTacoShop	MOVE	581.8738444	149541.578	12.492	1186.227	256	0:09:42	41:32:22	0:00:12	0:19:46
MoveTo	destinationTeddysEateryAndParlor	MOVE	290.1278594	72241.837	16.717	783.487	247	0:04:50	20:04:02	0:00:17	0:13:03
MoveTo	destinationTheBoilerRoom	MOVE	283.4964484	79662.502	38.309	750.651	279	0:04:43	22:07:43	0:00:38	0:12:31
MoveTo	destinationTheFourAndFour	MOVE	420.4683425	106798.959	8.608	973.581	251	0:07:00	29:39:59	0:00:09	0:16:14
MoveTo	destinationTheNorthernGentlemansClub	MOVE	490.4702878	132917.448	38.77	863.799	268	0:08:10	36:55:17	0:00:39	0:14:24
MoveTo	destinationTheToastedFrog	MOVE	289.5797333	73842.832	9.331	787.939	252	0:04:50	20:30:43	0:00:09	0:13:08
MoveTo	destinationVFW	MOVE	258.8772448	62389.416	15.685	798.051	239	0:04:19	17:19:49	0:00:16	0:13:18
MoveTo	destinationVinylTaco	MOVE	318.9891227	88359.987	59.215	944.327	275	0:05:19	24:32:40	0:00:59	0:15:44
MoveTo	destinationWildTerraCider	MOVE	660.7049813	177068.935	78.943	1144.5	266	0:11:01	49:11:09	0:01:19	0:19:05
MoveTo	destinationWurstBierHall	MOVE	337.6336757	87447.122	38.835	877.41	254	0:05:38	24:17:27	0:00:39	0:14:37

Figure 5. Table of information produced from simulation.

Topic	Data to be analyzed	What data is produced?	How can the data be used?
Transportation	Monitoring optimal routes	Fastest route of the least miles and time required	Provide estimations on time of travel
	Road congestions	Number of vehicles at a given location	Provide areas of congestion to be optimized or reorganized
	Road construction and accident sites	Efficiency of travel of alternate paths of travel	Provide alternate routes to possible road closures
	Public transportation efficiency	Efficiency of travel Areas of use Cost of use	Provide the efficiency of public transportation in a large or small scale
	Snow or emergency routes	Efficiency of a given route, response time	Provides the city the means to plan smarter routes for response teams for emergencies or weather conditions
	Alternate means of travel	Cost of use/upkeep Areas of use Efficiency of travel Percentage used by population	Provide the efficiency and feasibility of alternate means of travel
Pedestrian	Safety of urban environment	Track areas of crime and closed off areas	Find and reduce areas of crime to make them more safe for pedestrians, or track change of pedestrian flow due to closed off areas
	Walkability of urban environment	Sidewalk layout efficiency	Is a "15-minute city" achievable in the given area? Provide information on what can be changed to achieve this goal.
	Accessibility of amenities	Time or distance from a given location required for living	Provide information of distance of amenities like stores, work, education, or housing
	Accessibility of public transportation	Distance from a bus route/assembly or a subway station entry	Provide optimal locations for public transportation with high areas of use
	Accessibility of nightlife	Lighting feasibility Number of places of interest or amenities for nightlife	Provide the number of street lights needed for nightlife Provide information of open or closed amenities for nightlife
Infrastructure	Water and power supply	Amount of water and power supply used or needed	Provide the cost and amount required in a given location
	Waste Management	Efficiency of waste collection and tracking the amount collected	Provide information of waste collection and its efficiency
	Infrastructure placement	Efficiency and accessibility of infrastructure	Provide optimal locations of law enforcement, education, and healthcare for response times and accessibility
Environment	Healthcare	Areas of disease spreading or high pedestrian count	Provide information of disease spreading and other health concerns
	Air and water pollution	Areas of high pollutants and the causes	Provide information on the amount of pollution in an urban setting to find an efficient solution
	Green Spaces	Amount of green spaces in a given urban environment	Provide information on whether more green spaces, such as parks or fields, are needed

Figure 6. Table to guide creation of simulation and models.

4.2 Project Objectives

With AnyLogic’s GIS capabilities, a map of the simulation is easily accessible. In Figure 7, the orange points, also known as GIS Points, can be placed to mark any location throughout the model. It can also be used to markup routes, boundaries, and differentiate between GIS Points. This GIS map includes the fifty public assembly areas from Figure 8, along with forty-five packing locations.

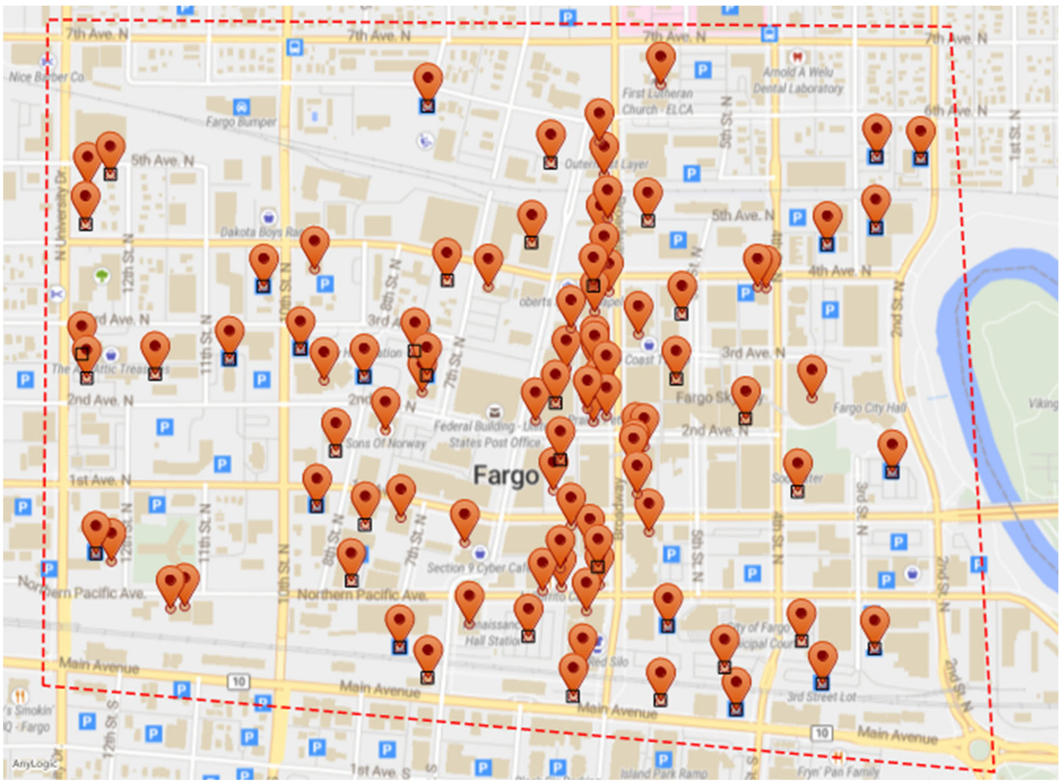

Figure 7. Fall semester digital AnyLogic model.

