Vehicular Traffic Modeling Governed by Cellular Phone Trajectories

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***Abstract*— This paper briefly outlines the combination of an Agent Based Modeling (ABM) framework for modeling the flow of traffic in an urban center, using a 3D gaming platform and incorporating real world data extracted from cell phone trajectories to guide agent movements. Results are compared against two other sets of real world data. The model validation shows considerable promise both for the simulation itself and the use of cellular location data to infer traffic patterns.**

Keywords- Agent Based Model, Serious Games, Intelligent Traffic Systems.

1 INTRODUCTION

As access to data from cellular service providers improves, there is a tremendous opportunity to utilize these data within simulations of a traffic modeling environment. Modeling interactions between vehicles, pedestrians, and infrastructure is a very complex problem, exacerbated by the fact that most agents are stochastic, as well as the fact that assumptions concerning rational behavior may not always be accurate.

Although transportation engineering and planning has all of the apparent accoutrements of a reliable, replicable scientific approach to problem solving, ultimately, traffic generation is a social phenomenon, which introduces a measure of unpredictability and emergence in the process. For example, higher fuel prices, a major social event or weather can influence social behaviour markedly in the way that people choose to take a trip, when to take it, how they take it, the routes chosen, or indeed whether they take a trip at all [1].

In these situations with considerable unpredictability, one of the most reasonable modeling paradigms is an agent based model (ABM) approach, where one of the methodology's strength is to model a system from the ground up and its potential to capture emergent behavior [2]. In most environments, the traffic control system is not responsive in "real time" but rather governed by historical averages and expert estimates, as well as intuition and experience tuned to average or typical patterns of behavior and traffic flow. The future holds the potential of using real time data for highly responsive real time control systems vetted in ABM simulations. Even under these circumstances, there are situations that will likely arise that would be difficult to predict (emergent behavior) but where interventions could be studied and be put in place to mitigate or minimize the detrimental impact associated with this type of self organization.

Emergent behavior arises as a collection of individual behaviors interact, and where their behavioural 'whole' is greater than, or qualitatively different than the individual contributions. Often the individuals are simple agents with relatively simple rules of behavior. The most extreme variation of these ideas from a computation perspective is associated with cellular automata [3]. Although interesting, they are not the best suited for modeling complex systems involving more complex agents such as would be the case with traffic flow in an urban area, due to their difficulty in modeling heterogeneous agent behaviours [4].

The contributing technologies to improve or assist in wireless application assisted traffic control management include:

- The ability to collect data in real time from a statistically meaningful sample, providing a statistically meaningful representation of pedestrian and vehicular traffic.
- The ability to generate models of existing urban area in requisite detail to model pedestrians and vehicles.
- The ability to combine real data (from multiple sources where available) with an underlying topographical model, providing the framework for an ABM with instrumentation to allow for predicting or detecting emergent behavior.

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- The ability to invoke controls to better manage real traffic based on predictions and feedback derived from the ABM modeling efforts.

The contribution of this work arises from the novel combination of real data, ABM, and high fidelity game technologies, which together provide a very powerful platform for traffic control engineers. The long term objective of this research is to demonstrate aspects of infrastructure modeling and the incorporation of an ABM within that framework for simulating and modeling pedestrian and vehicular traffic and their interaction with as much real data as possible.

2 FRAMEWORK OVERVIEW

Rather than building the software completely from the ground up, several off-the-shelf software suites were combined to provide a highly visualized means of traffic simulation. This helps to ensure "higher quality [software]… as one can assume that these components are used in different games, different environments; more rigidly [tested] and [stressed] the quality of the component rather than in a single game setting" [5].

For the ABM ITS prototype, the Unity Game Engine was used as the platform to build an urban traffic model. 3D models and street network were created and processed in Procedural's CityEngine (CE). CE was originally designed for artists as a tool to quickly generate urban environments based on simple rule sets defined either by Procedural or by the end user. However, since its initial release it has been expanded upon so that it can import real world data from several sources. Using CE, we were able to create a street network of Winnipeg from OpenStreetMap.org, an open source competitor to Google Maps.

From OpenStreeMap.org, the city of Winnipeg, Canada, a medium-sized urban centre of 700,000 residents, was exported. These data were then imported into CE as a graph representing the street network of the city. In this phase, CE is invaluable as it can easily import data provided by OpenStreetMap and offers tools for automatically or manually cleaning up or correcting errors in the data. Because of the importance of zoning information on the type and distribution of traffic, a zoning map of the city was imported into CE. This zoning map was used to guide the generation of buildings; i.e.: the downtown area generally should have office towers and residential areas should be made up of single- and multi-family dwellings.

