Bicycles in Urban Areas

Review of Existing Methods for Modeling Behavior

Heather Twaddle, Tobias Schendzielorz, and Oliver Fakler

As the number of bicyclists in urban areas continues to increase, the need to realistically model the movement and interactions of bicyclists is rapidly gaining importance in the accurate modeling of mixed urban traffic. In response to this need, several approaches to modeling bicyclists' movements and interactions have been developed. This study summarized selected modeling approaches that depict the state of the art in bicycle modeling. The overall modeling of bicycles was divided into modeling of uninfluenced operational and tactical behavior and influenced operational and tactical behavior. The ability to model bicyclist behavior on each of these levels was evaluated on the basis of the results of an extensive literature review and input from an expert workshop that included industry professionals and academics with extensive experience in traffic modeling. The results of the assessment indicate that although the approaches used to model uninfluenced and influenced behavior on the operational level vary in their level of detail and ability to reproduce reality correctly, it is possible to model most bicyclist behavior at this level. There is a need to validate and calibrate these models with empirical data collected from a variety of locations and traffic situations. The state of the art in modeling the tactical behavior of bicyclists is, however, less developed. It is important to model the uninfluenced and influenced tactical behavior of bicyclists accurately because bicycle behavior is less constrained by road markings and traffic regulations.

Urban planners and governments are faced with the dilemma of providing high-quality mobility services to a growing population, while at the same time minimizing energy consumption, reducing harmful environmental impacts, and cultivating a lively and safe urban environment. As a means of meeting these challenges, the bicycle has resurfaced as a valuable transportation mode. Policy revisions and infrastructure amendments aimed at increasing bicycle use have led to a significant increase in the bicycle modal share in many urban areas. As a result, the traffic composition is becoming increasingly heterogeneous, with bicycles, motor vehicles, pedestrians, and other road user groups sharing the road space. Planning for the needs of many road user groups with widely varying physical and dynamic characteristics and protecting vulnerable road users, including bicyclists and pedestrians, have become key challenges in urban transportation.

H. Twaddle, Traffic Engineering and Control, Technische Universität München, Arcisstrasse 21, 80333 Munich, Germany. T. Schendzielorz, Heusch/Boesefeldt GmbH, Zenettistrasse 34, 80337 Munich, Germany. O. Fakler, TRANSVER GmbH, 80538 Munich, Germany. Corresponding author: H. Twaddle, heather.twaddle@tum.de.

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Traffic simulations are a common tool used in assessing proposed transportation measures before they are implemented. However, the accuracy and reliability of these assessments depends on the realistic modeling of the movements and interactions of different types of road users. Several characteristics of bicyclists and bicycle traffic differ considerably from those of car drivers and motor vehicle streams. Because of their different physical and dynamic characteristics, bicyclists and motor vehicles behave differently while traveling in urban space. First, the dynamic characteristics of bicyclists, including their speed, acceleration, and deceleration profiles, differ considerably from those of motor vehicles because of the natural physical limits of bicyclists. In addition, bicyclists tend to minimize changes in speed and number of stops, to reduce the required physical exertion. In contrast with motor vehicle drivers, evidence from empirical studies indicates that bicyclists crossing an intersecting traffic stream prefer to adapt their trajectory (their speed, lateral position, or a combination of both) rather than come to a complete stop and wait (*1, 2*).

Second, physical characteristics, including size and flexibility, differentiate bicyclists from motor vehicles. Because bicycles are much narrower, they are able to utilize lateral space within a traffic lane or bicycle lane to a greater degree than motor vehicles. This lateral flexibility greatly reduces the influence of leading vehicles on the movement of bicyclists. Empirical data indicate that situations seldom occur where the movement of a bicyclist is limited by the speed and behavior of leading road users over a longer time period (*3, 4*). Not only do bicyclists have a greater degree of lateral flexibility within a lane, they can also switch easily between different types of available infrastructure (e.g., roadway, bicycle lane, or sidewalk). This can lead to bicyclists riding in discordance with the traffic laws (e.g., against the traffic flow, on sidewalks, in pedestrian zones, and so forth). Research indicates that in Germany 8–20% of bicyclists ride in the wrong direction, depending on the infrastructure, and 2–15% ride on the sidewalk (*5, 6*). Alrutz et al. found that many bicyclists do not stop at red lights, especially at intersections where a major road crosses a minor road (*5*). In Australia, it was found that 6.9% of commuting cyclists run red lights (*7*). The actual portion of bicyclists that break traffic rules likely depends strongly on the bicycle and driving infrastructure and the mobility culture. These differences must be considered and reflected in the modeling of mixed traffic, to realistically depict these streams in traffic simulations.