Simulating Fargo’s downtown urban area was made possible by reaching out to city departments to get public assembly permits. The two primary departments that had accessible information were the Building Inspections Department and the Fire Department. These permits contain the address, name, and occupancy of the building. Being a public assembly means that these locations are open to the public, which include restaurants, university departments, and other places of gathering. The following information in Figure 8 outlines the area of research and the information necessary to create the model:

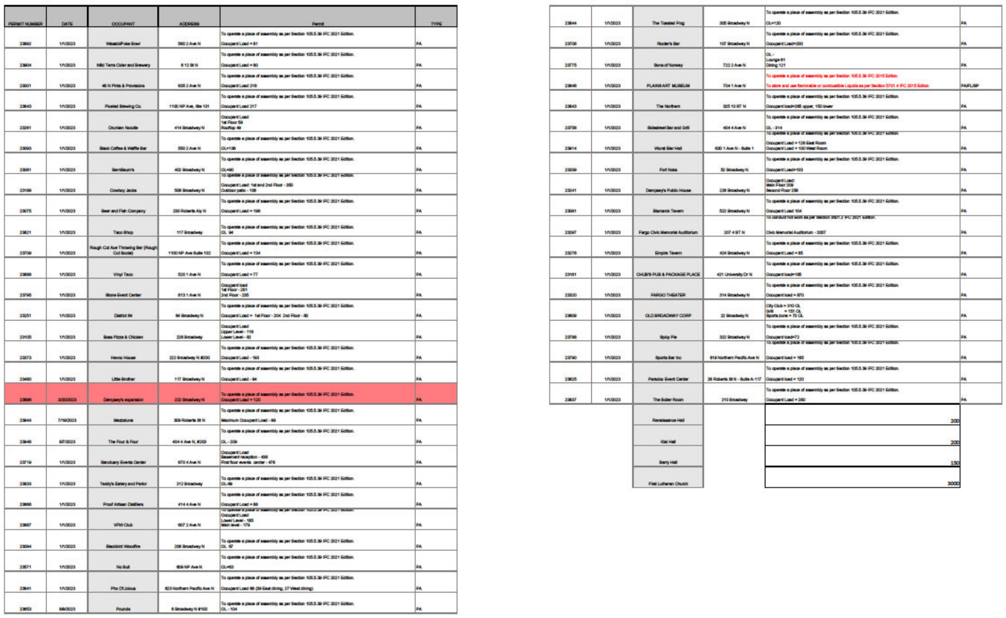

Figure 8. Public assembly information provided by city officials.

Within each block holds adjustable variables that impact the model's performance. Additional code can also be added for advanced models. Each block can be changed separately to become unique. Major variables include the location, rate, probability, speed, capacity, and delay time. For example, two Delay blocks can have different locations with different capacities. By measuring these variables, a diagram of the information simulation is possible, both at the end of the simulation and when it is currently running. Figure 9-10 portray the Delay block settings and final diagrams produced by the running simulation. It is worth noting that these diagrams provide occupancy of used parking spots and vacancies of the parking locations.

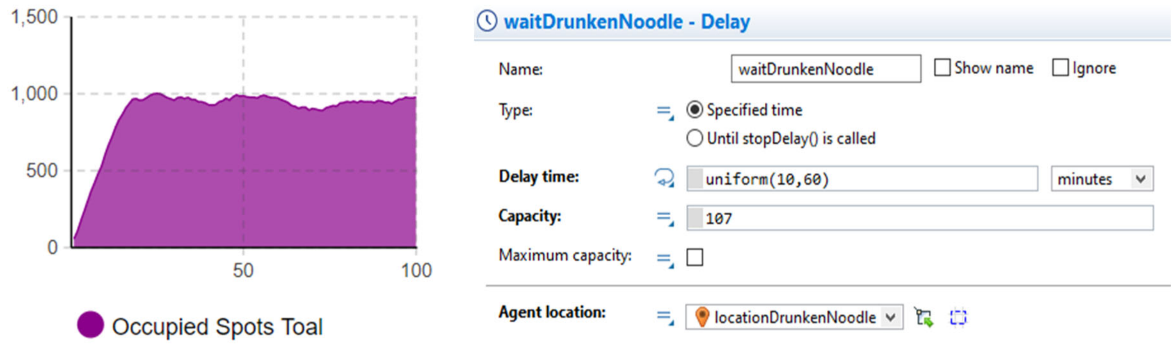

Figure 9. Fall semester diagrams.

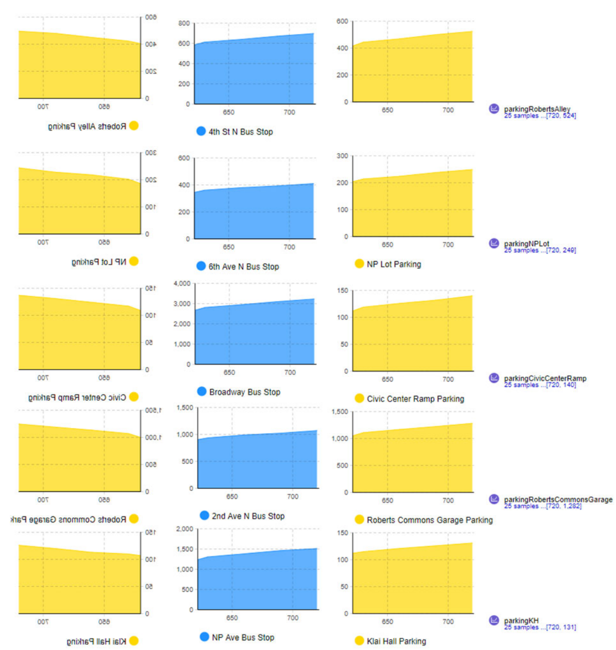

Figure 10. Fall semester diagrams of parking vacancy.

