4th International Conference on Countermeasures to Urban Heat Island, 30-31 May and 1 June 2016,
National University of Singapore, Singapore

Analyzing The Impact Of Driving Behavior At Traffic Lights On Urban Heat *

Wagner[1] and Viswanathan[2]

[1] *Michael Wagner, TUM CREATE, michael.wagner@tum-create.edu.sg*
[2] *Vaisagh Viswanathan, TUM CREATE, vaisagh.viswanathan@tum-create.edu.sg*

Keywords: Modelling, Simulation, Urban Traffic Thermodynamics, Cellular Automata

Abstract

Studies have shown that traffic contributes up to a third of the anthropogenic heat produced in urban areas. To study localized effects of traffic on urban heat, conventional thermodynamic models are only of limited use because of their computational costs or low resolution. We are using our recently proposed Cellular Automata (CA) based Anthropogenic Heat Simulation to examine heat effects of dynamic traffic flow in close proximity to traffic lights. In this work, we use our method to study the impact that driving behaviour near a traffic light can have on urban heat.

1. Introduction

The term Urban Heat Island (UHI) describes urban and metropolitan areas with measurably higher temperature compared to their surrounding rural areas. In tropical cities with high amounts of sun radiation year round and waste heat from air conditioning this difference can reach up to $7°$C. For Singapore, (Quah & Roth, 2012) estimates that traffic alone is responsible for up to 30% of the anthropogenic heat emissions, making it the second highest contributor after built environment. This is reason enough to have a closer look at the contribution of traffic to UHI, possibly leading to mitigation strategies. The past has seen development of numerous thermodynamic models for heat flow and heat emissons. Computational Fluid Dynamics (CFD) can yield very accurate and detailed representations of local physical processes. Other models like the Urban Energy Balance (UEB) take a more macro scale approach and aim at quantizing energy propagation rather than localizing it. The challenge in simulating the heat emissions from traffic is that it falls into a niche between both extremes. CFD models are only viable in static scenarios and energy balances like the UEB lack all spatial information. We recently proposed a Cellular Automata based Traffic Heat Simulater (THS) (Wagner, Viswanathan, Pelzer, Berger, & Aydt, 2015) that can address this issue. In this paper, we present a more advanced version of the THS and use it to analyze the impact of driving behavior on anthropogenic heat. The paper aims to highlight the impact that Intelligent Transportation Systems of the future can have on UHI and also the usefulness of our technique for studying these impacts.

2. Related Work

Numerous models have been proposed for simulating propagation of thermal energy. They can be distinguished by their level of detail and the methods they use. CFD models are most famous for their

*This work was financially supported by the Singapore National Research Foundation under its Campus for Research Excellence And Technological Enterprise (CREATE) programme.

accuracy (Blazek, 2005; Wesseling, 2000), which comes at a cost. This kind of simulation is generally aimed at small scale scenarios, e.g., individual vehicle parts. It is also not suited for application in dynamic scenarios, like traffic flow on roads or intersections. On the other end of the spectrum UEB models are designed to simulate energy transfer over large urban areas (Grimmond et al., 2010). In contrast to CFD there is no spatial propagation modeled is the UEB is entirely focused on quantifying the energy exchange. The work of (Ksaibati et al., 2002) examines heat propagation within the pavement layer. They propose a network-based model of heat dissipation inside pavement layers using a *finite difference mesh*. Similar to a CA, the pavement layer is modeled in form of a grid where the thermal energy is propagated between neighboring nodes. Although this work does not include any energy fluxes from vehicles it offers a valueable approach of how solar radiation and other meteorological processes can be represented in a grid based model. Other emission models have been conceived for qualitative measurements instead of spatial ones. The work by (Prusa, Segal, Temeyer, Gallus, & Takle, 2002) explores heat emissions on a local level. While only making quantitative statements about vehicle heat emissions and omitting spatial propagation, it does deliver a detailed description of the involved processes.