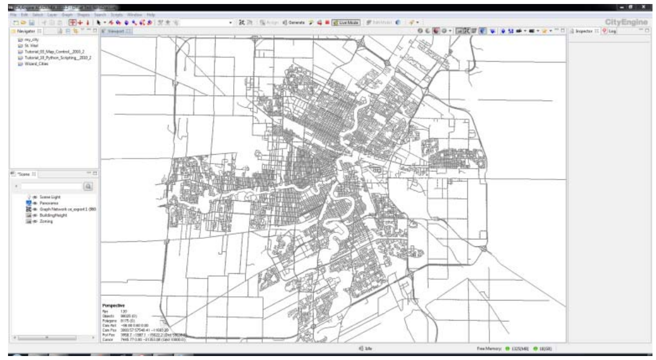


Figure 1: The street network as seen in CityEngine.

Because one of the goals of the research is to make the simulation usable as a serious game for transportation training and planning purposes, using a game engine as a base is very natural. Game engines generally incorporate renderers, user controls, physics models, networking, sound and other systems, saving considerable development time.

3 SIMULATION DESCRIPTION

Within the framework, there are several subsystems and data structures that work in concert to give the appearance of a living (if simplified) city. Of these, the most important are the agent behaviour system, street graph, and institutional models.

Street Network

In the model, the street network is represented as a graph. A graph is a good isomorphism to a street network in that intersections can be represented by vertices and streets represented by edges.

In our framework, traffic controls are simulated on vertices; street capacity and speed limits are represented by edge weights. For simplicity, we set the weights of edges to the geometric distance between their endpoints, for major arteries this weight is then halved to promote the use of main streets by agents in the model. Collisions are not currently modeled.

Because the street graph will be editable during a simulation run in the future (to model street closures, etc) precomputing shortest paths is not desirable; we originally tested live computing the shortest paths but the performance hit was too high. As a compromise, agents will find all paths up to ten edges long, and take the one that is ends the closest to their target. This helps prevent agents from becoming stuck in local minima in terms of their distance to target.

Cellular data have been provided to us courtesy of MTS Allstream (MTS), the province's largest provider of telecommunication services. The data provided gives an anonymized identifier to a cellular device and the antenna sector with which it is associated for the majority of any given hour. In spite of the data being relatively sparse, it provides remarkable correlations to data extracted by more traditional means, such as the Winnipeg Area Travel Survey

By using cellular trajectory and zoning data, vehicle (proxying for agent) behaviours similar to real world traffic systems emerge. Generally, many agents will move towards commercial or industrial areas in the morning, then back again to more residential areas in the evening. Even though the cell phone trajectory data is quantized to an antenna sector, the agent is constrained to proceed towards their destination along real roadways.

Agent Behaviour

Currently, agents move about the city along the edges defined in the street graph. In the current model, agent behaviour is driven primarily by data from MTS on agent movement patterns (times, origins, destinations, etc.) and trajectories. To move throughout the city, agents have a travel component that is activated and seeded with their target location(s). The travel component causes the agent to move along a path that follows the edges defined in the street graph on a path towards their goal. Most agents use these data to schedule their movement and will always know where they need to be next. They calculate the rough travel time required to reach their next location and generally leave their current area early enough to be on time.

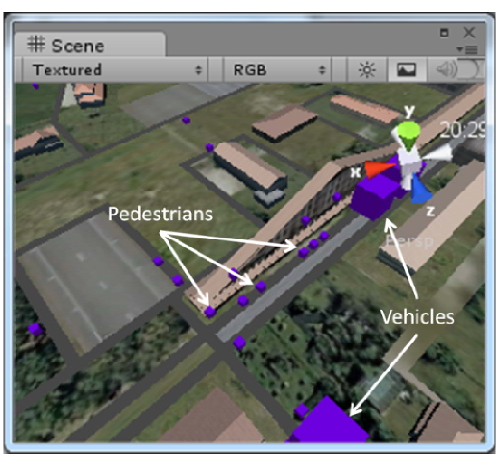


Figure 2: Large cubes represent agents in vehicles while small cubes represent pedestrians.

