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A Microscopic Traffic Flow Model for Shared Space

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Affidavit

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and that I have explicitly indicated all material which has been quoted either literally or by content from the sources used. The text document uploaded to TUGRAZonline is identical to the present doctoral thesis.

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Abstract

Where multiple functions of roads interfere, conflict avoidance reaches human and technological limits and constitutes one of the major challenges in transportation engineering. In the last two decades, several concepts of self-explaining roads have brought versatile options to urban planning and have became valuable tools to manage heterogeneous traffic flows. Shared space and Begegnungszone ("encounter zone") are the most popular concepts for urban roads and squares. From a scientific and road planning perspective, there are still gaps in the understanding and predicting the complex interaction of different road users.

Microscopic traffic flow models allow dynamic simulation of pedestrians, vehicles, driver behavior and the interaction among each other and with infrastructure. This dissertation structures the problem of simulating traffic flows on shared space and creates new ways of applying agent based microscopic modeling. The underlying multi-agent social-force model describes the impact of social and technical interaction of traffic dynamics by establishing fields of force in analogy to physical models in Newtonian dynamics. The infrastructure is described by a force field keep agents on their path. Agents avoid obstacles and use their individual preferences. With bringing vehicles as non-holonomic objects in the world of social forces, both a single-track model and a bicycle model are introduced. To solve interaction processes on a tactical level, the conflicts are transferred to non-cooperative games with perfect information. This approach offers the novelty to mathematically combine social and rule-based behavior. Finally, the dissertation describes the model calibration approach based on real world trajectories. The model is applied to a shared space layout that is already implemented in Austria to compare the simulated traffic flow to real world data.

The major part of empirical data for calibration is acquired at an intersection in Austria that had been changed from a conventional design to a shared space setting and some years later to a Begegnungszone. The calibrated parameters clearly show a plausible contrast in social and rule-based behavior between shared space and Begegnungszone.

Abstract (German)

Im Straßenverkehr werden ab bestimmten Verkehrsstärken die Konflikte unterschiedlicher Verkehrsmodi meist durch eine weitgehende räumliche und zeitliche Trennung der jeweiligen Verkehrsmodi reduziert und entsch{"a}rft. Die Trennung führt nicht immer zur Erfüllung der gewünschten Verkehrssicherheitsziele oder Leistungsfähigkeit. Europaweit sind daher in den letzten Jahren verstärkt Konzepte zur gemischten Führung des Verkehrs untersucht und umgesetzt worden. Die Planungen solcher neuer Mischverkehrsanlagen kann durch wissenschaftliche Arbeit unterstützt werden, um planerische und politische Entscheidungen zu untermauern. Mikroskopische Verkehrssimulationen - erprobte Werkzeuge von Planern - sind derzeit noch ungenügend auf Mischverkehr eingestellt. Es existieren Modelle entweder für den motorisierten Individualverkehr oder den Fußgängerverkehr oder aber sie weisen eine sehr eingeschränkte Interaktionsmodellierung zwischen unterschiedlichen Modi auf.

Zielsetzung dieser Dissertation ist daher die Untersuchung des Bewegungsverhaltens in heterogenen Mischverkehren und die darauf aufbauende Anwendung von mathematischen Modellen zur Abbildung desselben. Es werden Ansätze entwickelt, die Modelle sozialer Kräfte auch auf den Fahrzeugverkehr auszudehnen. Die Grundidee hierbei ist, die Interaktion zwischen Fußgängern, Kraftfahrzeugen und Radfahrern durch Kraftfelder zu beschreiben, welche die Beschleunigung der Objekte im zeitlichen Ablauf beeinflussen. Speziell die Interaktion zwischen Fußgängern und Fahrzeugen bedarf einer Erweiterung der mathematischen Modelle.

Das Kalibrieren der Modelle erfolgt anhand von umfangreichen Realdaten von Mischverkehr in Österreich. Zum Tracking der verschiedenen Objekte in den Videobildern werden semiautomatische Methoden eingesetzt. Die auf diese Art kalibrierten und validierten mathematischen Modelle können in der Folge verwendet werden, um fundierte quantitative Prognosen der Auswirkungen unterschiedlicher Oberflächenplanungen auf Leistungsfähigkeit, Geschwindigkeit, Gefahrenpotential und Raumnutzung zu erzielen. Im Framework des Modells ist insbesonders das spieltheoretische Interaktionsmodell neuartig. Dieses zeigt den Einfluss von sozialen, regelbasierten (StVO) und physikalischen Aspekten auf das Verkehrsverhalten.

