Abstract— The so called “free crossing area” (FCA) is one possible traffic regime to design a street according to the shared space-idea in Switzerland. By removing all zebra crossings, pedestrians are able to cross the street freely at any point, strengthening the interaction between traffic modes. FCAs have shown to work very well, particularly on traffic-oriented streets with high vehicle volumes. This street layout has only been used reluctantly until now, one reason being the difficulty to identify the effects of FCA in advance. For this purpose, traffic simulation offers a great opportunity, helping planners assessing different traffic layouts in an early stage. In this work, a microscopic simulation of FCA has been set up in Vissim, implementing non-standardized solutions through the COM API. The simulation focusses on the interaction behavior between pedestrians and vehicles, which is modelled using conditional probabilities. The model was calibrated and validated using data from the FCA in Köniz, which is based on the Bernese Model – a similar philosophy to shared space. Results show, that regardless of its simplifications, the simulation model is able to represent vehicle travel times and vehicle continuity very well on a high generalization level. It is accurate enough to allow a comparison of traditional pedestrian crossing designs and FCA with respect to delay and capacity. This analysis shows, that since mean delay for every user in FCA is in most cases lower than in comparison to traditional street layouts as zebra crossings, the regime should always be considered when designing a street, especially in situations of high pedestrian activity.

Keywords—Bernese Model; free crossing area; microscopic traffic simulation; mixed traffic; shared space; Vissim

I. INTRODUCTION

Shared space can be described as a philosophy, which aims to improve the quality of streets by placing motorized and non-motorized traffic on the same level. Important elements of shared spaces are a high interaction between traffic modes, self-organized traffic by reducing regulations and the integration of social and traffic behavior in a single street layout [1]. In Switzerland, three major street designs related to shared space exist: The so-called encounter zone or shared zone (20 km/h-speed limit), 30 km/h speed limit zones in residential areas and free crossing areas (FCA). By removing all pedestrian crossings, FCAs allow pedestrians to cross the street freely at any location. Even though they still need to give way to traffic on the road, the created uncertainty forces road users to communicate, which is yet another key element of shared space. In Switzerland, there is a tendency to implement mixed-traffic-schemes also on traffic-oriented streets with a high vehicle volume [2]. FCAs have shown to work very well on such streets. A prominent example is the central area of Köniz, which is based on the Bernese Model – a similar philosophy to shared space. Despite the several positive effects of FCAs shown in research (e.g. [3], [4]), only few such areas have been implemented until today. One reason being, that the effects on traffic flow and capacity are difficult to predict, which can hold political decision-makers from establishing FCAs.

Microscopic traffic simulations offer a great possibility in assessing different street layouts. Until now, commercial microscopic traffic simulation software as Vissim or Aimsun are unable to simulate shared space with built-in functions. Research in the field of microscopic simulation of shared space is relatively new and ongoing. Several simulation models have been developed and tested, but are not yet ready-to-use for the general public (i.a. [5], [6] and [7]).

In this work, a microscopic traffic model to simulate FCAs has been developed in Vissim in order to assess traffic quality and capacity using the case study of Köniz. In section 2 the “Bernese Model” is introduced and the situation in Köniz is presented. Section 3 describes the structure of the simulation model and the implementation in Vissim. The model is calibrated and validated in section 4 and results are presented in section 5: First, simulation results are compared to data collected in Köniz. Second, based on generalizations of the model, capacity of FCAs is assessed and compared to other layouts.

II. BERNES MODEL IN KÖNIZ

The Bernese Model [8] can be described as a planning philosophy with similar aims as the shared space-concept, while being independently developed. In contrast to shared space, which is an abstract concept, the Bernese Model follows
a standardized process defined by public authorities. According to the Bernese Model, several street designs are proposed, FCA being one of them. Solutions should be worked out together with the community and based on local conditions.

