Model for rural transportation planning considering simulating mobility and traffic kills in the badger *Meles meles*

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**ABSTRACT**

Large-scale spatial planning requires careful use and presentation of spatial data as it provides a means for communication with local stakeholders and decision makers. This is especially true for endangered species, such as the badger (*Meles meles*) in the Netherlands. To effectively mitigate the badger’s traffic mortality in an area, two types of tools are needed. The first one estimates the probability of a successful road crossing for individual animals. The second tool is GIS-based and not only models the movement patterns of animals but also estimates an animal’s daily number of road crossings. With data on population size as well as on road and traffic characteristics, a combination of both tools provides a measure of the mortality risk roads pose to wildlife in an area. Such estimations proved to be invaluable in a planning process with local inhabitants in the municipality of Brummen (the Netherlands), where ecological as well as safety problems appear. Our study demonstrates the applicability of GIS tools in balancing ecological consequences of road network options with a different distribution of traffic flows over the area in spatial planning and ecology.

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*Meles meles*

1. **Introduction**

Roads and their traffic are a principle cause of fragmentation and disturbance of wildlife habitats. Consequently, animals experience increased resistance for moving through the landscape and collision risks during crossing of roads (Forman et al., 2003). Traffic mortality is even one of major causes of death for many species in human-dominated landscapes (Groot Bruinderink and Hazebroek, 1996; Trombulak and Frissell, 2000). For the most common species, traffic mortality is not considered to be a severe threat to population survival (Seiler, 2002). However, for many endangered or rare species, traffic mortality is most likely responsible for regional extinction (e.g., local in western Europe, badgers (*Meles meles*): Lankester et al., 1991; Clarke et al., 1998). Because of declining biodiversity and risk of accidents, interventions in wildlife habitats are frequently applied to reduce these negative effects. In this paper, we focus on traffic mortality and the planning of interventions to mitigate mortality.

Mitigation interventions include keeping wildlife off the road (e.g., fences: Putman, 1997), providing alternative routes (e.g., fauna passages and ecoducts: Keller and Pfister, 1997) or reducing the risk of collisions (e.g., highway lighting or mirrors: Putman, 1997). Most of these interventions involve technical devices that change roads. However, other interventions that do not depend on technology may also reduce resistance for animal movement and traffic mortality, such as the reduction of traffic volume or speed, and the periodic closing of roads (during the night or a specific season). Reduction (temporary or permanent) in traffic volume might drastically decrease the barrier and mortality effect (Van Langevelde and Jaarsma, 2004). To effectively apply mitigating...
interventions, insight into the effects of road and traffic characteristics on both resistance for animal movement and traffic mortality is needed (Forman and Alexander, 1998; Jaeger and Fahrig, 2004; Van Langevelde and Jaarsma, 2004). These mitigating interventions require a careful redesigning of the road network by changing road and/or traffic characteristics. In related papers, we proposed a strategy based on the concept of a “traffic-calmed area” (Jaarsma, 1997), where the effects of minor and major roads are not separately mitigated, but are mitigated in conjunction with one another (Jaarsma and Willems, 2002; Van Langevelde et al., submitted for publication).

In human-dominated landscapes, changing the accessibility of locations by changing traffic flow characteristics, like reducing speed or closing roads, requires the interests of local stakeholders, such as village inhabitants, farmers using the land, shop keepers, recreational facility exploiters, etc., to be carefully balanced. Plans for redesigning the road network should be discussed with these stakeholders and the consequences for different land uses be made explicit. One way to do this is by developing scenarios (Dammers, 2000; De Nijs et al., 2004), showing the predicted autonomous development in an area compared to various options for mitigating interventions (i.e. the scenarios applied to the predicted development). In this paper, we present a computational framework for simulating traffic mortality due to infrastructure and for forecasting the results for 2015 of different scenarios with interventions that mitigate the negative effects of roads and their traffic on wildlife.

Therefore, this paper aims (1) to show spatially explicit tools for providing a measure of the mortality risk roads pose to wildlife in an area and (2) to illustrate the value of such estimations in rural spatial and transportation planning. We present an application for the badger in the municipality of Brummen, the Netherlands, where ecological as well as traffic safety problems have appeared. The autonomous development for 2015 and several scenarios with different priorities to interests of transportation and ecology were developed and the consequences of these scenarios for wildlife are presented.

2. Methods

To effectively mitigate traffic mortality in an area, data are needed about (daily) animal movement through the landscape combined with data on the probability of successfully crossing a road encountered by an animal. Therefore, two types of models are needed. We used a model of successful road crossing for animals (the traversability model) and a spatially explicit model to simulate the animals’ movement in a landscape (SmallSteps).