The goal of the research project Urban Space: User-Oriented Assistance Systems and Network Management (UR:BAN), a transportation research project funded by the German Federal Ministry of Economics and Technology, was to develop advanced driver assistance systems and intelligent transport systems to increase traffic safety and efficiency and reduce harmful environmental impacts. Within the UR:BAN subproject Human Factors in Traffic, several methods are used to evaluate the impacts of the developed ITS and ADAS solutions, including observations at real test sites, driver simulation studies, and microscopic simulation techniques. However, currently available microscopic simulation tools are limited in their capacity to model realistic bicycle trajectories, especially anticipatory and tactical behavior, as well as interactions between bicycle and motor vehicle traffic. For this reason, new or extended models will be developed within UR:BAN, to realistically depict the movements and interactions of bicyclists. These improved tools will make it possible to assess future bicycle traffic and assistance systems with microscopic simulation techniques.

This paper provides a summary of the first steps that have been taken in the research project. A literature review is carried out to identify the unique characteristics of bicycle traffic at intersections and on road segments in urban areas. The existing approaches for modeling bicyclists and their interactions with motor vehicles are reviewed and described in the following section. The models were organized into four categories: longitudinally continuous models, cellular automata, social force models, and logic models. The study assessed the ability to realistically model bicycle traffic on four levels: uninfluenced operational, uninfluenced tactical, influenced operational, and influenced tactical. In addition, the results of an expert workshop, including product managers, developers, and users of current state of the art microscopic simulation environments, such as VISSIM or SUMO, were assessed. Finally, the study identified shortcomings in the existing methods for modeling bicycle behavior and provides recommendations for future model development.

METHODS OF MODELING BICYCLE MOVEMENT

Microscopic traffic simulation tools include Aimsun, SUMO, and DRACULA. Barceló provided a detailed description of state-of-the-art simulation tools (*8*). The majority of currently available and widely used microscopic traffic simulation tools focus on the movement and interaction of motorized vehicles (the main exception being VISSIM). If it is possible to include bicycles in the simulation, they are modeled with the same behavior models used to depict motor vehicle traffic. The parameters are typically adjusted to reflect the lower traveling speed of bicycles. However, several unique characteristics of bicyclists' behavior make the adoption of these traditional vehicle behavior models difficult and, at times, unrealistic. Nevertheless, several models have been independently developed to model bicycle traffic more accurately. This section will summarize a selection of these models. This is by no means an exhaustive list of all existing models, but is meant to introduce the main concepts used currently in modeling bicycle behavior.

Longitudinally Continuous Models

The majority of traffic simulation tools utilize two models to independently model the longitudinal and lateral motion of road users (VISSIM, Aimsun, SUMO). Longitudinal motion models are space continuous and time discrete and typically utilize one of the three types of car following models: Gazis-Herman-Rothery models, safety distance models, and psychophysical models. All of these use the speed and position of a leading vehicle to determine the behavior of the following vehicle. If there are no other vehicles or leading vehicles are far enough ahead of the vehicle not to influence the behavior, vehicles strive to maintain a predefined speed. The lateral movement of motor vehicles, and often bicycles, is modeled with a discrete lane choice model, where the position and speed of other road users and the desired route of the individual vehicle are taken into account in the lane-choosing process. Lateral movement within a lane is not possible in most discrete choice lane selection models. If such models are used to simulate mixed traffic streams, single bicyclists quickly form a moving bottleneck on the road, which is rarely the case in reality, as faster cars overtake bicycles at the earliest opportunity.

Several extensions to longitudinal continuous and laterally discrete models have been proposed with the aim of more realistically modeling bicycle traffic. One possibility is to divide the lane into a number of smaller strips and use a discrete model to select the strip within the lane (*9, 10*). This solution makes it possible for vehicles and bicycles to select their lateral position optimally as well as interact and pass one another within one lane. In addition, because a discrete choice model rather than a continuous lateral model is implemented, the required computing power is relatively low.