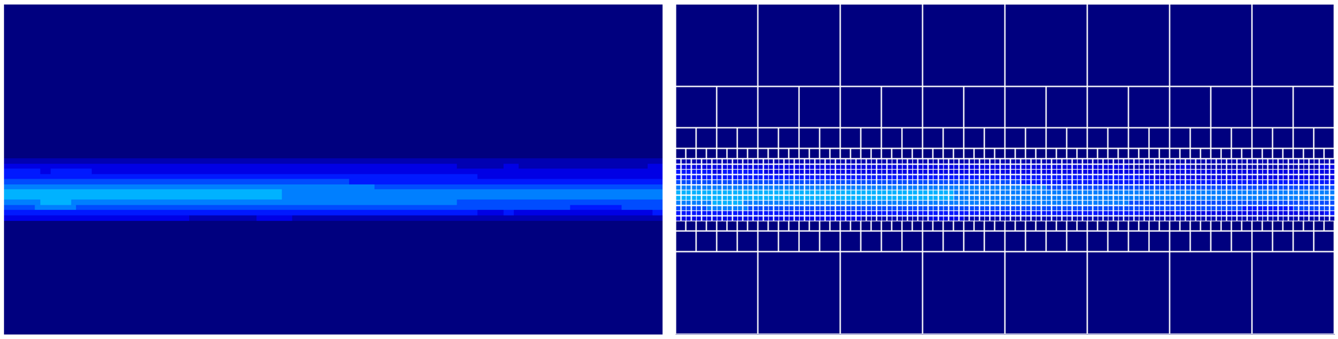
The model used in this work discretizes space and time. Furthermore, the state space of a CA model is also discrete and finite. In each time step the values of all cells are updated synchronously based on the values of cells in their neighborhood. Depending on the type of neighborhood (i.e., von Neumann, Moore), and the type of lattice (triangular, square, hexagonal, etc.), the exact number of cells in the neighborhood of a given cell can vary (Hoekstra, Kroc, & Sloot, 2010). CA models are popular for modeling systems that would be complicated to model mathematically but can be approximated reasonably by a simulation model that is discretized in space and time. For example, indoor egress simulations use CAs to approximate fire/ smoke propagation (Aydt, Lees, Turner, & Cai, 2014). Driver behavior patterns and variations thereof are a widely accepted way of regulating fuel usage and, consequently, carbon emissions (Barkenbus, 2010; Alessandrini, Cattivera, Filippi, & Ortenzi, 2012). In a similar vein, in this work, we use the THS to examine the effect that behavioral patterns in driving can have on *heat* emissions.

3. Urban Traffic and Thermodynamics Model

The system we use consists of two main components: traffic generation and the physical simulation. The former is done by SEMSim, a nanoscopic agent-based traffic simulation which can simulate road going traffic up to a scale of a whole city (Xu, Aydt, & Lees, 2012; Viswanathan et al., 2016). Nanoscopic in this context designates the high level of detail of the simulation. Each vehicle is considered an autonomous agent and all its subcomponents simulated individually.

The cellular automaton approximates the spatial propagation of thermal energy by discretizing the simulated space. The computational model is explained in more detail in (Wagner et al., 2015). Here we briefly give an overview of the workings of the model and focus on the differences. It uses the vehicle power output and traces generated by SEMSim. With this information the cellular automaton can then project emissions into the discretized space and simulate the heat propagation there. Important here is that cell size can be varied to balance between accuracy and computational costs. Smaller cells increase the accuracy of the physical simulation while considerably increasing the required runtime. Within the context of this work we are using a straight one way road section for the sake of simplicity. However, in general the CA can process any kind of two-dimensional road layout and is not restricted to one-way roads.

To cope with the extensive amount of computational time and memory space required to run this automaton, the CA was modified to make use of a dynamic grid resolution. At simulation start the CA consists of a single large cell. If a temperature change is detected in the system, i.e., by vehicles entering the scene, the inital single cell is split into subcells according to the octree hierarchy (Meagher, 1980). This means physical processes can be locally simulated in the desired higher resolution while unaffected areas with homogeneous temperature remain clusters of low resolution, as shown in Figure 1. Furthermore free convection has been remodeled to better fit into the CA concept as well. Instead of considering whole columns of air at a time for convective force, each cell now individually regulates its horizontal in- and outflow of energy. This happens according to temperature and density differences between horizontal



(a) Temperature Visualization of the asphalt in a subsection of the CA

(b) Temperature Visualization with CA grid overlay

Figure 1: Left: Average air temperature development in the simulated environment over time. Right: Average asphalt temperature development in the simulated environment over time.