The other primary component within the agent model is a pedestrian component. Although it works in a similar fashion to the travel component, agent movement is slower and they move along the street graph in a random fashion but keeping them within a certain range of their target. Agents in both vehicle and pedestrian mode can be seen in the Figure 2. Pedestrians also have the option of entering an institution removing them from the simulation until another cell phone trajectory movement is encountered.

In the simulations, we used roughly 25,000 agents with each assigned their own schedule. This is a higher number of agents that have been used within the visualization framework thus far, as rendering considerations have kept the agent counts lower in previous simulations. The pedestrian modeling simulations are not used further here other than to illustrate the hybrid nature of the ABM agents.

Model Validation

In order to determine the validity of the model, we compare the results to the Winnipeg Area Traffic Survey (WATS) [6] conducted in 2007 as commissioned by the City of Winnipeg. The WATS report includes how many people made trips, their districts of origin and destination, and the period of day during the day these trips occur.

In the WATS data set, approximately 32,700 users recorded over 88,000 trips over various modes of transportation. The final dataset represents 4.4% of all households within Winnipeg. Given the size of the dataset and the information included, it was an obvious choice to use for a comparison of results generated via simulation.

To see if the model behaves as expected on a more local level, certain intersections have traffic counters simulated. In the model these are Bluetooth tracking devices although any other traffic counting means would be sufficient. These can also be used to validate the model as well as the Bluetooth ITS technologies when they become more widespread in the future. In Figure 3, a traffic counter can be seen on a downtown bridge; the tracker is represented as a blue, semi-translucent sphere. Figure 4 illustrates the placement of a Bluetooth tracker on a major thoroughfare. For the purposes here, the Bluetooth tracker is merely a means of collecting arterial flows of cell phone trajectories.

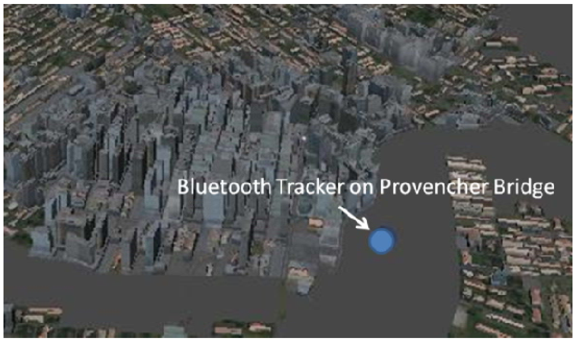


Figure 3: Zoomed in Bluetooth tracker on a major ingress/egress point to downtown

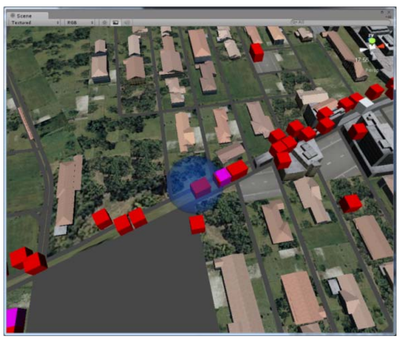


Figure 4: Zoomed in Bluetooth tracker on a major thoroughfare (e.g. Portage and Wolseley)

4 Results

As the work is still in early validation phases, this section focuses on high level data such as trips made per hour. To validate more localized behaviours, we will focus on trips made to the downtown region of Winnipeg. This also allows comparison with survey data extracted by other means.

As can be seen in Figure 5, there is a large disparity between the numbers of trips per hour as derived from WATS and from our simulations in absolute terms. Primarily this is due to the fact that Winnipeg has a population of 700,000 and our simulation only has a population of roughly 25,000 agents. However, even though this is the case, similar patterns and features can be seen in both distributions. Local minima and maxima occur at roughly the same time periods each day. In addition, the WATS graph is also scaled as the survey only sampled 4.4% of Winnipeg. Additional discrepancy would be related the fact that the data was collected approximately three years apart.