Besonders interessant ist der Umstand, dass während der Arbeit an dieser Dissertation der Sonnenfelsplatz in Graz von einem konventionellen Kreisverkehr im Jahr 2011 zu einem Shared Space umgebaut und 2013 als Begegnungszone verordnet wurde. Der Zusammenhang zwischen sozialem bzw. normativem Verhalten und der "Evolution" der Infrastruktur ist hier empirisch erfasst und wird auch durch das spieltheoretische Modell mathematisch dargestellt.

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Abbreviations

ACC Automatic Cruise Control

AIMSUN Adv. Interactive Microscopic Sim. for Urban and Non-Urban Networks

API Application Programming Interface

BA Behavioral Adaptation

BRT Bus Rapid Transit

CA Cellular Automata

DLL Dynamic Link Library

ICC Intelligent Cruise Control

IDM Intelligent Driver Model

ITS Intelligent Transport Systems

MAS Multi Agent System

MMLOS Multi Modal Level of Service

PID Proportional Integrative Derivative

LOS Level-Of-Service

OD Origin-Destination

ODE Ordinary Differential Equation

PDF Probability Density Function

RHT Risk Homeostasis Theory

ROW Right Of Way

SFM Social Force Model

SPNE Subgame Perfect Nash Equilibrium

TCT Traffic Conflict Technique

TTC Time to Collision

VDM Vehicle Dynamic Model

VISSIM Verkehr In Städten - Simulations Modell

Nomenclature

α Model constant (context: benefit cost cellular model)

α Spatial constant, slightly less than a agent's diameter (context: SFM)

β Slip angle (context: car model)

β_j Set of best answers to S_j (context: tactical model)

χ Pitch angle of a car (context: car model)

$\delta_v(bike)$ Vehicle control parameter (context: steering model)

γ Direction of an agent, γ is zero when continued at the current trajectory (context: interaction model)

λ Steering angle (context: car model)

λ_c Flow of vehicles [vehicles/h] (context: flow model)

λ_p Flow of pedestrians [pedestrians/h] (context: flow model)

λ_{df} Discrete Fr*é*chet distance (context: infrastructure model)

λ_{S1}, λ_{S2} Eigenvalues of the oscillation equation (context: bicycle model)

ψ Yaw angle of a car (context: car model)

τ_α Time constant of the SFM for agent α (context: SFM)

θ_E Weight of energy loss disutility (context: tactical model)

Θ_m Certain direction to the target (context: routing)

θ_N Weight of normative related disutility (context: tactical model)

θ_R Weight of the distance related disutility (context: tactical model)

θ_S Weight of social related disutility (context: tactical model)

θ_V Weight of velocity dependent disutility (context: tactical model)

Θ_i, Θ_j Directions of agent i or j (context: tactical model)

Θ_{opt} Optimum walking direction (context: routing)

φ Roll angle, between the vehicle's body and z-axis (context: vehicle model)

φ_d Desired walking direction (context: routing)

$\vec{e}_\alpha^{\,0}(t)$ Directional unit vector for agent α (context: SFM)

$\vec{f}(t)$ Resulting force vector in a certain moment (context: tactical model)

$\vec{f}_\alpha^{\,0}$ Driving force vector of agent α (context: SFM)

$\vec{f}_{Guide}(t)$ Resulting guiding force vector in a certain moment (context: tactical model)

$\vec{f}_{SF}(t)$ Resulting social force vector in a certain moment (context: tactical model)

$\vec{f}_{Tactics}(t)$ Resulting tactical force vector in a certain moment (context: tactical model)

$\vec{x}_\alpha(t)$ Position vector of agent α (context: SFM)

a Shape of Beta distribution $d_{lateral}$ (context: infrastructure model)

$a(t)$ Time-dependent acceleration of an agent or of an observed road-user (context: kinematic models)

$a_f(v)$ Speed-dependent acceleration of an agent or of an observed road-user during free flow (context: car following model)

a_t Constant - the acceleration threshold (context: steering model)

a_{xy}, b_y Parameters of matrices of dynamic vehicle equations (context: steering model)

b Shape of Beta distribution $d_{lateral}$ (context: infrastructure model)

b_r, b_l Boundary of the road's central lane within the road's cross-section (context: infrastructure model)

c Profile center within the road's profile (context: infrastructure model)

c_h, c_v Constants in the model for a specific car characteristic (front and rear) dynamics (context: car model)

$C_{i,j}$ Conflict entity (interaction) between agent i and agent j (context: tactical model)

$C_{x,y}$ Cell grid matrix containing the combination of density and relative speed (context: interaction model)