2.1. Traversability model

The first tool, the traversability model (Van Langevelde and Jaarsma, 2004; Jaarsma et al., 2006), estimates the probability of a successful road crossing for individual animals. Assumptions in this model are (1) a prompt traverse of a road by an animal with a constant speed and (2) a kill of the animal in a collision if a car arrives before it leaves the car’s lane. In the latter case, the appearing gap in the traffic flow, i.e. the time until the next car arrives, is smaller than the time necessary for the animal for its traversing. The study of Van Langevelde and Jaarsma (2004) estimates the number of victims related to characteristics of the species (the animal’s length and traversing speed), the pavement width, and the traffic volume (deciding for the appearance of gaps in the traffic flow) in the following way.

In traffic flow theory, the Poisson distribution is used to simulate the probability \( P(x) \) that \( x \) vehicles arrive at a given location on a one-way road in time period \( T \) (in s). This probability can be described as

\[
P(x) = \frac{(\lambda T)^x e^{-\lambda T}}{x!}
\]

where \( \lambda \) is the traffic volume in vehicles s\(^{-1}\). For a successful traversing, \( x \) should be equal to 0, at least during the time period \( T \) when the animal "occupies" the road for traversing. For \( x = 0 \), Eq. (1) changes into

\[
P(0) = e^{-\lambda T}
\]

In other words, \( P(0) \) is the probability that the front of the next car does not arrive within a period of \( T \) seconds, given a traffic flow with an average of \( \lambda \) vehicles s\(^{-1}\). The relevant length of the time period \( T \) depends on road, traffic, and species characteristics as mentioned above. Van Langevelde and Jaarsma (2004) derived that the animal can traverse a road without a collision with probability \( P_c \) that equals

\[
P_c = e^{-\frac{L_a}{B}}
\]

where \( B \) is the width of pavement (in m), \( L_a \) is the animal’s length (in m) and \( V_a \) is the speed of the animal traversing the road (in m s\(^{-1}\)). A recent study (Jaarsma et al., 2006) prefers, for theoretical reasons, the car’s length, width and speed as explanatory factors for the probability of a collision. Mathematically, for a car width of 2 m and a road pavement width of 4 m both models give the same result. Because most minor roads in the Brummen region are characterized by pavement widths in a range between 3.6 and 4.7 m (Van den Berg et al., 2005), we did not re-calculate the results with the model based on car characteristics.

2.2. Simulation of animal movement

The second tool, SmallSteps, is a generic movement model, which simulates the movement of animals through a spatial-realistic landscape (Baveco, 2003). We used it to estimate the daily number of road crossings, either in absolute or in relative numbers. SmallSteps has been applied at different spatial scales and for different species, ranging from butterflies (Sneep et al., 2005) to small (Jepsen et al., 2004) and large mammals (Van der Sluijs et al., 2003). In most applications the simulated movement represents the movement of dispersing individuals. For the badger, we adapted the model to represent the daily (nocturnal) foraging movements instead of dispersal (see below).

In SmallSteps, movement is simulated on a fixed time-step basis. The basic movement pattern is assumed to be a correlated random walk (Kareiva and Shigesada, 1983). The simulation begins by drawing a random (exponentially-distributed) move-
length and a random (normally-distributed) turning-angle. Move-length and turning-angle probability density functions have to be defined for each type of landscape element. When the movement trajectory hits the boundary between two landscape element types, transition-probabilities defined for each possible pair of landscape element types determine whether the animal crosses the boundary or returns.

In the badger model (Van der Grift and Bavoco, 2002), we added, to each (correlated random-walk) displacement vector, a small vector perpendicular to the axis from the current position to the home-range center in order to make the individual circle around the home-range center. In addition, we added a vector directed towards the home-range center, which represents the “centrifugal” force and keeps the animal at a more or less constant distance from home-range center. The size of these vectors as well as the standard correlated walk parameters were calibrated such that the resulting daily movement patterns closely resembled observed patterns (Brown et al., 1993; Neal and Cheeseman, 1996). Actual parameter values are given in Table 1.