In AnyLogic, blocks are used to define where the pedestrian starts, moves, waits, and stays. The Source Block, for example, defines where the pedestrian begins in the simulation. They can start from a certain point of the map (building) or in a defined area (downtown area). In the Source Block, we can set parameters that define how the pedestrian acts or moves, such as arrival rate and speed. Figure 11 outlines how these blocks can come together to create a functional simulation. The following section provides the initial idea of the simulation process:

- Hierarchical Model: Start at Downtown Building > Move to another Building > Loop or go to nearest Parking Lot
- Distributed Model: Start at Downtown Building > Move to another Building > Loop or go to a Parking Lot
- Intersectional Parking Model: Start at Downtown Fargo > Move to nearest intersection > Move to nearest Parking Lot > End
- Centralized Parking Model: Start at Downtown Building > Move to nearest Bus Stop > Move to Central Parking Location > End
- Bike Traffic Model: Start at Downtown Fargo -> Move to Building > Move to Building > Loop or End

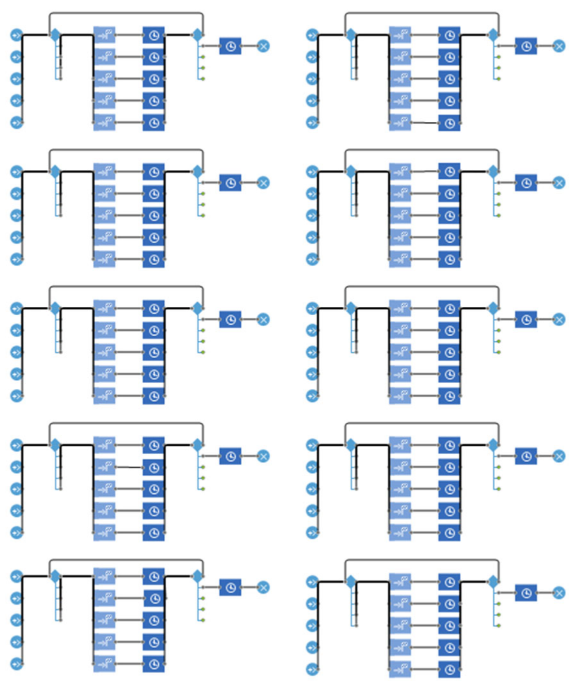

Figure 11. Fall semester logic.

Altogether, these blocks can be connected to simulate pedestrian movement. Additional coding is used to simulate pedestrian movement to the nearest destination. For example, Figure 12 includes the pedestrian movement towards the nearest defined destination. In this case, it is a parking spot.

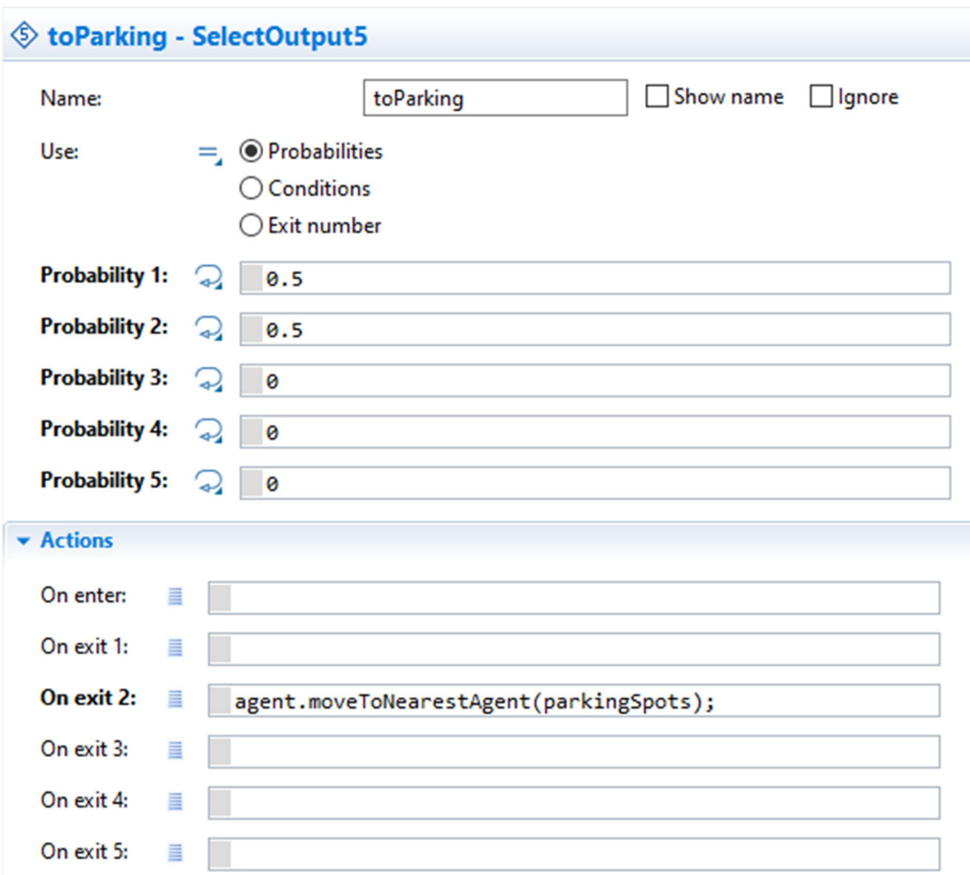

Figure 12. Travel to nearest function.

The results provide just an example of what information can be accessed from a smart city simulation. This includes the time it takes to move between points and the number of pedestrians moved in this way. Varying information from the graph sections are resulted from the “MoveToNearest” line of code which redirects the pedestrian’s path of travel. For example, if a pedestrian wants to go to the nearest parking space or lot, the pedestrian will not choose one the furthest away.

The amount of time it takes from one point to another can show if the downtown area is "walkable" or accessible by foot traffic. If the parking locations are farther away, the data would result in a longer time and distance traveled. In this way, urban planners can use this information to find areas of issue and perhaps adjust the urban area to accommodate pedestrians.

The following diagrams, Figure 13-16, show the spring semester logic blocks to create a more advanced model. They explore alternative means of travel while studying the accessibility to certain amenities, such as green spaces, bus stations, certain stores, and apartment buildings.