Falkenberg et al. proposed a model with a continuous lateral axis (*3*). Bicyclists select their lateral position within the lane with the aim of maximizing the minimum time to collision (TTC) with other bicycles, pedestrians, and motor vehicles. TTC is defined as the time remaining until two road users collide, given they stay on the same path with the same speed. The working principle of the model is shown in Figure 1. The arrows represent the calculated TTC between other road users in the near vicinity. If no other road users are traveling in the near vicinity, bicyclists select their lateral position based on a predefined preference (normally to the right-hand side). Longitudinal movement is modeled with one of two Wiedemann psychophysical models (74 or 99). The models assume that because bicyclists are also human beings, the same psychological factors (desired speed and following distance) and physical factors (perception threshold and imperfect vehicle control) can be used to determine their following behavior. This assumption was not tested, but subsequent use of the model in VISSIM (*11, 12*) has shown that it is capable of realistically depicting bicycle traffic in most situations. Carrignon noted, however, that the bicyclists in VISSIM do not interact realistically with the edges of the infrastructure (usually a curb or lane marking) in all situations (*11*). In addition, bicyclists are depicted with a diamond shape instead of the typical rectangle shape used for motor vehicles. This allows for more realistic queuing at stop points in VISSIM.

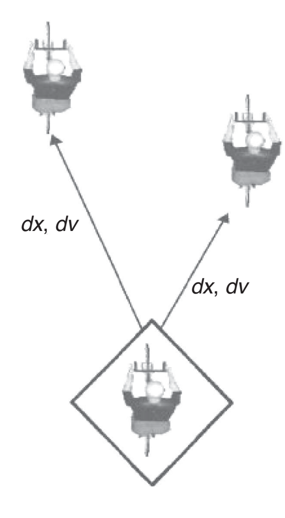

FIGURE 1 Continuous lateral movement model by Falkenberg et al. (*3*) (*dx* = distance; *dv* = speed difference).

Cellular Automata Models

Cellular automata (CA) are time- and space-discrete models. In the original model by Nagel and Schreckenberg, the two-dimensional space is divided into a grid of identically sized cells, each 7.5 m long, or roughly the length of one car (*13*). Vehicles within the model follow predefined routes through the cell raster and use four driving regimes: acceleration, deceleration, randomization, and update and move. Cells do not overlap each other and it is not possible for more than one road user to occupy a cell during one time step. For this reason, the original CA from Nagel and Schreckenberg provided a simple and fast method for modeling heterogeneous traffic flows that follow lane discipline. However, the possibilities for modeling mixed traffic streams and the interaction between different modes of transportation are limited. Several extensions of the original CA have been suggested to make it possible to include bicycle traffic.

One option for including many types of road users in a CA is to create a raster of cells that are sized in accordance with the dimensions of the smallest road user (width and length) and allow road users to occupy more than one cell per time step. This method was used by Yao et al. to model situations in China where more than one lane of bicycle traffic runs along a street with one or more lanes of car traffic (*14*). Each cell in the model represents 1 m × 1 m in reality. A bicycle occupies 3 × 1 cells and a car occupies 5 × 3 cells. Interactions between bicycles and cars are classified into two types: friction and blockage. The driving resistance for car drivers is then determined based on the presence of bicycles in the next lane and by bicycles that leave the bicycle lane and travel into the car lanes. This model has not yet been empirically validated or calibrated.

Mallikarjuna and Ramachandra Rao used a similar approach to model mixed traffic streams in India (*15*). In this model, the cell lengths are based on the acceleration and deceleration properties of road users and the cell widths are based on the width and observed lateral spacing maintained between different groups of road users. The lateral position of the road users is updated in a first step. To consider the different lateral behaviors of the road user types, a two-lane road is divided into five sublanes and five types of lateral movements are defined. The longitudinal position is subsequently updated depending on the acceleration and deceleration characteristics of the road user type and the available space to move forward.

Vasic and Ruskin developed a CA to depict car traffic and single-file bicycle traffic (*16–18*). In this model, a cell raster with appropriately sized cells is created for each type of road user (in this case, bicycles and car drivers). When the pathway of more than one stream of road users intersects or overlaps, the cells in this CA model also overlap. The movement of the vehicles is then determined by the impingement of the leading cells. A cell is impinged on if it is occupied or any of the overlapping cells are occupied. The lateral interaction between bicycles and cars traveling in the same direction on the same road right of way is only considered on narrow roads where the velocity of the cars is limited based on the longitudinal distance to the next leading bicycle. The advantage of the model proposed by Vasic and Ruskin is that the geometry of the intersection can be directly translated into a fitting raster of cells. Complex interactions are extracted from this relatively complex raster of CA cells. Examples of the spatial constructs used by Vasic and Ruskin are shown in Figure 2. This model has not yet been validated or calibrated with empirical data.