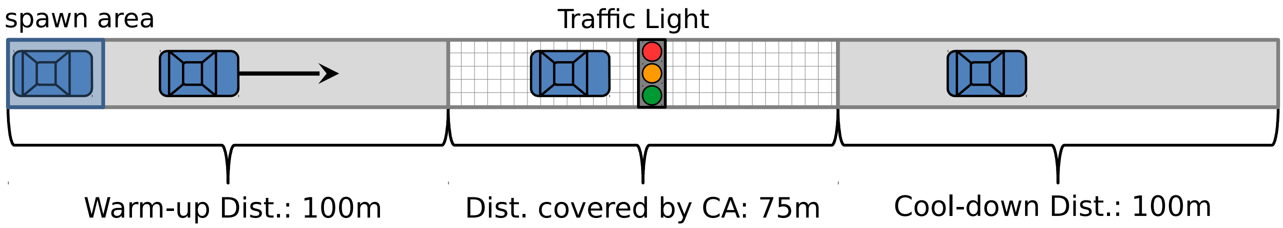
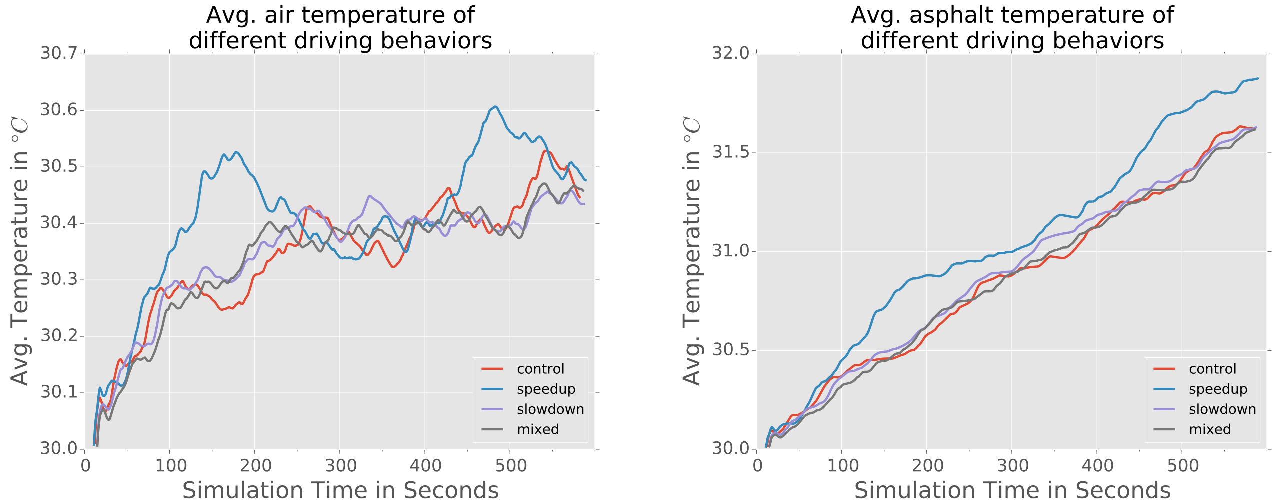


Figure 2: The setup of the vehicle experiments. (Illustration not to scale)

neighbors. The aim of this work is to demonstrate the usefulness of the model in studying the impact of different driving behaviors at traffic lights. Similarly to how driver behavior can influence the fuel economy it may have an effect on heat emissions as well.

