Including Pedestrian and Bicycle Traffic in the Traffic Simulation SUMO

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Abstract
Being available since 2002, the open source traffic simulation SUMO has gained a state of being accepted by a large community. Albeit SUMO allows to model inter-modal trip chains for individually simulated persons it still lacks models for the dynamics of pedestrians and bicycles as well as for the interaction between these traffic modes and motorised traffic. Closing this gap is one of the tasks scheduled within the COLOMBO project. This paper outlines the requirements put on a pedestrian model, list available prerequisites that are used, and show currently followed approaches for implementing pedestrian models into SUMO.

Keywords:
Pedestrians, Bicycles, Traffic Modelling, open source.

Introduction

The interest in both pedestrian and bicycle traffic has increased in recent past for several reasons. One of the first to name is the wish to reduce traffic's ecological impact. A major attempt is to move travellers from using own cars to other modes of transport – walking, riding a bike, or using the public transport. A further approach is to increase the use of car-sharing that is assumed to reduce the amount of vehicles in urban areas. In any case, the offered modes of travel have to be attractive enough for being used. Traffic simulations allow to benchmark each mode, making them comparable and revealing bottlenecks in the transport infrastructure that make a certain mode unattractive.
Besides environmental issues, traffic safety is a further work topic that puts its focus on pedestrians and bicycles due to their vulnerability against motorised traffic and because of the growing interest in "shared spaces" – areas used by different transport modes simultaneously. The currently used models for both vehicle and pedestrian traffic are not yet fine-grained enough to answer traffic safety research questions well. Nonetheless, the inclusion of pedestrians into a traffic simulation is assumed to be an important step towards obtaining new, better models. A third reason for including pedestrians and bicycles in a microscopic traffic simulation are their influences on the motorised traffic flow, mainly at

controlled intersections.

"Simulation of Urban MObility" [1,2] is a microscopic traffic simulation developed by the German Aerospace Center (DLR). SUMO was released as an open source application in 2002 and is continuously developed since that time. Within the scope of the COLOMBO project [3,4], SUMO is extended by models for pedestrian and bicycle traffic. Within COLOMBO, the interaction between pedestrians, bicycles, and traffic lights is in the major focus. Nonetheless, the resulting inclusion of pedestrians and bicycles attempts to contribute to a simulation system that allows working on the aforementioned topics as well.

Modelling pedestrian traffic is well-covered by scientific literature. The topics range from modal split to pedestrian dynamics. In the following, the technical view on extending an existing traffic simulation is given. It starts with an overview about the major technical context that influenced the performed work. Then, the implementation itself is presented by outlining the performed extensions. Traffic simulations are often used to replicate an area of the real world. Therefore, a discussion on the availability of respectively needed data follows. Afterwards, some initial evaluations of the implemented models is given. This report closes with a summary.

Prerequisites and Requirements

Some basic issues have to be regarded when including pedestrian and bicycle traffic in SUMO. On the one hand, SUMO is already a mature application suite. Therefore, performed extensions should neither change its basic behaviour nor the modalities of using it. On the other hand, the extensions shall allow performing investigations that consider pedestrian flows across one or few intersections. Other application areas for pedestrian simulation are of lesser importance. Therefore, emphasis is given to aspects that influence the behaviour of road traffic and pedestrians at traffic lights. The following sub-sections describe both, the requirements posed from the view point of SUMO as well as from the one of the scheduled work.

Requirements from SUMO as an Eco-system

Besides a traffic simulation application, SUMO includes other applications that help in preparing scenarios. On the one hand, one can find tools for generating or importing road networks (*netgenerate* and *netconvert*, respectively). On the other hand, some tools for generating a microscopic demand (*activitygen*, *od2trips*, *dfrouter*) as well as for computing routes through the simulated road networks (*jtrrouter*, *duarouter*) exist. All tools generate data that is compatible with the simulation itself. When extending the simulation by pedestrians and bicycles, one should take into account that both the definitions of road networks as well as demand descriptions have to be adapted. These changes must be replicated within all applications that are included in the suite.

Besides taking care for the interoperability between the suite's applications, the "user experience" – the way a user interacts with the applications – should be kept similar to prior versions. Interfaces to the user, such as command line parameters, input files, or the available on-line interaction API (application programming interface) should not be changed but rather extended by new methods.