Gould and Karner used a CA to attempt to derive the macroscopic properties of bicycles traveling on a one-way bicycle lane (*4*). The lane was divided into two hypothetical lanes and bicyclists were divided into two groups, slow and fast riders. The model was operated with the extended rules proposed by Rickert et al. and was validated and calibrated with empirical data (*19*). The results from the

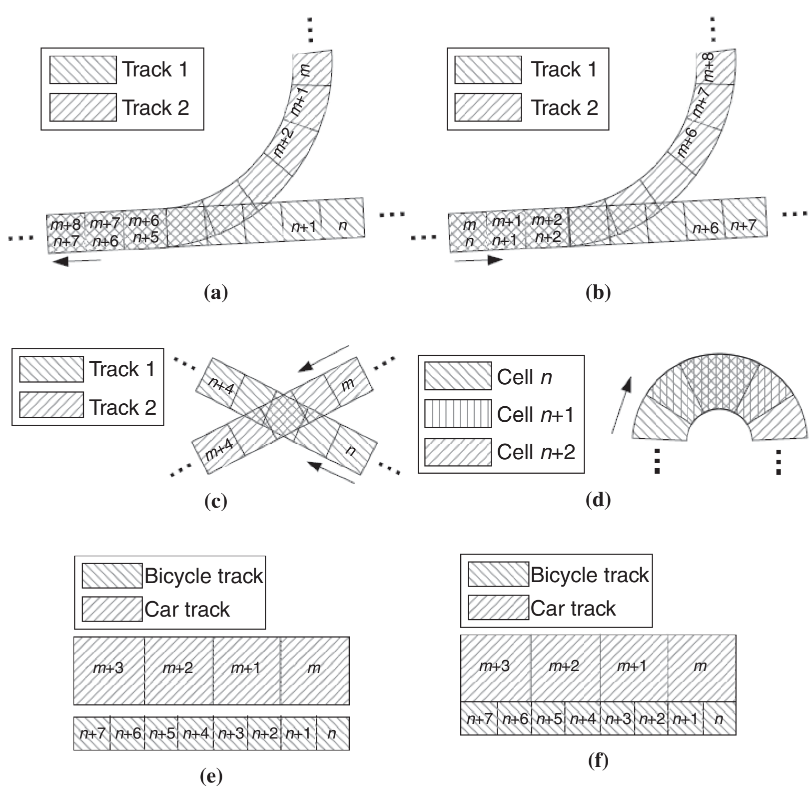

FIGURE 2 Examples of spatial constructs used by Vasic and Ruskin (*16–18*) (*m* and *n* = positive whole numbers that indicate location of construct in road network).

simulation provided a relationship between density (bicycles/ft^2) and flow (bicycles/h/ft). However, no observations were made in reality where the density of bicycles reached or passed a critical level and began to negatively affect the bicycle flow (bicycles/h).

A final option is to allow more than one road user to occupy a cell in one time step (*20, 21*). This would provide a macroscopic approach to estimating the capacity of bicycle infrastructure and will not be discussed further.

Social Force Models

A generalized social force model was first proposed by Helbing and Molnar to model pedestrian dynamics (*22*). The basic operating principle of this model is based on the concept that pedestrians move in reaction to the sum of a number of attractive and repulsive forces, namely,

- Attraction toward the destination,
- Repulsion from obstacles, and
- Repulsion from other pedestrians (or other road users).

Movement within social force models is not bound to the longitudinal and lateral axis, but instead modeled road users move freely on a two-dimensional plane. However, unlike pedestrians, bicyclists move primarily along the longitudinal axis of the given roadway. Several bicycle models based on an adapted form of the original social force model have been developed and are summarized.