4. Experiments

In order to measure the driver behavior influence on the average environment temperature, we simulate three behavioral patterns used by motorists when approaching a traffic light. First *speedup* behavior is defined as drivers accelerating during a yellow phase to pass the traffic light before it turns red. If this behavior is successful the vehicle does not need to come to a halt at all. On the other end of the spectrum, drivers with *slowdown* behavior approach a red traffic light very slowly in order to reach it just in time for it to shift to green again. As opposed to the first prototype this only works if the traffic light is already red and there is sufficient distance to slow down without performing a full stop. Finally, *mixed* behavior is a hybrid of the first and second to try and combine both ways to a nominally more intelligent behavior. In order to measure the driver behavior influence on the average environment temperature, we are using the simulation system on an area of 75 by 75 meters. Our experiment setup consists of a straight section of road with a traffic light at the midpoint. For the sake of simplicity and reduction of variables in the experiment there is no intersection at the traffic light and vehicles all move in the same direction. Figure 2 shows the experiment setup of the simulation. The road is running through the middle of the simulated area and in total stretches over a length of 275 meters. Start and end point of the road are equidistant to the centre and situated a hundred meters outside of the area boundaries to allow for a warmup and cooldown phase for each simulated vehicle. One simulation run lasts for 10 minutes of simulated time. During that time vehicles will be created by a poisson process. The random distribution affects the delta time between each vehicle initialization. This allows an isolated warm up for each vehicle before entering the section of the road within the area of interest. That area describes the section of



(a) Average Air Temperatures per Driver Behavior (b) Average Asphalt Temperatures per Driver Behavior

Figure 3: Left: Average air temperature development in the simulated environment over time. Right: Average asphalt temperature development in the simulated environment over time.

the road covered by the CA, a square area of 75 meters side length and 5 meters in height. The CA uses a three-dimensional grid of cubic cells side length of 15 cm. This size was chosen to achieve a grid resolution high enough for sufficiently accurate physics simulation while keeping computational costs and runtime at an acceptable level.

5. Results

Table 1 shows the average vehicle throughput for each driving behavior and the control group.

The simulation allows us to plot the temperature over time of the area of interest at a level of detail of 15 cm. Currently work is being done in developing visualizations that enable a better study of the simulated environment (Berger, Peter, Cristie, & Kumar, 2015). Figure 3 shows how temperature in the area changes over time. The air temperature in 3a displays notably more fluctuations than asphalt temperature as it is affected by more volatile dynamics. Heat emissions from the exhaust system and warmed up engine block are dissipated into the environment due to free and forced convection. Free convection describes the natural rise of heated air due to differences in density to colder air layers while forced convection arises from air turbulences caused by the vehicle movements. In comparison asphalt temperatures show much clearer differences. The pavement is heated up mostly by radiation from engine and exhaust pipes as well as tire friction. Thermal dissipation happens much slower in solid materials, by conduction within the asphalt and convection from asphalt to air. Among all driving behavior variants in 3b, *speedup* stands out. The average temperature measured during these runs is consistently higher than in the other cases. It can be assumed that this is caused by the continued accelerations towards the end of green phases, as the vehicle throughput for other behaviors (Table 1) is not significantly different in comparison.

Table 1: Vehicle Throughput over Traffic Light per Driving Behavior

Behavioral Pattern	**Avg. Count**	**Max**	**Min**
Control Group	236	255	216
Speedup	246	266	229
Slowdown	248	271	227
Mixed	255	271	242

6. Future Work

In this work we present an agent-based simulation system for experimentally exploring anthropogenic heat emissions. We show its capability of simulating complex physical processes in a large scale dynamic environment. The system is aimed to be a tool for city planners and researchers who are interested to aid their design and development processes by explorative use of computer simulation. Future plans for the simulation encompass the integration of other environmental properties like buildings and trees as they are important factors for increasing and regulating the UHI. This will allow us to simulate complex feedback effects, e.g., heat radiation from buildings to the pavement and vice versa, heating up of vehicles which in turn emit more heat due to increased use of airconditioning systems. Its high level of detail enables the traffic simulation to simulate a wide range of possible scenarios. These include especially comparisons between physical effects of vehicles with certain engine types, i.e., internal combustion vs electric vs hybrid. Other subjects of interest are driving behavior patterns and information dissemination among traffic participants (Litescu, Viswanathan, Lees, Knoll, & Aydt, 2015).