$crit_p$ Critical gap size for pedestrians [s/pedestrians] (context: flow model)

$d_{conflict}$ Distance, where a driver or pedestrian start to react on a potential conflict [m] (context: tactical model)

D_i, D_j Absolute position vector of decision towards conflict solving of agent i or j (context: tactical model)

$d_{lateral}$ Weight of the center guiding (context: infrastructure model)

e_r, e_l End of the road surface within the road's cross-section (context: infrastructure model)

e_v Desired directional vector (context: steering model)

F_{qh} Lateral force at the rear (context: car model)

F_{qv} Lateral force at the front (context: car model)

$func(X)$ Strength of the influence of a cell within the routing (context: routing)

g Gravity constant (context: bicycle model)

gr_{car}, gl_{car} Right and left boundaries for cars within the road's cross-section (context: infrastructure model)

gr_{cycle}, gl_{cycle} Right and left boundaries for cyclists within the road's cross-section (context: Infrastructure model)

gr_{ped}, gl_{ped} Right and left boundaries for pedestrians within the road's cross-section (context: infrastructure model)

I Integrative control constant (context: steering model)

k_a Constant, describing the controller's proportional factor (context: steering model)

k_c Static control constant vehicle model (context: steering model)

k_v Velocity dependent vehicle control model (context: steering model)

k_x Coupling constant in the cell-based routing (context: routing)

k_{mode} Vector of constants, changing the look-ahead for each mode of transport (context: steering model)

k_{st} Proportional factor in the steering (context: steering model)

k_v Factor in the steering, reducing the steering angle proportional with speed (context: steering model)

kb_c Static parameter in bicycle control (context: steering model)

kb_v Velocity dependent parameter in bicycle control (context: steering model)

L Look-ahead distance [m] (context: steering model)

l Length of the vehicle (context: bicycle model)

$L_i^j(\Theta_m)$ Walking distance (context: routing)

l_{acc1} Desired direction vector of an agent (context: steering model)

l_{gf1} "Error" vector, created of the sum of forces of the guiding force field (context: steering model)

l_{sf1} "Error" vector, created by the agent's percepted sum of social forces (context: steering model)

m Mass of an entity (context: car model)

$n_{sensing}$ Sensing steps (context: steering model)

$n_{simtactical}$ Sub-simulation time-steps (context: steering model)

P Proportional control constant (context: steering model)

$P(i, j)$ Outcome (matrix) of the Stackelberg game (context: tactical model)

$P_L(i)$ Conditional probability of the leader (context: tactical model)

p_x Probability of each cell for a specific agent (context: routing)

$Pr(accept_p)$ Probability of a pedestrian to take a chance to cross a street (context: flow model)

$Pr(gap_c > crit_p)$ Probability that gap_c is longer than $crit_p$ (context: flow model)

r Distance between both axles of the vehicle (context: bicycle model)

S Cost score of a cell k related to agents or objects (context: benefit cost cellular model)

s^* Desired distance in front of agent α (context: car following model)

s_α Actual distance in front of agent α (context: car following model)

s_i^{eq} Sub-game Perfect Nash Equilibrium of agent i (context: tactical model)

s_r, s_l Beginning of the area of the road's side area within the road's cross-section (context: infrastructure model)

S_i, S_j Chosen strategy of agent i or j (context: tactical model)

s_{xy} Spatial vector, describing the position of agent x after choosing strategy y (context: tactical model)

$t_{lookahead}$ Look-ahead time (vehicle model) [s] (context: steering model)

$t_{sensing}$ Time-step duration of the so called sensing run [s] (context: steering model)

$t_{simStep}$ Simulation step duration [s] (context: tactical model)

$u(t)$ Lateral velocity of the vehicle (context: car model)

$u_L(i)$ Expected utility values of the leader (context: tactical model)

$v(t)$ Longitudinal velocity of the vehicle (context: car model)

v_α^0 Speed scalar, desired velocity of agent α (context: SFM)

v_α Speed of an agent α (context: kinematic models)

$v_{bike-center}$ Threshold: Bicycles use center [m/s] (context: infrastructure model)

V_{ij} Velocity dependent disutility matrix of agent i and j (context: tactical model)

V_i, V_j Scalar matrix for all strategy pairs, containing velocities of agent i and j (context: tactical model)

v_n Speed of agent n (context: kinematic models)

w_{gf} Weight of the guiding force (context: steering model)

w_{sf} Weight of the social force (context: steering model)

X_i, X_j Absolute position vector (point), of agent i or j is made (context: tactical model)

y_{ijn} Exponent in the log-likelihood method (value=1 is applied here) (context: interaction model)

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