### 2.3. Combination output traversability model and SmallSteps

Based on Eq. (3), the number of traffic victims of a species $a$, $D_a$, during time period $\tau$ can be estimated by

$$D_a = (1 - P_a)K_a\tau,$$

where $K_a$, is the number of attempts to traverse the road by individuals of species $a$ during the time period $\tau$. The parameter $K_a$, is, however, difficult to measure and depends on several species and landscape characteristics such as home-range size, movement behavior during foraging or dispersal, road density, and the location of the road with respect to, for example, the locations of the badger setts and their foraging areas. We therefore suggest that the model not be applied to calculate the absolute number of traffic kills of a species during a certain period of time. Instead, we used the model as a measure of the mortality risk a road poses to all the badger setts in its neighborhood. This value provides a measure of the risk an individual badger runs at each sett. The second output refers to the number of times a single road is crossed by any badger when a single individual badger is moving around within each home-range. This value is effectively an estimate of $K_{a\tau}$ with $\tau$ set to one day. When multiplied by the $(1-P_a)$ value for this particular road (Eq. (4)), the result provides a measure of the mortality risk a road poses to all the setts in its neighborhood.

### 2.4. Combination with road and traffic characteristics

We applied the two models for estimating changes in traffic mortality in the study area Brummen for the autonomous development in 2015 and three scenarios. The scenarios differ in giving priority either to accessibility or to preserve the natural values of the area, as will be explained in the next section. For the autonomous development and these scenarios, the road network and the belonging traffic characteristics in 2015 were estimated. We used a traditional transportation model to calculate the traffic generation and the future distribution of flows over the network (volumes per road section, $\lambda$). From these flows, “traditional” items in traffic planning were derived per road section: pavement width ($W$), traffic safety (expressed in the number of fatalities and injuries), and noise loads. Fatalities and injuries for the study area were calculated by multiplying Dutch accident risks per road category with volume and length per road section, summoned over all sections. Noise loads were calculated per road section with legal formulae, considering volume, speed and traffic composition. These impacts will be mentioned when we present the results per scenario.

### Table 1 – The parameters that describe the walking pattern of the badger in the model SmallSteps (Van der Grift and Bavoco, 2002)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Used values</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step size (average of exponential distribution)</td>
<td>10 m (time step 1 min)</td>
<td>(Brown et al., 1993; Neal and Cheeseman, 1996)</td>
</tr>
<tr>
<td>Turning angle (standard deviation of normal distribution)</td>
<td>0.26 (1/12π)</td>
<td>(Brown et al., 1993; Neal and Cheeseman, 1996)</td>
</tr>
<tr>
<td>Average distance between territory border and sett</td>
<td>800 m</td>
<td>Van Apeldoorn et al. (1997)</td>
</tr>
<tr>
<td>Average crossed distance per night</td>
<td>3000 m</td>
<td>Van der Grift and Bavoco (2002)</td>
</tr>
<tr>
<td>Maximum distance to sett at the ending of the movement</td>
<td>100 m</td>
<td>-</td>
</tr>
</tbody>
</table>

### 3. Study area

The study area (Fig. 1) is situated in the municipality of Brummen, in the province of Gelderland in the Netherlands. Three large villages are located in the area: Brummen, Dieren and Eerbeek. The area is a transition zone from the large forest and heather landscape of the Veluwe to the river landscape of the river IJssel. The rural area of the municipality Brummen is a small-scale landscape with agricultural fields and forest patches, small villages, brook valleys and estates (Arisz, 2005; Van den Berg et al., 2005). Due to the location of the study area...
(next to the Veluwe, the largest terrestrial nature reserve in the Netherlands) and the presence of several recreational facilities, recreation is an important type of land use in the area.

One of the umbrella species for Dutch nature policy and present in the study area is the badger. The largest sett of the region is situated in the study area. In the period 1995–2005, in total 58 badgers became victim to road kill. This is on average 5 per year with a range between 1 and 15 road kills per year (Fig. 2).

The study area is bounded by a canal (Apeldoorns Kanaal) in the west, and two major rural roads (regional N789 in the west and provincial N348 in the east). The canal in the west (beside N789) was considered to be an absolute barrier for badgers. This enabled us to work with a clearly defined badger population. A third major road (regional N787) crosses the area (Fig. 1). The area is opened-up by minor roads, collectors as well as access roads, which mainly have an east–west orientation (Van den Berg et al., 2005). Several of these roads intersect or border the nature reserves. In addition to the local inhabitants, the minor roads are also used by through traffic, which conflicts with their access function (Van den Berg et al., 2005). The actual use of the roads implies two important problems. The legal speed limits are frequently exceeded and the traffic volume on the minor roads exceeds the roads’ carrying capacity. This has resulted in verge damage and a relatively high number of accidents with people and animals. Traffic volumes on the roads in the area have increased in the past (Arisz, 2005) and are expected to grow...
in the future (Van den Berg et al., 2005). Contrary to the development in the Netherlands and in the province of Gelderland, the number of traffic victims in Brummen is increasing. The level in Brummen in the period 1999–2003 is 7.4% above the level in 1989–1993, where at the same time the level in the province of Gelderland decreases with 8.0%.