In Köniz, the transformation of the central area was finished in 2005 and included not only a reorganization of traffic according to the Bernese Model, but also urban development. The main aim was to bring back life to the dead city center by strengthening commercial activity and reducing the dominance of motorized traffic (from 2000-2001 nearly 20000 vehicles crossed the city per day). Traffic situation got even worse after substituting all signalized intersections with roundabouts and simple zebra-crossings. Because of large numbers of pedestrians crossing the main street between two shopping centers at only one point, capacity rapidly dropped. This was when Köniz decided to participate in a national study and implement FCA. In the center, all zebra crossings were removed, instead a median area was marked to help pedestrians cross the street. Additionally, the speed limit was reduced from 50 km/h to 30 km/h, which is uncommon in Switzerland on streets with a high traffic volume. The effects on traffic were extremely positive: vehicle travel time dropped, and traffic got more continuous, leading to fewer stops and less emissions. Investigations also showed, that traffic safety has not decreased, and social interactions and commercial activity have increased. [3], [4], [9]

III. MICROSCOPIC SIMULATION MODEL

A. Model structure

In this project, the aim is to evaluate the possibilities and limits in microscopic simulation of shared space. The focus lies in developing a model only as complex as needed to sufficiently assess capacity and traffic quality of FCAs, particularly in comparison with other, standard pedestrian crossing layouts. The model was implemented using the microscopic traffic simulation software Vissim\(^1\). Though Vissim can model vehicle and pedestrian behavior very well, controlling their interaction is limited by using the tools “priority rules” and “conflict areas”. This is sufficient to model standard pedestrian crossings, but not for simulating shared space, where the interactions are much more complex. The main problem in Vissim lies in the fact, that pedestrians and vehicles are not based on the same behavioral model – vehicles use the car following model (CFM), pedestrians the social force model (SFM). That’s why road users cannot “see” each other and interactions need to be modeled via fixed rules. However, Vissim allows to implement non-standardized solutions using the COM-interface to access many attributes and methods during the simulation\(^2\).

The requirements of the simulation were defined based on the three layer-structure introduced in [10]. On the first layer, the model must be able to compute trajectories of the road users, assuming free-flow conditions. In cases, where more

\(1\) Vissim (PTV), version 9.00-12, 64-bit, thesis license

\(2\) Python (2.7.14, 64 bit) was used in this project

than one person uses the road and no change in behavior would lead to collision, a conflict is detected. In shared spaces, more than in conventional street designs, road users try to avoid conflicts well in advance and react accordingly. This is handled on the second layer. In some situations, such long-range collision avoidance (LRCA) is not possible, for example when behavior of other users is misinterpreted or not observable due to obstacles. Those cases require immediate reaction (short range collision avoidance, SRCA), which is covered by the third layer [10]. The first layer is already implemented in Vissim. Trajectories of pedestrians are calculated using the flood-fill-algorithm, those of cars are predefined by car lanes. On the third layer, interactions between pedestrians are handled well with the SFM, those between vehicles with the CFM. To cover interactions between different modes and LRCA (Layer 2), priority rules and non-standardized solutions are needed. Since this project aims to analyze road capacity, LRCA between pedestrians can be neglected, while the CFM for LRCA between cars is accurate enough. Hence, the focus must lay on handling vehicle-pedestrian interactions, LRCA in particular.

As proposed in [11] the interaction behavior in the model is based on two types of road users. Users either show “prudential” behavior (give way to other users) or “aggressive” behavior (showing no consideration for other users). This leads to a total of four possible interaction cases (Table 1). Cases A, B and C cover LRCA, in case D SRCA is required. In general, the following reaction behavior types are possible:

- Link-based vehicles can either continue with desired speed (aggressive behavior) or decelerate (prudential).
- Area-based pedestrians can either continue with desired speed and trajectory (aggressive) or decelerate and/or change trajectory to let vehicle pass (prudential). Theoretically, acceleration to cross in front of a car without disturbing it is also possible, but has been rarely observed in Köniz.

Tabling the decision, which user will behave in which way, is complex for which research shows different approaches. In [6] game theory was used, in [5] the decision is