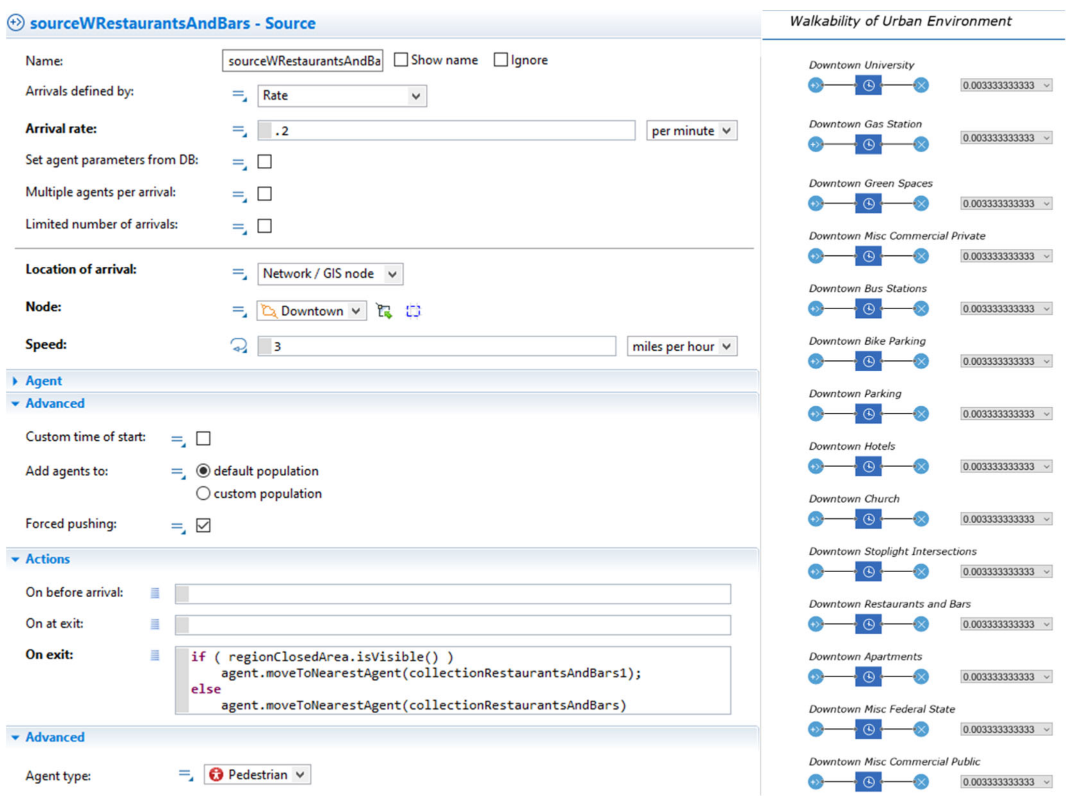

Figure 13. Event scenario function and final foot travel logic.

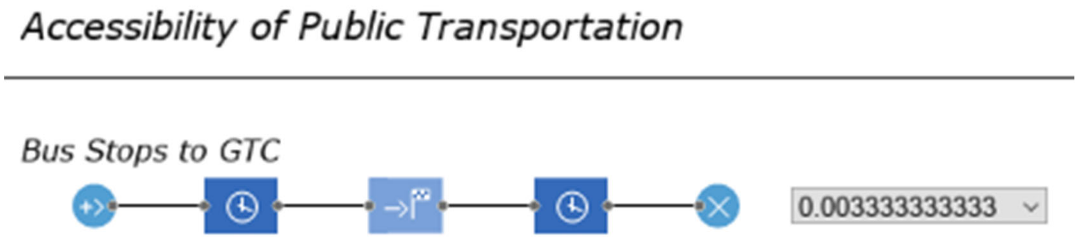

Figure 14. Final public transportation logic.

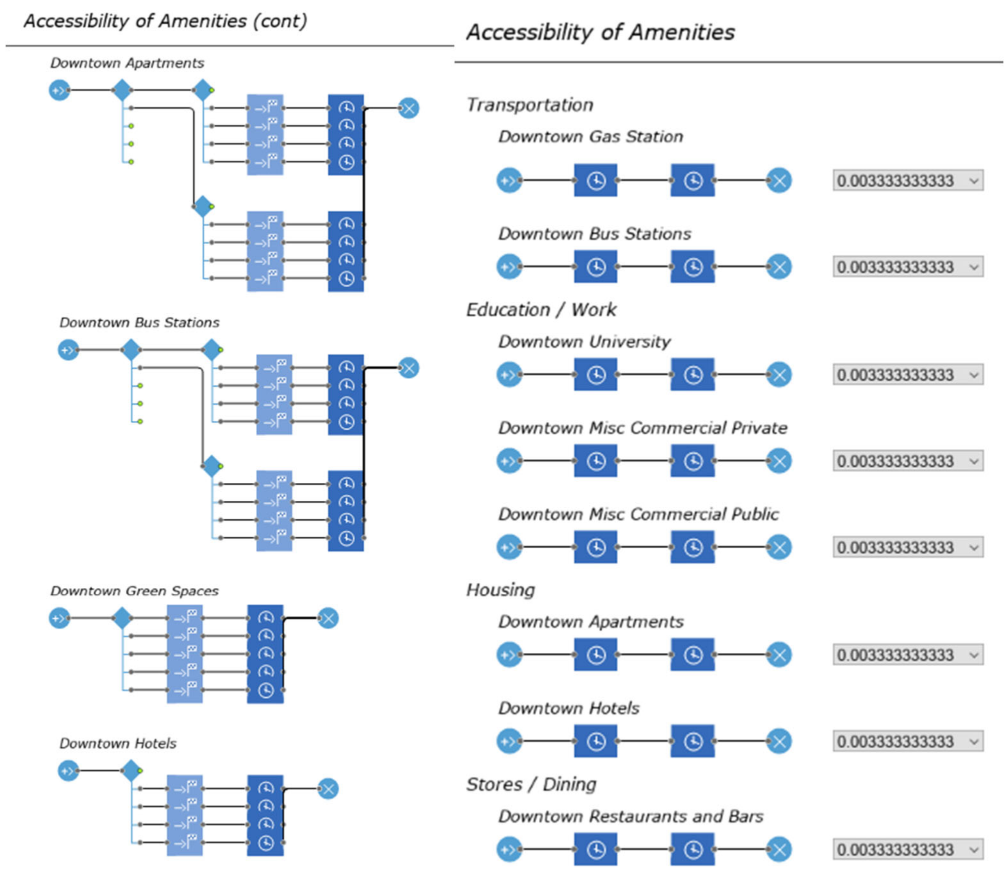

Figure 15. Final accessibility of amenities logic.