There are several conflicting interests in the area. It is clear, however, that traffic safety for both human and animals has to be improved. As a result, three scenarios for 2015 with different priority to the conflicting interests have been developed with a specific road network for each (Van den Berg et al., 2005; Fig. 3a–c). The first scenario is called Accessible Rural Area. The main idea of this scenario is that the rural area of the municipality becomes more and better accessible. The minor roads in the area will be adjusted to carry the expected increased traffic numbers. The area will be opened up by a dense net of high quality minor collector roads. Cyclists and pedestrians can move on separate bicycle paths and sidewalks. The second scenario is the Rest and Accessibility scenario. In this scenario, the amount of traffic on most of the minor roads will be reduced, but one east–west oriented road will be upgraded to a regional road, to carry the extra traffic that is excluded from the other minor roads. The existing provincial and regional roads will carry also increased traffic flows. The final scenario is Rest and Space. The main idea here is to ensure the natural and recreational values of the area with low noise loads. In this scenario, the minor roads are only used by local residents for access, which drastically reduces traffic volumes. All through traffic will use the existing provincial and regional roads in the area, which will result in an increased traffic volume.

4. Results

With data on location of the setts, road and traffic characteristics, a combination of both tools allows the roads which pose
the largest mortality risk to the setts to be identified. The SmallSteps model was first used to identify the roads with large numbers of badger crossings per road. The GIS based output of the number of crosses per road per night, divided into relative classes compared to the average value in the area, is shown in Fig. 4. Many of the minor roads are more than average crossed by badgers. These roads intersect or border the nature reserves in the study area.

By combining the model for the probability of a successful road crossing with SmallSteps, the scenarios’ effects for the badger can be predicted. In combining the two models, we first estimated the autonomous development in 2015 when no specific measures have been taken (Fig. 5a). The autonomous development shows several east–west oriented roads with large volumes. These thoroughfares have large negative influences on the badger. Therefore, mitigating interventions for the area from an ecological point of view seem advisable. Next, each scenario is compared with the autonomous development.

In the scenario Accessible Rural Area, the traffic safety will slightly decrease on the minor roads (Van den Berg et al., 2005). On the provincial roads on the edges of the study area, the traffic safety will stay the same. With increased traffic numbers, a part of the recreational values in the area will further decrease due to high noise load. The situation for the badger in this scenario is shown in Fig. 5b. Compared to the autonomous development, the predicted situation for the badger deteriorates.
With the decreased traffic volumes on all minor roads except the upgraded one in the scenario Rest and Accessibility, overall the traffic safety on minor roads will increase as well as the recreational values of the area (Van den Berg et al., 2005). In this scenario, the noise levels due to traffic will decrease on the minor roads, except for the upgraded road. The area will become more attractive for recreation. The situation for the badger in this scenario is shown in Fig. 5c. The
situation on most of the minor roads greatly improves. However, on the upgraded minor road, the situation becomes worse because of the increase in traffic on that particular road.

With the decreased traffic numbers on all the minor roads in the scenario Rest and Space, the traffic safety will increase (Van den Berg et al., 2005). Because more traffic is bundled on the provincial roads, the traffic safety will decrease here. Around the nature reserves, the noise levels will decrease because of the decreased traffic numbers. As a result, the landscape values in the area will be less devalued by the traffic, and the recreational attractiveness will increase. The situation for the badger in this scenario can be found in Fig. 5d. Because all through traffic will be directed via the provincial roads, the situation on all the minor roads will improve. With these roads bordering or intersecting the nature reserves, movement of badgers in their territories is less risky.

5. Discussion

The rural road network was built in an era when transportation planners focused on providing safe and efficient transport with little regard for wildlife. “That is changing ... the call for new knowledge and skills is stronger than ever” (Forman et al., 2003; p xiii). Against this background, we present a computational framework for simulating traffic mortality due to infrastructure and for forecasting the consequences of different interventions that mitigate the negative effects of roads and their traffic on wildlife. The framework consists of combining a model to determine the probability of a successful road crossing with a model for animal movement. In the scenario study, we show that this combination of tools can be used to predict the ecological impacts of changing road and traffic characteristics for individual road sections as well as to compare and contrast scenarios for a regional road network in order to visualize ecological consequences of these options for both decision makers and local inhabitants. As an input in local spatial planning processes, we argue that these results could be useful (1) to inform local people and decision makers about problems and visualize several options with different consequences and (2) to provide ecologists, transportation engineers and land use planners with information to improve the balance of ecological and economic/technical interests.