References

Alessandrini, A., Cattivera, A., Filippi, F., & Ortenzi, F. (2012). Driving style influence on car co2 emissions. In *2012 international emission inventory conference.*

Aydt, H., Lees, M. H., Turner, S. J., & Cai, W. (2014). Toward simulation-based egress optimization in smart buildings using symbiotic simulation. In *Pedestrian and evacuation dynamics 2012* (pp. 987–999). Springer.

Barkenbus, J. N. (2010). Eco-driving: An overlooked climate change initiative. *Energy Policy*, *38*(2), 762 - 769. doi: http://dx.doi.org/10.1016/j.enpol.2009.10.021

Berger, M., Peter, B., Cristie, V., & Kumar, A. (2015). CAD integrated workflow with urban simulation-design loop process. In C. Brebbia & W. Florez-Escobar (Eds.), *The sustainable city x* (pp. 11–22). Southampton: WIT Press.

Blazek, J. (2005). *Computational fluid dynamics: Principles and applications (second edition)* (Second Edition ed.). Oxford: Elsevier Science. doi: http://dx.doi.org/10.1016/B978-0-08-044506-9.50017-5

Grimmond, C., Blackett, M., Best, M., Barlow, J., Baik, J., Belcher, S., . . . others (2010). The international urban energy balance models comparison project: first results from phase 1. *Journal of applied meteorology and climatology*, *49*(6), 1268–1292.

Hoekstra, A., Kroc, J., & Sloot, P. (2010). *Simulating complex systems by cellular automata*. Springer Berlin Heidelberg.

Ksaibati, K., of Wyoming. Department of Civil, U., Engineering, A., Yavuzturk, C., Consortium, M. P., & (U.S.), U. T. R. C. P. (2002). *Assessment of temperature fluctuations in asphalt pavements due to thermal environmental conditions using a two-dimensional transient finite difference approach*. Department of Civil and Architectural Engineering, University of Wyoming.

Litescu, S., Viswanathan, V., Lees, M., Knoll, A., & Aydt, H. (2015). Information impact on transportation systems. *(accepted by) Journal of Computational Science*.

Meagher, D. (1980). *Octree encoding: a new technique for the representation, manipulation and display of arbitrary 3-d objects by computer*. Rensselaer Polytechnic Institute. Image Processing Laboratory.

Prusa, J. M., Segal, M., Temeyer, B. R., Gallus, W. A., Jr., & Takle, E. S. (2002). Conceptual and scaling evaluation of vehicle traffic thermal effects on snow/ice-covered roads. *Journal of Applied Meteorology*, *41*, 1225-1240. doi: 10.1175/1520-0450(2002)041⟨1225:CASEOV⟩2.0.CO;2

Quah, A. K. L., & Roth, M. (2012, January). Diurnal and weekly variation of anthropogenic heat emissions in a tropical city, singapore. *Atmospheric Environment*, *46*, 92–103. doi: 10.1016/j.atmosenv.2011.10.015

Viswanathan, V., Zehe, D., Ivanchev, J., Pelzer, D., Knoll, A., & Aydt, H. (2016, January). Simulation-assisted exploration of charging infrastructure requirements for electric vehicles in urban environments. *Journal of Computational Science*, *12*, 1-10. doi: http://dx.doi.org/10.1016/j.jocs.2015.10.012

Wagner, M., Viswanathan, V., Pelzer, D., Berger, M., & Aydt, H. (2015). Cellular automata-based anthropogenic heat simulation. In *International conference on computational science 2015.*

Wesseling, P. (2000). *Principles of computational fluid dynamics*. Secaucus, NJ, USA: Springer-Verlag New York, Inc.

Xu, Y., Aydt, H., & Lees, M. (2012). Semsim : A distributed architecture for multi-scale traffic simulation. In *26th acm/ieee/scs workshop on principles of advanced and distributed simulation (pads).* Zhangjiajie, China: IEEE.