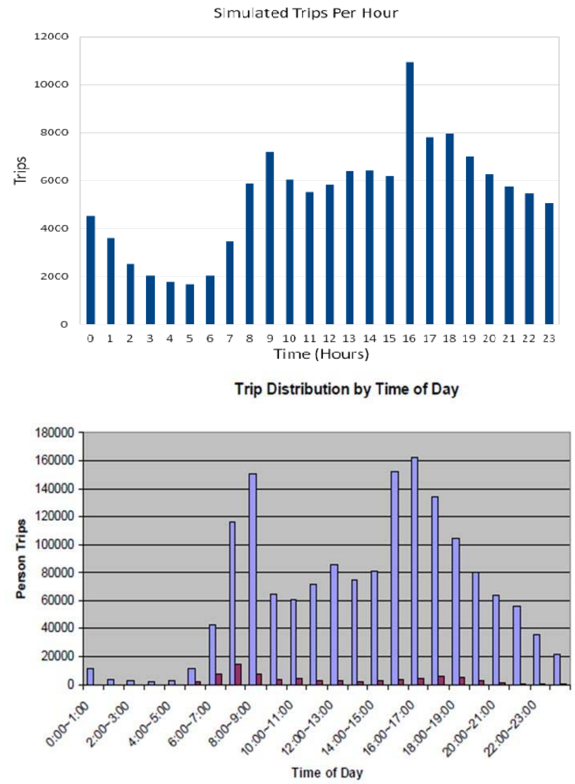
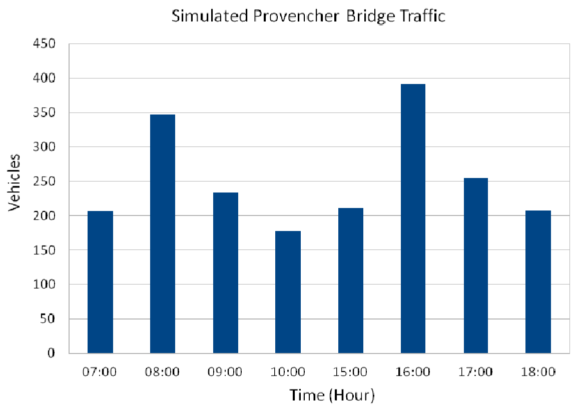


Figure 5: (Top) The results of our simulations based on cellular data provided by MTS. (Bottom) The trip distribution by time of day as reported in the WATS Report.

As illustrated, the number of trips lulls between midnight and roughly 6:00 a.m., when they spike. There is again a reduction in the amount of trips made until the early afternoon and a sharp increase in the number of trips between 4:00 – 5:00 p.m., followed by a steady decline into the evening and night.

Presumably, this pattern typifies a population that predominantly moves from residential to downtown areas for work-related reasons, on a regular daytime schedule, in addition to attending to responsibilities in the evening.

Although the simulation numbers are much lower, the graph in Figure 6 demonstrates similar qualitative features. In this more local comparison, the features are not as similar as in the global comparison, however, peaks occur at the same times of day.



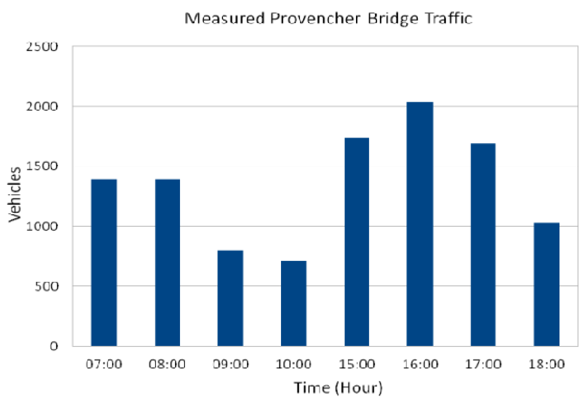


Figure 6: Comparison between measured and simulated traffic during peak simulated traffic. In each graph, the first four measurements are westbound, and the final four are eastbound.

Although these results show promise for both the simulator and the use of cellular service data for inferring a population's mobility patterns in an urban center, there is still much work to do. The test data received from MTS only covers a five-day period in Fall 2010 and has many gaps. These gaps represent periods in time where we do not have a record for an individual; this could mean that they have shut off their cellular device. With a larger number of records the gaps in any individual's record will have a smaller impact on the overall simulation results, and we are currently receiving a more extensive data set from MTS for future work.

5 CONCLUSIONS AND FUTURE WORK

This work has demonstrated the considerable potential of combining real data, ABM, and high fidelity game technologies. The results compare favorably with survey and mechanical counters and have the potential to replace these types of cumbersome data collection methods with automated techniques leveraging the prevalence of Smartphones and their related infrastructure technology.

In the future, the simulator will undergo "gamification" [7] so that users (traffic engineers/city planners) can influence traffic flow throughout the simulation manually. This will allow users, the use of the simulator as a place where one can experiment with road closures or openings, changes in population density, etc in a low-cost virtual space. One advantage serious games provide is as a means of communicating in an easily recognized "lexicon" [8], however, possibly more importantly is that such a tool can decrease the cost of training new planners as well as making their training more engaging [9].

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