Figure 16. Final alternate transportation methods logic.

4.3 Project Design and Documentation

For the spring semester, a more advanced GIS map was created to accurately produce data in the downtown area. This includes modeling all the main buildings, parking locations, and green spaces. With more location the pedestrians can travel to, the simulation becomes more dynamic. However, architects and urban planners may find some issues worth exploring. It is important to note that these challenges can be overcome with more accessible information and team integration. Through the creation of the simulation, four main challenges arose to overcome:

- Time to produce. Further Advanced models could result in taking a vast amount of time to produce. For comparison, the fall semester model only has fifty buildings and forty-five parking spaces. If the advanced models include residential buildings and private buildings, more time could be needed.
- Computational limitations. Modeling a specific zone is more feasible compared to the entirety of the city. However, it may be possible with efficient resources.
- Multiple departments are needed for information. The collaborative effort of universities, city departments, historical preservation, and private businesses is needed to require accurate information of occupancy and other additional information. In Fargo's case, private buildings and older/historical buildings must be individually accessed. This can vary from city to city depending on if the information is archived. Overall, this may take a large amount of time and money.
- Zoning. In the case of mixed-use buildings, the contrasting use of spaces between private and public areas can prove to be difficult to access necessary information.

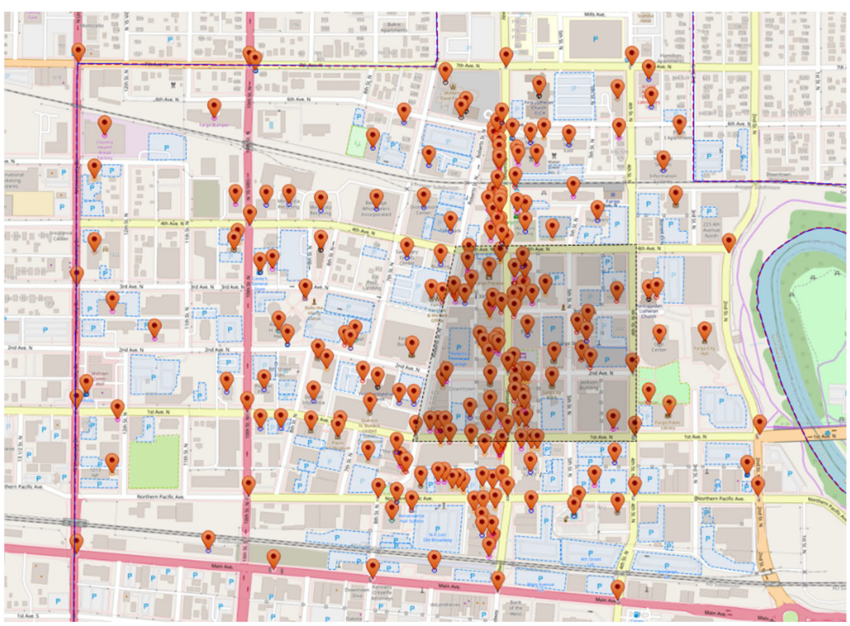

Figure 17. Spring semester final digital AnyLogic model.

While the challenges of smart city modeling are proven to be difficult to overcome, benefits such as designing for efficiency to benefit the health and wellness of the pedestrian outweigh these difficulties. This research mostly focused on the efficiency of downtown Fargo vacancies. However, with future improvements and accessible information, future models can become more advanced and provide numerous benefits regarding the urban environment. Complex systems are capable of adaptation to changing conditions, often in more ways than one (Levy et al, 2016). As such, these simulations can be adjustable to certain scenarios of the project location, and do not specifically have to follow a specific workflow. However, distance and time are the key factors of pedestrian mapping that overall results in pedestrian efficiency. Figure 18-25 are the results of the spring semester simulation. These diagrams explore multiple means of transportation in the downtown area, such as foot travel, bus transportation, bike travel, and car travel. Additionally, an event scenario is studied to see how the average travel time changes when an entire area is removed from the simulation. In this case, Figure 17 shows a black square around an important block of the downtown area. This scenario, when the event is triggered, blocks pedestrian movement in the indicated area. As a result, the nearest movement travel can change drastically which increases possible travel time.

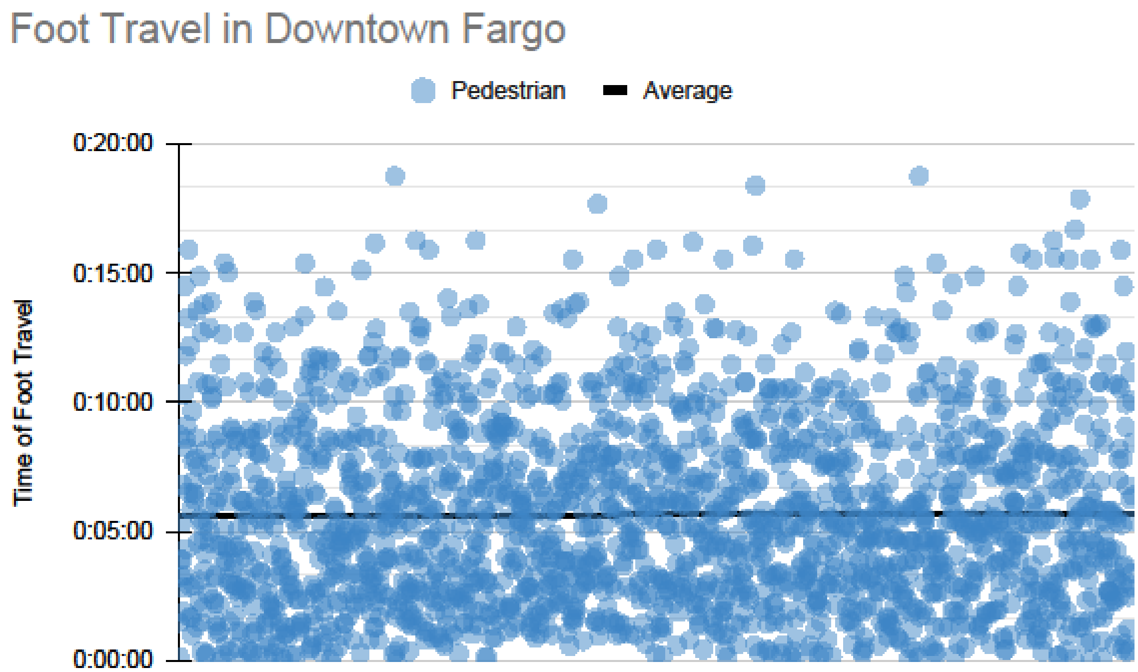

Figure 18. Foot travel in downtown Fargo results.