Li et al. developed a social force model that considers homogeneous automobile and bicycle streams as well as mixed bicycle-automobile traffic streams (*23*). The forces acting on bicyclists are a forward driving force that relates the current speed with the desired speed, repulsive forces from other bicyclists, and a repulsive force from the edges of the infrastructure that keeps bicycles within the bicycle lane. Bicyclists exit the bicycle lane and ride with the motorized traffic if the density of bicyclists within the bicycle lane is large enough that the repulsive forces from the other bicyclists overtake the repulsive force from the lane edge. The repulsive force enacted on bicyclists by the motor vehicles in the model is considerably larger than the force enacted by the bicyclists. This is intended to reflect the fact that cars have a greater influence within the road space than bicyclists. This model was not validated or calibrated using empirical data.

Liang et al. developed a social force model that utilizes two regimes, free-flow traffic and congested traffic, to model bicycle traffic (*24*). The model used in free-flow traffic considers two of the same forces described by Li et al. (*23*), a driving force and a repulsive force from other road users (depicted as $\vec{F}^{\text{drv}}$ and $\vec{F}^{\text{ca}}$, respectively, in Figure 3). Bicyclists are depicted within the model

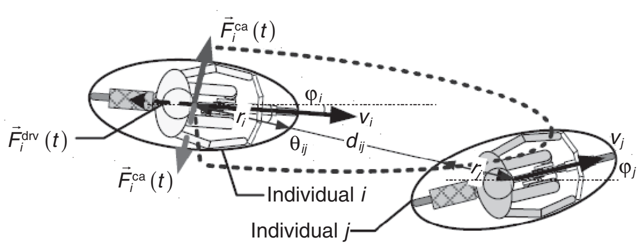

FIGURE 3 Social force model by Liang et al. (*24*) [t = time step; φ = angle between lane direction and velocity vector; θ = angle between lane direction and connection vector; v = instantaneous velocity (m/s); d = separation distance (m); r = bicycle elliptical radius (m)].

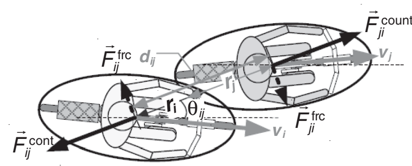

FIGURE 4 Physical interaction model by Liang et al. (*24*).

as ellipses. If two bicycles come near enough to one another that their ellipses overlap, a physical model takes over that prevents a collision from occurring. The two forces acting in this case are the contact force $\vec{F}^{\text{cont}}$, which counteracts compression of the ellipse, and the sliding friction force $\vec{F}^{\text{frc}}$, which restricts relative tangential motion, as shown in Figure 4.

Schönauer et al. used an adapted social force approach to model intersections with no separated infrastructure for pedestrians, bicyclists, and motor vehicles (shared space) (*25*). All three modes must select their path through the intersection based on the geometry of the infrastructure and the behavior of other road users. This is done with three models: an infrastructure model, an operational model, and a tactical model. The infrastructure model builds a force field that uses repulsive forces from the infrastructure edges to push the road users into their intended path. The operational model is again an adapted form of the model proposed by Helbing and Molnar (*22*). To consider the reduced degrees of freedom associated with motor vehicles and bicycles, the single-track model for car dynamics shown by Kramer is used (*26*).

Logic Models

Logic model approaches are used to depict the conscious choice behavior, or tactical behavior, of bicyclists, including the selection of infrastructure and the method used to cross intersections. Only a limited number of existing models consider the tactical behavior of bicyclists.

To correctly model the movement of road users at uncontrolled intersections with infrastructure that is shared by all road users, Schönauer et al. added a tactical force vector to their social force model (*25*). The movement of the road users is derived from the sum of the infrastructure guiding force, the adapted social force model, and the tactical force model. The tactical force model is based on the Stackelberg game concept, which is a nonsymmetric hierarchical game model with follower and leader players (*27*). Potential conflicts between road users are identified based on the planned trajectories of the uninfluenced road users. Various possibilities for avoiding conflict are considered by both road users. An example of the identification of different strategies, including acceleration, deceleration, and dodging left and right, is shown in Figure 5.

The range of options is created by first determining the strategy of the leading road user and then the reactive strategy of the following road users. The total utility of the strategy is the sum of the partial payoffs for both road users. The validity of the tactical force model has not yet been tested with empirical data.