<table>
<thead>
<tr>
<th>Case</th>
<th>Behavior of road users</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Vehicle decelerates well in advance</td>
</tr>
<tr>
<td></td>
<td>Vehicle gives way to pedestrian</td>
</tr>
<tr>
<td>B</td>
<td>Pedestrian enters road without hesitation</td>
</tr>
<tr>
<td></td>
<td>Pedestrian waits until vehicle nearly stops</td>
</tr>
<tr>
<td></td>
<td>Vehicle decelerates well in advance</td>
</tr>
<tr>
<td></td>
<td>Vehicle gives way to pedestrian</td>
</tr>
<tr>
<td>C</td>
<td>Pedestrian and car show prudent behavior</td>
</tr>
<tr>
<td></td>
<td>Vehicle decelerates well in advance</td>
</tr>
<tr>
<td></td>
<td>Pedestrian waits until vehicle nearly stops</td>
</tr>
<tr>
<td></td>
<td>Pedestrian continues with desired speed</td>
</tr>
<tr>
<td></td>
<td>Pedestrian decelerates or changes trajectory (continues walking parallel to road border)</td>
</tr>
<tr>
<td></td>
<td>Pedestrian gives way to vehicle</td>
</tr>
<tr>
<td>D</td>
<td>Car and pedestrian show aggressive behavior</td>
</tr>
<tr>
<td></td>
<td>Vehicle decelerates well in advance</td>
</tr>
<tr>
<td></td>
<td>At least one of the users is forced to abruptly stop and/or change trajectory (SRCA)</td>
</tr>
<tr>
<td></td>
<td>Precedence for user, which is closer to conflict</td>
</tr>
</tbody>
</table>
made based on geometrical attributes. In this thesis, a pragmatic approach is proposed: The behavior of drivers is assumed to be known and fixed. The behavior of pedestrians is set accordingly by using conditional probabilities. Calibration of those parameters is presented in section 4.

B. Implementation in Vissim

In Vissim, vehicles can only pass a large pedestrian area, if the whole section is completely free of pedestrians. To deal with this problem, several thin pedestrian links are created. Slight overlapping ensures that pedestrians are still able to walk diagonally. At the crossing points between vehicle and pedestrian links, multiple priority rules control the deceleration/stopping behavior of the road users based on the standardized interaction types. For example, pedestrians who show an aggressive behavior accept a smaller time gap to cross the street, prudent users require higher time gaps which may lead to a full stop at the street border even if the car is decelerating.

In addition to deceleration, pedestrians can change their trajectory and, for example, let a vehicle pass by crossing the street behind it (interaction type C). To model such behavior, pedestrians must be able to “see” cars, which is not possible in Vissim, per se. An innovative approach to this problem is presented in [12]. Every car is additionally represented by a group of “dummy-pedestrians” which is created using event-based scripts. In this case, “real” pedestrians evade the group of “dummies”. Visual tests show, that this approach seems to work well. However, the model is very computationally expensive (for the Köniz case study a Real-Time-Ratio between 1/5 and 1/10 has been observed3), which makes calibration nearly impossible. For this reason, evading behavior of pedestrians was not considered. This simplification seems acceptable, since observations in Köniz show, that letting vehicles pass by decelerating is more common than a change of trajectory.

The behavior of road users (aggressive/prudent) is controlled by event based scripts. It takes advantage of the possibility to change vehicle and pedestrian classes of agents during the simulation. Vehicles, which are added to the simulation are either created as part of the aggressive or the prudent vehicle class. They generally keep their behavior type throughout the simulation. Only in cases, when vehicle speed drops below a certain threshold, prudent behavior is assumed and vehicle class is changed accordingly, until speed rises again. Pedestrian behavior is set based on the behavior of the closest approaching vehicle and pre-defined conditional probabilities. Since priority rules can be set selectively for certain vehicle/pedestrian types, the model is able to represent all interaction cases realistically.

Only using priority rules in Vissim can lead to problems with pedestrians walking “through” cars. This could be solved by adding conflict areas with modified parameters, so that they do not have an influence on interaction behavior.

IV. CALIBRATION

A. Interaction behaviour

The probabilities defining the interaction behavior were calibrated evaluating 1½ hour video data of the FCA in Köniz (11. Nov. 2014, 11:30 am to 13:00 pm). In every interaction, the behavior of the involved road users was either classified as “aggressive” or “prudent” and the outcome of the interaction (which user takes precedence) was recorded. Table 1 shows some of the criteria used for classification. In pedestrian groups only the first interaction was noted.

Observations show, that the defined interaction cases are suitable to reproduce the interaction behavior. Only in rare cases outcomes could be observed, which the model does not account for (Fig. 1). For example in the case, when both users show prudent behavior, with the vehicle taking precedence in the end. According to case C, vehicle would give way to the pedestrian.