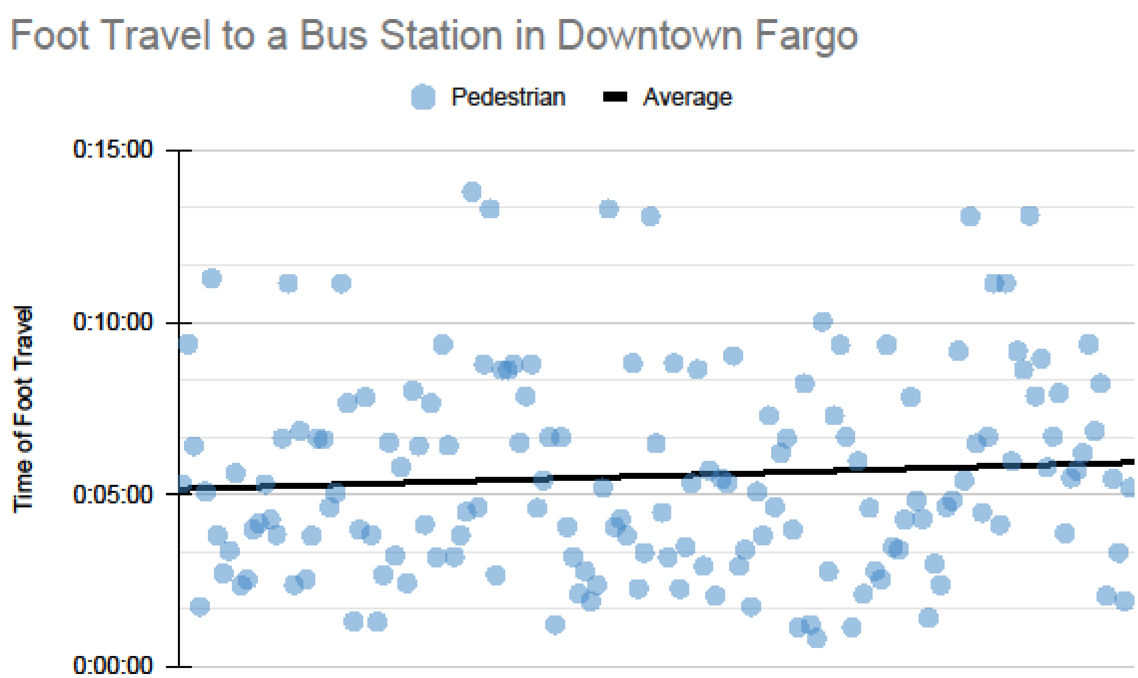

Figure 19. Foot travel a bus station in downtown Fargo results.

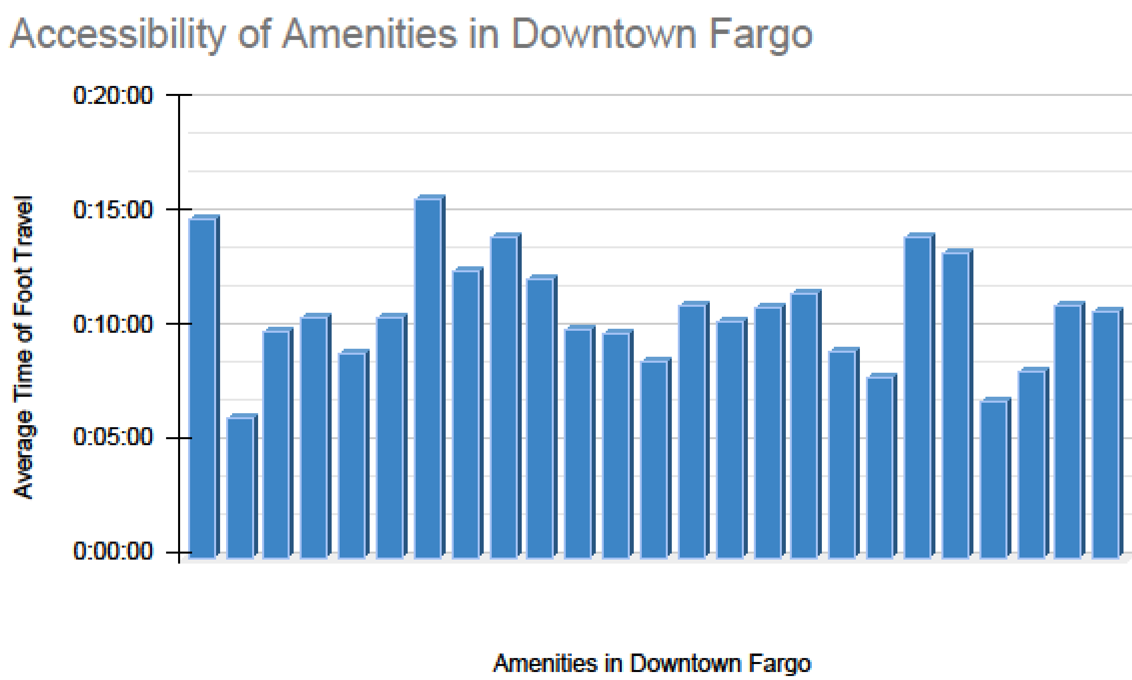

Figure 20. Accessibility of amenities in downtown Fargo results.