Multi-Modal Journeys in SUMO

SUMO is a microscopic simulation of road traffic where each vehicle is defined and simulated individually. Every vehicle is assigned to a configurable vehicle type and the large amount of a vehicle type's parameters allows modelling a large range of different characteristics. With version 0.9.3, a public transport model was introduced. The model allows SUMO to load "bus stops" and simulated vehicles may get a list of such stops to halt at while following its route. The duration of each stop is determined either by a given duration or a given departure time. Additionally, the simulation was extended by road use classes that may be assigned to lanes and to vehicles for realising lane use restrictions, such as dedicated bus lanes. This model allows to investigate travel times of public busses through a road network, albeit it does not include methods that replicate that a bus driver may adapt the speed and halt durations to follow the time schedule.

In subsequent releases, SUMO was extended by a model of single persons, each following an inter-modal trip chain. This trip chain consists of single "stages". The following stage types are supplied:

- "walking": The person follows the path of given edges at a constant speed.
- "driving": The person uses a named vehicle; if the vehicle is not present at the edge the person is located at, the person waits for the vehicle to arrive. The vehicle may as well be a public transport vehicle. On arrival, the person continues the trip chain.
- "waiting": The person remains at the place it is located at. This stage allows to model activities, such as staying at home or at the work place.

Requirements from COLOMBO

The work presented herein is performed within the context of the project COLOMBO [3, 4], co-funded by the European Commission. The major objective of the project is the development of environment-friendly traffic management solutions for traffic surveillance and traffic control, the latter via traffic lights. All these solutions use data collected from vehicular communication (V2X), assuming that a low rate of equipment with V2X technology can be exploited to gain a valid representation of the traffic state at a macroscopic level. Besides swarm-based, self-configuring and -optimising traffic light algorithms, the project works on traffic surveillance algorithms, including a local emission monitoring system or an incidents monitoring and reporting system.

The solutions are designed and then implemented as software models that may be evaluated using the involved simulation suite. No real-world deployment takes place within the project. The used simulation suite consists mainly of the ns-3 [5] communication simulator and the traffic simulation SUMO, both joined using a middleware named iCS that was developed within the iTETRIS project [6, 7] to simulate V2X-based applications. Putting a strong focus on the development of environment-friendly solutions, COLOMBO's simulation system relies additionally on the PHEM emission model [8]. To allow faster, direct computation of emissions, a derivative of PHEM named

PHEMlight was generated and included in SUMO [9]. The complete simulation suite is accompanied by optimization tools involving state-of-the art algorithms configuration techniques [10].
Extending SUMO by pedestrian and bicycle dynamics has a three-fold reason within COLOMBO. The first is the assumed improvement of connectivity and data amount when taking road-side pedestrians into account. The second is the influence of these transport modes on traffic light performance that needs to be accounted for. The third is the benefit of the slow speed nature of pedestrians to make them a good traffic observer for distributed traffic monitoring.
As such, the models must be capable to simulate pedestrian and bicycle movements along roads (for communication investigations) and replicate their influence on the performance of a traffic light.

Implementation

As discussed, embedding pedestrian and bicycle traffic requires taking into account different aspects. In the following, the changes on the different applications included in the simulation suite are presented.

Network Model
Most of nowadays traffic simulations work on a microscopic scale – vehicles choose a speed and a lane individually, depending on the surrounding traffic situation. Often, the occupation of a lane is binary: either a lane’s position is occupied by a vehicle or not, a shared (in lateral means) usage of a lane is usually not covered. Therefore, the models could be named to have one and a half dimensions. But pedestrian dynamics models usually operate on a two dimensional area and especially at pedestrian crossings, pedestrians wait besides each other, not in a queue. Consequently, pedestrian sidewalks must be modelled in a different way than lanes used by vehicles.
The chosen approach keeps the concept of lanes at the network definition level nonetheless. Sidewalks used by pedestrians are modelled as own lanes where only pedestrians are allowed. The major attributes of a lane that are of importance herein are its geometrical shape given as a polyline and its width. The realisation of an areal interpretation of this information is thereby the task of the simulation, presented and justified in a later section. The according changes to SUMO’s network preparation modules mainly include new possibilities to define whether a road should have a sidewalk or not. To ease the import of large road networks, this information can be assigned to “edge types” which change the interpretation of similar edges. Edge types used during the import of road networks, mainly OpenStreetMap and Navteq networks, have been accordingly extended.
Another technical challenge is the realisation of pedestrian crossings. When looking at intersections, the inclusion of pedestrian crossings yields in a large increase of the intersection’s complexity. Within SUMO, a right-of-way matrix determines which vehicles must stop to let higher prioritized vehicles pass [11]. Vehicles wait either at the stop line, or within the intersection. The network building modules have been accordingly extended. The major challenge was to compute the conflict and the right-of-way matrices correctly, due to the new conflict areas introduced by new lanes for new travel