In total, 306 interactions were observed. Results show, that interaction behavior depends on the direction of travel of the pedestrian. Pedestrians coming from the median area have the right of way in 86%, pedestrians coming from outside in 39% of the cases (Fig. 1). In interactions with busses, pedestrians almost always show prudent behavior. Interaction case D, which requires immediate reaction (SRCA) was only observed three times. Based on these results, the model was simplified, assuming only interaction type A in case a pedestrian comes from the median area. In addition, all busses were modelled as being “aggressive”. The behavior of the cars was set as follows:

\[
P(\text{veh}_\text{pm}) = 0.4
\]

(1)

Parameters of pedestrians coming from outside as follows:

\[
P(\text{ped}_{\text{age}}|\text{veh}_\text{pm}) = 0.97
\]

(2)

\[
P(\text{ped}_{\text{age}}|\text{veh}_\text{pr}) = 0.53
\]

(3)

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Interaction type} & \text{Predominant pedestrian behavior} & \text{Predominant vehicle behavior} & \text{Outcome} \\
\hline
\text{A} & \text{A} & \text{A} & \text{A} \\
\hline
\text{B} & \text{B} & \text{B} & \text{B} \\
\hline
\text{C} & \text{B} & \text{A} & \text{A} \\
\hline
\text{D} & \text{B} & \text{A} & \text{B} \\
\hline
\end{array}
\]

Fig. 1. Results of interaction evaluation in Köniz.

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3 750 ped/h, 1000 veh/h, 80 m long FCA. System: Intel i7-7600U (2.90 GHz), 20.0 GB RAM. Vissim 9.00-12, 64 bit.
B. Other parameters

A bus-stop with a bus line running every 3 minutes in each direction is located in the middle of the FCA. Its effects on traffic must be considered in the simulation. Observations show, that in 80% of all cases, at least some cars use the median area to overtake stopping busses. In Vissim, this was implemented by only simulating some of the busses stopping the full observed mean stopping time, for all other busses a minimal stopping time is assumed, to account for some disturbance.

Parameters of the priority rules and intersections (minimum headways and gap times) are difficult to observe and were calibrated based on visual comparison of the simulation and the real observed behavior. For input parameters like traffic volume, traffic speed and pedestrian volume, already existing data could be used. Traffic volume in the central FCA consists of a total of 750 crossing pedestrians per hour and 1'150 vehicles per hour (representing the state of 2016). For all other parameters, Vissim-standard values were used.

In order to minimize influence of the intersection “Sonnenweg”, simulation has been split into two parts (Fig. 2). First, only the central FCA was modelled and calibrated as discussed before, followed by comparing the results to real data. This model is hereafter referred to as the FCA model. In a second step, simulation was extended to the whole city center, including calibrating intersection parameters on a “trial-and-error” basis, without changing the original FCA model (hereafter referred to as the combined model). Pedestrian crossings in the northern part were modelled as normal zebra-crossings at a total of 5 locations, since pedestrian volume is significantly lower than in the central area.
V. RESULTS

A. Comparison with real data

To validate the model, simulation results were compared to real data. The following comparative parameters were chosen: vehicle travel times, number of vehicle stops and mean stopping duration. Parameters were gathered by evaluating GPS data from 27 vehicle trips per direction of travel (carried out in October 2014, evening peak hour). For vehicle travel times, additional public transport data could be used (480 trips per direction, carried out in October and November 2017, evening peak hour). The mean values of both measurements are comparable (Fig. 3).

Simulation was carried out in Vissim using 5 simulation runs with different random seeds and a duration of one simulation hour per run (with an addition of 900 seconds warm-up-time without influence on the results). Data was collected only on central FCA area between intersection “Sonnenweg” and roundabout “Bläuacker”. Travel time results in simulation (FCA model) are slightly lower than observed (Fig. 3). The number of stops per vehicle-kilometers are comparable, but mean stopping time in simulation is again lower than observed (Fig. 4).

B. Comparison with situation without FCA

Using the combined model, simulation result using FCA (30 km/h speed limit) was compared to a model without FCA, but instead standard zebra crossings and 50 km/h speed limit, representing the situation in Köniz before transformation. Pedestrian crossings were modelled at three different locations using standard Vissim parameters. Results show, that simulated vehicle travel times using zebra crossings are significantly higher compared to the model using FCA (Fig. 5). Therefore, the model is able to reproduce the changes observed in Köniz.