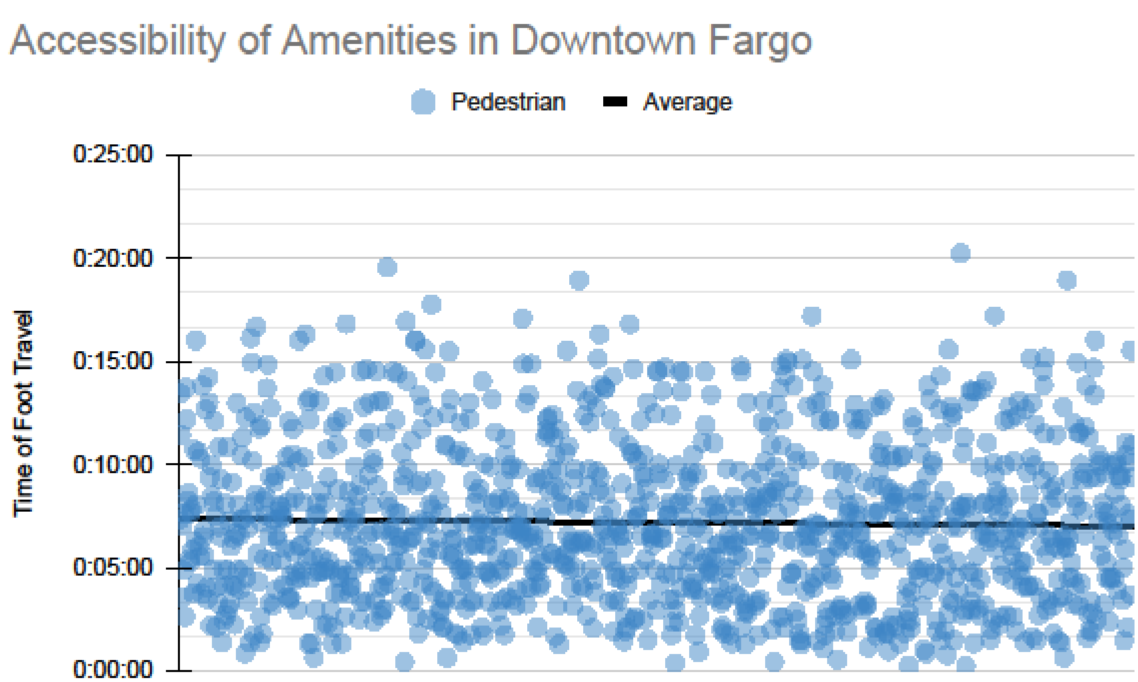

Figure 21. Accessibility of amenities in downtown Fargo results.

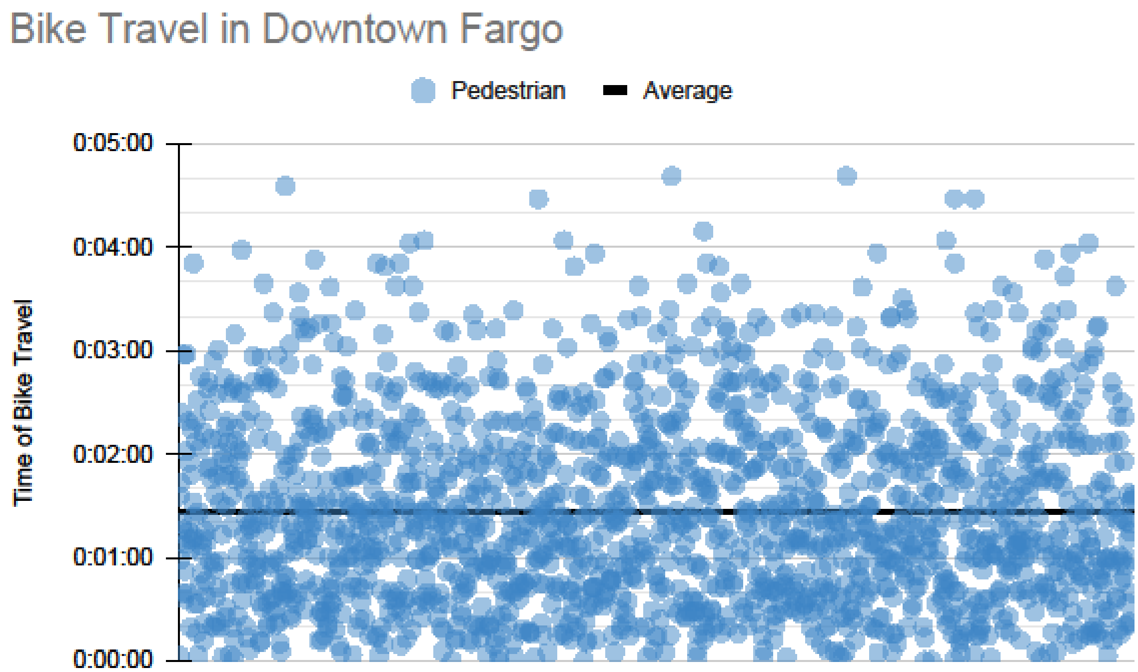

Figure 22. Bike travel in downtown Fargo results.

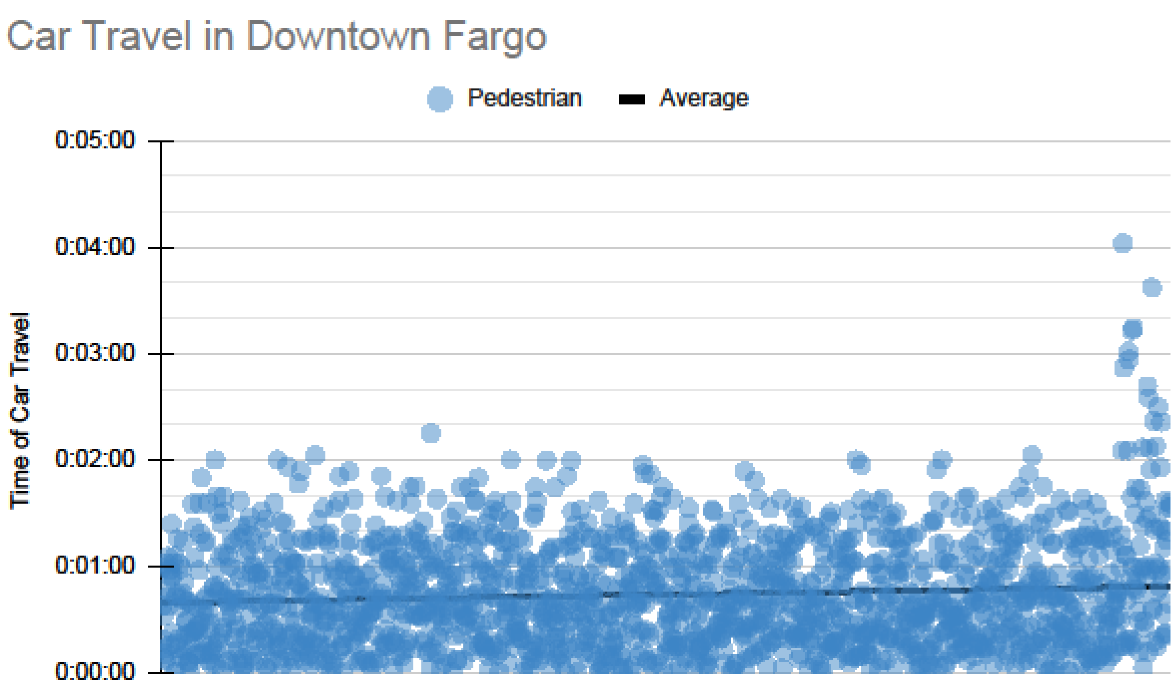

Figure 23. Car Travel in downtown Fargo results.