modes.

The current realisation of bicycle traffic relies on the already given lane usage restrictions, modelling explicit bicycle lanes. Network building had to be adapted nonetheless, as the introduction of dedicated bicycle lanes generates new conflict areas and the according intersections' right-of-way rules change. As well, the computation of lane-to-lane connectivity had to be changed, distinguishing the modes of travel.

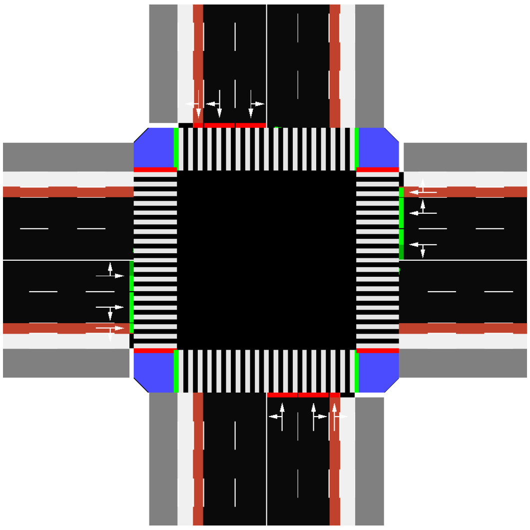

Figure 1 – The extended network model; black: usual road traffic lanes, grey: sidewalks, brown: bicycles, light blue: "walking areas"; crossings are striped

Route Computation

SUMO's traffic simulation relies on the definition of complete routes for each vehicle, where "complete" means that all passed edges are given in the correct order. This counts as well for the walking stages of the multi-modal travel model.

In SUMO, each edge is unidirectional. A bi-directional "road" is therefore modelled by two opposite "edges". This changes when introducing pedestrian lanes as pedestrians are allowed to use sidewalks in both directions and the existing multi-modal travel model did not regard this fact. Given the current implementation, routes computation is split into two parts. At the upper level, routes through the road network are computed. These routes consist of a list of all edges to pass as used for vehicle routes. Here, using sidewalks in both directions is realised by implementing a new router that expands the road network graph by using each edge in both directions. Given this, a person can travel along all edges with a sidewalk in both directions. This functionality was implemented into the *duarouter* application which computes routes based on shortest-path algorithms.

A further routing is implemented within the simulation that realises a routing over intersections. As the routes defined in SUMO only cover edges, a decision about which path shall be used to cross an intersection must be given. This is regarded to be dynamic and thus should be performed online within the simulation, regarding the current state of traffic lights ahead. The implemented algorithm computes the path along an intersection's crossings and walking areas to reach the next edge. It chooses the direction of the next green traffic light.

Bicycle routes lack a micro-routing, because bicycles cross the intersection as usually modelled motorised vehicles do.

Pedestrian Flow Models

As mentioned before, the traffic simulation is responsible for realising a representation of sidewalks as an area the simulated pedestrians may use. The major benefit is the possibility to use different models, not restricting them to a certain paradigm. The models implemented so far, presented in the following, use this possibility already.

The initially used linear movement model was reformulated to be usable with the new network characteristics. It moves pedestrians along the centre lines of sidewalk lanes with a constant speed. No interaction between pedestrians is modelled and pedestrians jump over an intersection. As such, it is not applicable to traffic light investigations. But being very fast in execution, it allows to simulate the behaviour of persons in large road networks, albeit with a reduced quality. In addition, the model can be executed without explicitly given sidewalks, reducing the network sizes. This model is accessible within SUMO as "*NonInteracting*".