Fig. 5 also shows, that travel times of the combined model can generally be compared to the observed public-transport travel-time-data.

C. Assessing capacity and traffic quality

For further analysis, the setting of the FCA model was generalized to compare the regime to other, traditional pedestrian crossing street layouts. The following designs were compared, using a 100-meter-long street section:

- **FCA**: 30 km/h speed limit, 10-meter-long pedestrian areas, pedestrians crossing using rectangular or slightly diagonal trajectories, evenly distributed pedestrian volume.
- **1 zebra crossing** in the middle of the area, 50 km/h speed limit.
- **2 zebra crossings** at both ends of the street section.
- **Signalized crossing** in the middle of the area, 60 s cycle time, 12 s pedestrian green, 45 s vehicle green.
The layouts were simulated in Vissim, using standard parameters for traditional crossing layouts. For capacity assessment, maximal vehicle throughput using different pedestrian volumes was measured. Results show, that capacity of FCA without pedestrians is lower than in traditional layouts, because of the lower speed limit. Capacity with higher pedestrian densities falls much faster in zebra-crossing-layouts than in FCA. After around 4 ped/(h*m) the capacity of FCA is higher than the one from 1 zebra crossing, after 7 ped/(h*m) higher than the one from 2 zebra crossings (Fig. 6). Based on a saturation flow of 1’800 veh/(h*lane), total capacity of the signalized crossing can be calculated as 2’700 veh/h (both lanes), independent of the pedestrian volume.

Road capacity does not take pedestrian situation in consideration, which, for example, suffer long waiting times at signalized intersections. To assess the overall traffic quality, the mean delay per road user (drivers and pedestrians) is evaluated. Delay of pedestrians is calculated by comparing actual travel times with travel times using shortest paths, delay of vehicles is compared to the situation with a speed limit of 50 km/h. Fig. 7 shows the results for a scenario, where pedestrian volume is fixed at 10 ped/(h*m), which represents the situation in Köniz. Vehicle volume is varied between 0 and 2000 veh/h. Until the capacity limit, FCA shows the lowest delay per user and therefore offers the highest overall traffic quality of all designs tested. Other scenarios show, that at lower pedestrian and higher vehicle volumes, the mean delay per user in FCA is slightly higher compared to the other layouts, because of its lower speed limit (30 km/h instead of 50 km/h).

VI. DISCUSSION AND CONCLUSION

FCA is a traffic regime to design a street according to the shared space-idea in Switzerland. In this work, a microscopic simulation of FCA has been set up in Vissim and was calibrated and validated using the case study of Köniz. Results show, that the simulation model is able to represent vehicle travel times and vehicle continuity well on a high generalization level. The application of the model is limited due to simplifying model assumptions. For example, the interaction behavior does not depend on geometrical parameters, but is pre-defined by probabilities. Also, prudent pedestrian behavior in interactions with cars is limited to decelerating, a change in trajectory was not modeled. Therefore, the model cannot be used to analyze detailed pedestrian behavior or vehicle travel times with high accuracy. Nevertheless, it can be used to compare FCA with other, traditional street designs, where high accuracy is not needed because of the larger differences in respect of travel times, delay and capacity.

Based on the capacity and traffic quality assessment, FCA should always be considered when designing a street, since in most cases, especially at high pedestrian volumes, mean delay for every user can be minimized compared to traditional street layouts. Only in situations with a low pedestrian-vehicle-ratio zebra-crossing seem to be more suitable, since FCA show no positive effect regarding delay.

Of course, the decision which layout to use must be based on several additional factors not discussed in this thesis. Most important, the simulation analysis was based on a perfectly distributed pedestrian volume. It can be assumed, that the positive effect of FCA is reduced, if pedestrians do not use the whole area for crossing, but instead only cross at single points. In addition, results are limited, since the model was calibrated using only one specific case study. Other static and/or dynamic characteristics could alter interaction behavior and therefore change results.

In future research, the presented model could be tested in other situations to further assess the model’s validity. In addition, more complex interaction behavior could be modelled. Since possibilities for this in Vissim are limited, building a more versatile simulation toolset should be considered. In general, Vissim is not suitable to model shared space until now. Implementing a behavior model, which can be used for pedestrians and vehicles (for example an extended SFM), is necessary to advance further research in this field.

REFERENCES