Huang and Wu proposed a model that makes use of fuzzy logic rules to determine the path-choosing behavior of bicyclists at uncontrolled intersections (*28*). The model consists of three submodels:

- A situation detection model, which detects the speed, direction, and position of all other road users within a given area. Conflict

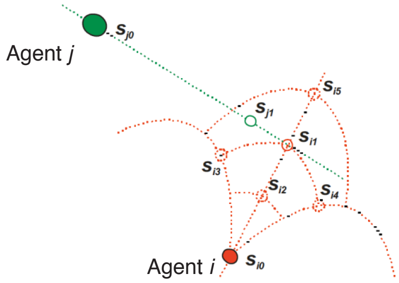

FIGURE 5 Identification of possible options for avoiding conflict by Schönauer et al. (*25*) (s_{if} and s_{jf} = potential strategies of agent i and j, respectively).

points with the detected road users are calculated, and fuzzy logic rules are used to estimate the relative danger associated with each.

- A path-sketching model, which uses the information collected by the situation detection model to determine possible trajectories. The directness, comfort, and efficiency are estimated for each of the possible trajectories, and fuzzy logic rules are used to evaluate each.
- A reactive path generation model, which carries out the path choice and sends information to the situation detection model.

The model tests used empirical data, and the results indicated that the modeled trajectories reflected those observed at the test site.

ASSESSMENT OF MODELING METHODS

The brief description of the models selected in the previous section offered an overview of the state of the art in modeling bicycles. An assessment was carried out to determine the suitability of the currently available models for the assessment of bicycle traffic quality and safety. The categorization used for assessing the state of the art in modeling of bicycle behavior is described below. In each category, the current approaches for modeling bicycle behavior are compared with bicycle movement and interaction in reality. Input from an expert workshop and results from the literature review were used to determine whether it is necessary to improve the identified deficits in each of the categories of microscopic traffic simulation tools. Whether the reviewed models have been validated and calibrated with data from reality was noted during the review, and the necessity to implement these steps in the future has been included in the assessment.

Assessment Categorization

The models were grouped according to the model approach and assessed separately according to their capacity to model behavior on the tactical and operational level (*29*). An attempt was made to include relevant models in the assessment. However, no specific number of models was set for each of the categories, because the number of existing models addressing each category differs. The following assessment categories were used:

- The operational level includes the automatic actions performed by a bicyclist to control the bicycle and ride through the traffic environment, such as controlling speed, following the road infrastructure, and maintaining a safe lateral distance from other objects and road users.
- The tactical level includes short-term maneuvers that a bicyclist consciously selects to deal with the current traffic situation. Examples of tactical behavior include avoiding collisions with other road users and objects through swerving or decelerating and finding a path through an intersection.
- Modeling approaches that deal with behavior on the strategic level, which include planning the trip and selecting a route, have not been assessed as this is not within the scope of the UR:BAN project.

The behavior of road users was divided into two types of movement: uninfluenced behavior, which occurs when movement is not affected by the presence or actions of other road users, and influenced behavior, which is a reaction to the presence or actions of other road users. The models were assessed regarding their capabilities within each subcategory (e.g., uninfluenced operational behavior and influenced tactical behavior).

Assessment Results: Operational Level

There are several possibilities for modeling the uninfluenced and influenced behavior of bicyclists at the operational level. The uninfluenced operational behavior of bicyclists is currently modeled by one of the following two approaches:

1. Definition of statistical distributions of desired speeds and sets of desired lateral positioning. In this method, bicycle movement is simplified onto one main axis (longitudinal) and the direction of travel is defined by links. Although this approach reduces the realism of the model, the required computing power is also reduced and the speed of the simulation is increased. According to the experts, extended car-following models or CA are sufficient for simulation tasks that do not require highly accurate simulation of bicycle traffic. However, if the goal is to analyze the capacity and level of service of intersections or road sections with many bicyclists or to analyze the safety at critical points, the implementation of a more accurate bicycle model is necessary.
2. Implementation of an attractive force. This force from the destination pulls bicyclists in the direction of the destination at a desired speed. Repulsive forces from the obstacles, other road users, and edges of the infrastructure either increase or decrease the traveled speed. Statistical distributions can be used to vary the desired traveling speed. The main advantage of this approach is that the infrastructure and situation are directly considered in the model. However, this increases the number of parameters and required computing power.