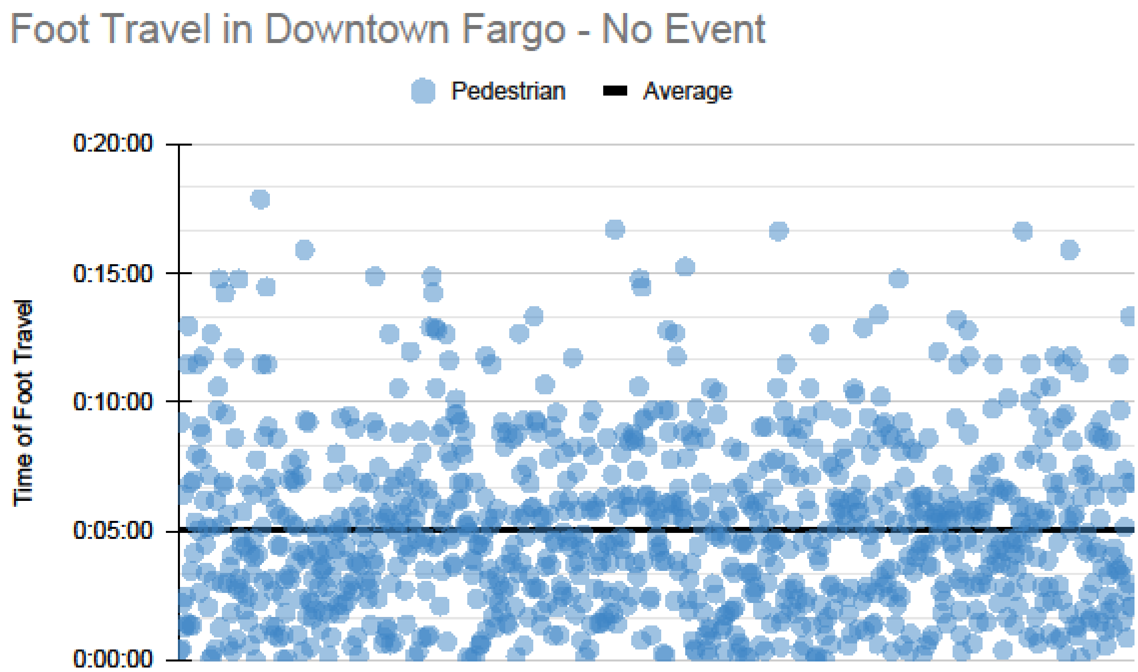

Figure 24. Event scenario foot travel without the event.

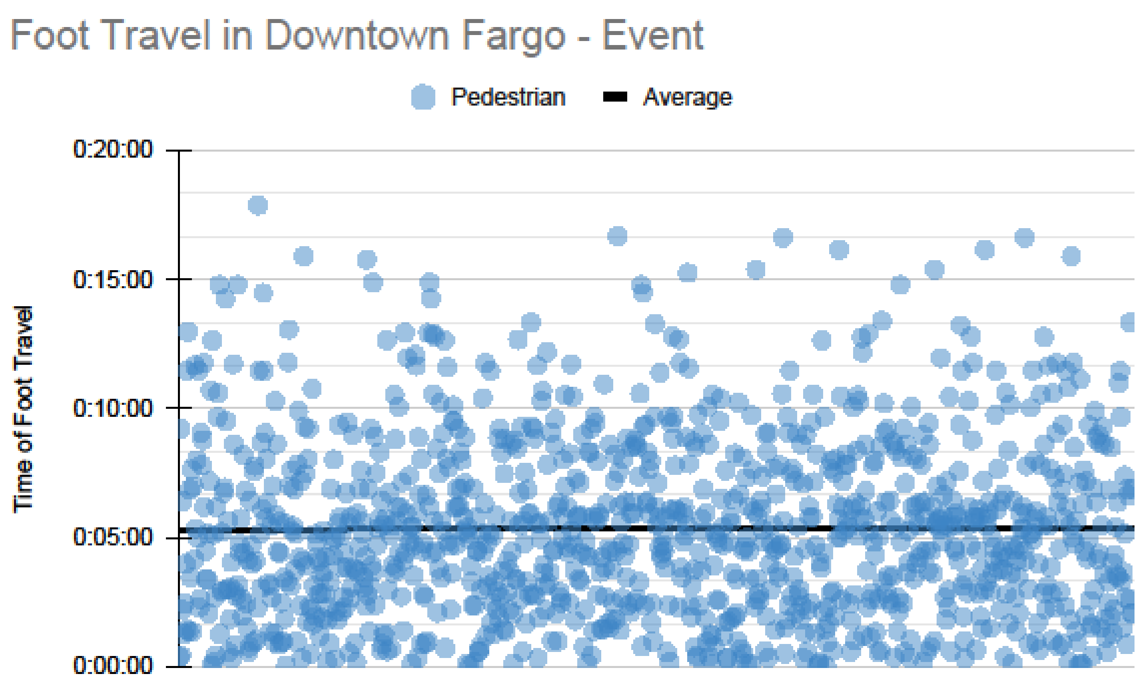

Figure 25. Event scenario foot travel with the event.

4.4 Conclusions

By examining multiple pedestrian simulations, the model during simulation exhibits plenty of movement in the downtown area. In addition, these studies were documented through a dataset that could record the pedestrians' movement and travel distance. Through this data, diagrams can be created to dictate the walkability or efficiency of the urban area. In this case, downtown Fargo meets expectations of a walkable urban environment while also providing accessible alternate means of transportation.

Real world uses such as showing the distance to necessary or common building types are important to show the walkability of urban environments. While the models only simulate the downtown Fargo area, future models could perhaps simulate an entire city. This would result in a more advanced and accurate model.

Using GIS integration with AnyLogic provided accurate locations and distances which helped with overall organization and efficiency. However, new city designs can still use this workflow, but sidewalks, roads, and buildings would have to be modeled from the ground up.

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