Two further models have been implemented to comply with the use cases of the COLOMBO project. The first, named "*Striping*" divides sidewalk lanes into stripes of a pre-defined width. Pedestrians move along the sidewalks regarding the place in front of them, usually trying to occupy the right-most stripe. In case of overtaking another, slower moving person or when encountering opposite (pedestrian) traffic, the pedestrian may change to a different stripe if there is enough free space. Both crossings as well as walking areas are passed as simple sidewalks.

The third model is based on the work performed by Antonini and Bierlaire for providing a "*disaggregate, fully estimable behavioral model based on discrete choice analysis*" [12]. The model uses a given two dimensional area. At the current time, the inclusion of the model into SUMO is undertaken.

Data Availability

Simulations rely on a correct representation of the investigated area, including both, the infrastructure as well as the demand. For simple, single intersection scenarios, such data can be generated by hand. But when moving to replicating larger parts of a real area, digital information about the infrastructure and the demand are needed. Therefore, during SUMO's development, a strong focus was put on importing data, while manual adaptations are less supported. Microscopic simulations need a detailed representation of the road network, including the correct lane numbers, speed limits, etc. As most of available data does not support all this required information in a sufficient quality, heuristics were implement that determine missing but required information [13].

When coming to the simulation of bicycles and pedestrians, the availability of proper data – mainly the existence of sidewalks and pedestrian crossings – has to be revalidated and the heuristics have to be implemented or – if existing – updated. One possible source of information about the infrastructure is OpenStreetMap, a crowd-sourced digital map. The OpenStreetMap database not only includes the road network usable by motorized traffic but also roads pedestrians and/or bicycles can use.

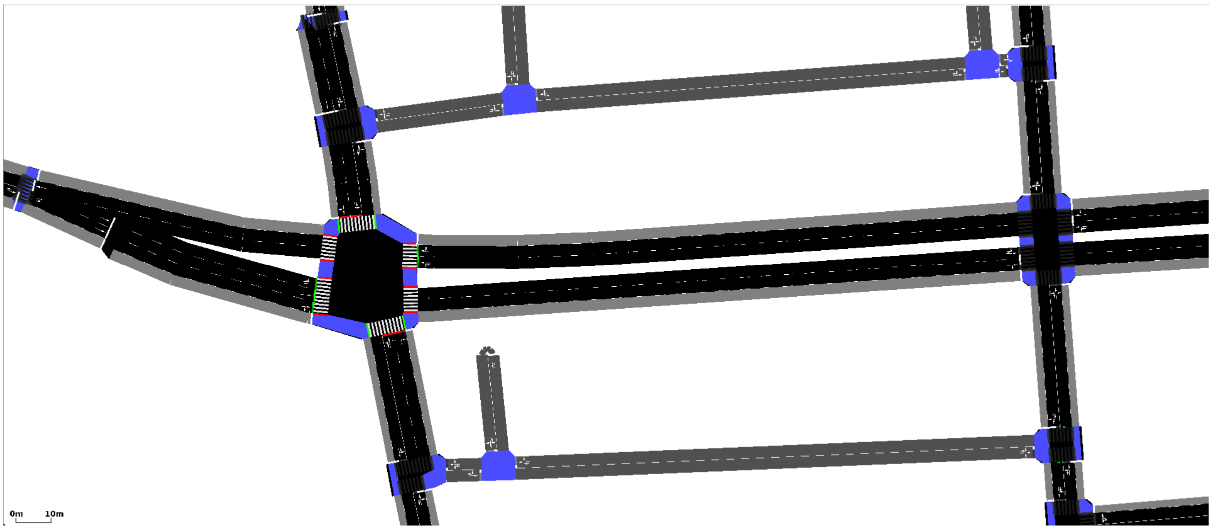

Figure 2 – Network obtained from OSM after applying lane usage heuristics; coloured as in Figure 1

Initial Evaluations

The described extensions have not yet been included in SUMO's release version and can only be obtained from a (publicly available) "branch" of the suite's source code repository. So far, the models are under evaluation. In the following, two example investigations are outlined.