Adjustments to the regional road network and/or the layout of specific road sections directly result in changes in volumes and speed. This, in turn, affects wildlife on a regional scale (Forman et al., 2003). So, there is a relationship between transportation planning and mitigating interventions focusing on a decreasing barrier and mortality effect for the fauna. With the scenario study, we could predict clear differences in impact on the badger between the scenarios due to different new road design and subsequent traffic flows. Based on our findings, we conclude that the differences can mainly be found on the minor roads. Because almost all of these roads intersect or border the nature areas, large improvements to the roads can be made for the badger. Traffic safety and recreational values also differ between the three scenarios.

When considering regional networks of major and minor roads in conjunction with one another, the scenarios based on the concept of “traffic-calmed rural areas” (Jaarsma, 1997) create opportunities for wildlife with few limitations for movement of individual animals (Jaarsma and Willems, 2002). The underlying idea of this concept is a clear separation between living space for human inhabitants as well as wildlife, and space for traffic flows. As a result, roads within traffic-calmed areas are designed for the preferred functions (inhabitants, wildlife) and not for the actual (through) traffic flows (Van Langevelde et al., submitted for publication). Local access within such traffic-calmed areas is offered by minor access roads with a moderate design for low speeds and low traffic volume. Through traffic will find faster and safer alternative routes using major roads. On the latter type of roads, which additionally give access from abroad to the traffic-calmed area, a concentration of traffic flows appears (Jaarsma, 1997). As a result, traffic will flow using the “safest” locations.

Some local people will welcome the concept of the traffic calmed area because of a better livability, safer conditions for their school-going children and/or better opportunities for sustainable wildlife, where others will reject it because of the hindrance by measures such as lower speed limits on minor access roads. Calculations of flows by traditional transportation models supplied with the information from the tools described in this paper may contribute to balancing the urge of making areas accessible, promoting safety, and protecting wildlife. Contrary to the “traditional” approach, the effects on wildlife, in addition to other benefits such as increased safety, will get full attention when designing rural infrastructure plans in this way. Our experience in Brummen shows that within this context a visualization of the impacts with spatially implicit tools is very revealing and useful to laymen.

In this paper, we use the badger as the representative animal for planning mitigating interventions for negative effects of traffic on wildlife movements. It is possible, however, to use the two tools for other animals that have comparative behavior when crossing a road. The only restriction is the availability of specific parameters describing the walking pattern of the animal (as given in Table 1 for the badger).

The combination of the two models is based on a limited number of road, traffic, vehicle and species characteristics. So far, the two models have not been tested in experiments (Van Langevelde and Jaarsma, 2004; Baveco, 2003). For such an experiment, reliable numbers of road crossings by individual animals as well as numbers of traffic kills per road section should be gathered. As far as we know, there are no studies on the former. In our study the small badger population and therefore limited badger road kill victims made it impossible to validate the outcome of the model study. Some studies provide numbers of victims, but due to scavengers or identification problems, especially for small animals, the actual numbers are difficult to measure. This conclusion has held true for the last seventy years (Stoner, 1936; Hels and Buchwald, 2001; Slater, 2002). It is therefore questionable whether an empirical experiment can provide reliable data for the validation of the absolute numbers of traffic kills as calculated by the model. When the model is used to provide a measure of mortality risk and be able to compare scenarios with it, systematic errors in the model by animal behavior, if any, will be eliminated by subtraction.

Due to a series of European directives on habitat protection for wildlife and the sharpened legislation for the protection of
nature, impacts of transportation plans on the natural environment must be considered very carefully (Tromčé, 2003). More specifically, the impacts of measures proposed in a transportation plan must be described for relevant (threatened) species in the region (Haq, 1997; Iuell et al., 2003). Changes in a regional road network and/or the layout of specific road sections cause changes in traffic volumes and speeds. So far, the tool is missing to “translate” this into impacts for wildlife movements. The tools presented in this paper enable transportation planners to include the impact of roads and their traffic flows on wildlife. They offer a relatively simple addition to the existing toolbox of the transportation planner and they only ask for a very limited number of ecological data. These data should already be available in the nature protection considerations of any planning procedure. If incorporated into spatial planning, these spatially explicit GIS-based tools provide a sound environment for both transportation planners and ecologists and for both decision makers and local inhabitants when balancing interests of nature and road network options on a regional scale.

REFERENCES