Many approaches have been used to model influenced behavior on the operational level. Lateral interactions are modeled with discrete choice methods or by implementing a continuous lateral axis and calculating TTC to other road users. The main disadvantage of both types of models is the heavy emphasis on the speed and position of surrounding road users and the lack of consideration of infrastructure and obstacles on the behavior of the individual bicyclist. In addition, to model the interactions of two intersecting traffic streams, conflict points are often used. At a conflict point, road users in the minor stream must stop at a predefined point on their travel path and wait until a suitably large gap between vehicles presents itself. The bicycle-specific characteristic of adapting the speed, lateral position, or a combination of both is difficult, or impossible, to depict in current simulation tools based on car-following models. The use of social force models makes it possible to consider interactions with many different road users in the longitudinal and lateral directions simultaneously. The modeling of interaction on the operative level in CA models is coarser but requires much less computing power.

According to input from the expert workshop, currently available models can be used to realistically depict bicycle movement on the operational level. However, these models must be calibrated with field data to accurately simulate traffic situations. The inclusion of the correct lateral spacing maintained between bicycles and other road users, while they are stopped and moving, is crucial in accurately determining the capacity of intersections and road sections. Similarly, the speed, acceleration, and deceleration profiles of bicyclists differ from those of motorized vehicles and must be investigated.

Assessment Results: Tactical Level

An assessment of currently available approaches revealed that far fewer options for modeling such bicycle behavior at the tactical level are currently available. No approaches were identified during the literature review or during the expert workshop that model uninfluenced tactical behavior. Examples of uninfluenced tactical behavior include infrastructure selection (bicycle lane, car lane, or sidewalk) and disobeying of traffic laws based on the geometry and signalization of the intersection and presence of obstacles. Existing simulation tools allow the integration of tactical models. For example, the selection probability for a car lane versus a bicycle lane can be modeled as a function of travel time gain, densities, individual preferences, and so forth. However, there is a lack of empirical data that would allow for the identification and calibration of these models.

A few models were identified that depict the influenced tactical behavior of bicyclists. The two logic models identified use the position, direction, and speed of nearby road users to identify potential conflict points and reassess the bicycle trajectory. The methods used for this reassessment differ between the two models. The model by Li et al. considers the tactical selection of infrastructure (bicycle lane and roadway), but only based on the density of bicyclists in the bicycle lane, which is not always realistic in places with less bicycle traffic (*23*). Two of the identified models are based on a social force approach (*30, 23*). It is not clear which model was used for the movement of the bicyclists in the fuzzy logic model by Huang, and Wu (*28*).

It is somewhat difficult to use car-following models and CA models to depict tactical behavior because the path and travel direction of the road users are predefined. The path selection is then modeled with discrete choice models Therefore, although it is possible to build many situations with these models, it is difficult to include all the possible tactical decisions of the road users. As the number of paths and the complexity of the path network increase, the required computing capacity also increases. The continuous two-dimensional plane of social force models increases the potential to model tactical behavior continuously.

The experts in the workshop agreed that there is a lack of understanding as to how bicyclists make tactical choices, and consequently bicycle behavior on this level is included in only a handful of models. However, concerns about the predictability of tactical bicycle behavior, including rule-breaking behavior, were raised by the experts.

CONCLUSION

Although the modeling of bicycle traffic is a relatively undeveloped field, the increase in bicycle traffic in many countries has made the inclusion of bicycles in traffic simulation tools necessary. Because the behavior of bicyclists is considerably different from that of motorized vehicles, it is not possible to directly adopt models developed for motorized traffic.

This evaluation of current bicycle models and the input from the expert workshop indicated that the approaches used to model uninfluenced and influenced behavior on the operational level vary in their level of detail and ability to reproduce reality correctly. Nevertheless, it is quite possible to model the majority of bicyclist behaviors on this level. It would be beneficial, however, to validate and calibrate several of the existing models with empirical data collected in a variety of locations and traffic situations.

The state of the art in modeling the tactical behavior of bicyclists is, however, less developed. The uninfluenced tactical behavior of bicyclists, which has received little attention, is important to include in models to consider how bicyclists behave before their actions are affected by the presence or actions of other road users. Only then will it be possible to adapt and change this behavior based on other bicyclists and motor vehicles in the vicinity. As bicyclists are much more flexible than car drivers, the question why they behave in the ways they do becomes at least as important as how they behave. To develop accurate models that depict the uninfluenced and influenced tactical behavior of bicyclists, empirical data, in the form of stated and observed preference, must be collected in various situations.

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