The very first observation to make is that the additional place offered by pedestrian crossings at intersections changes the capacity of let-moving vehicles significantly. Figure 3 was generated based on simulations of the first scenario of RiLSA's (German recommendations for traffic light deployment, [14]) examples. When incorporating pedestrian crossings, more left-moving vehicles can enter the network in order to wait for a gap in opposite stream. As a result, the intersection is capable to cope with the given demand.

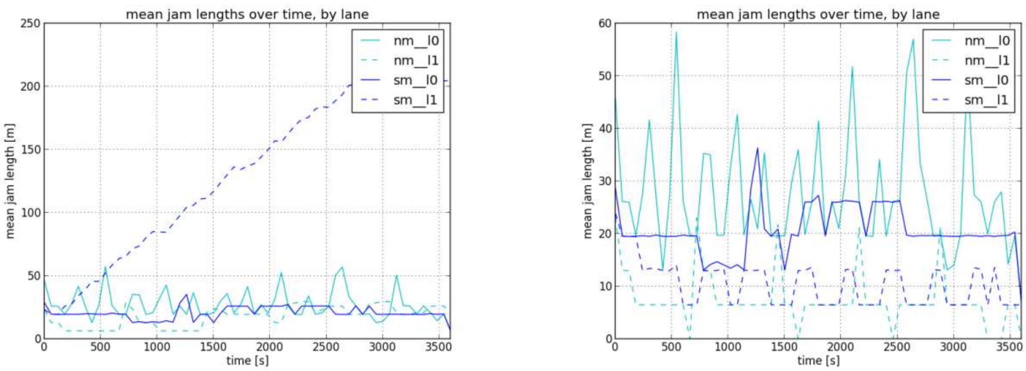

Figure 3 – Development of jam length when disregarding (left) or regarding (right) additional space at the intersection

A second evaluation investigates how pedestrian streams influence the capacity of an intersection. Both, the flow of right-turning vehicles are continuously increased as well as the flow of pedestrians that must be crossed. Two cases are regarded, namely an uncontrolled intersection and one controlled by a traffic light. At low and medium pedestrian flows, the uncontrolled intersection allows for higher flows due to the absence of “red” phases. However, at high pedestrian flows the TLS-controlled intersection allows for higher vehicle flows because vehicles already waiting within the intersection may drive each time, pedestrians have to wait at the red light.

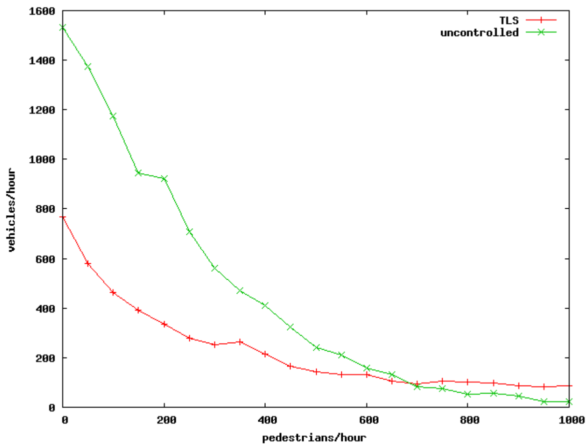

Figure 4 – Throughput of right-turning vehicles for different combinations of flows for such vehicles and crossing pedestrian flows for an uncontrolled (green) intersection and one controlled by a traffic light (red)

Summary

The extensions performed on the open source microscopic traffic simulation suite SUMO towards simulating pedestrian and bicycle traffic were presented. It was shown that many aspects have to addressed. Besides the traffic simulation itself, other applications had to be extended as well. Some initial evaluations show the effect of the pedestrian models on traffic behaviour, albeit a final calibration has not yet been done.

Not all of the applications for a pedestrian model given in the introduction can be covered. The major to name is the simulation of shared spaces, areas that are used by different modes of transport including vehicles, pedestrians, and bicycles, simultaneously. To allow such simulations, the vehicle movement models had to be extended in order to move within an area instead of following the center line of a lane.

As mentioned, setting up a pedestrian demand is only rudimentary supported at the current time. SUMO includes an application named *activitygen* which generates motorized traffic trips for a synthetic population described by socio-demographic data. This tool should be extended in the future to cover walks and bicycle usage as well.

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