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The Zebra Crossing Game – Using game theory to explain a discrepancy between road user behaviour and traffic rules

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ABSTRACT

In Norway, cyclists are allowed to cycle on pavements, and urban paths are often designated for use by both cyclists and pedestrians. Crossings between pavements/paths and the roadway are normally marked as zebra crossings. At these crossings, the law treats cyclists and pedestrians differently: whereas cyclists must give way to road traffic, the road traffic must give way to pedestrians.

On encountering road traffic at these crossings, a cyclist has three options: give way (a); cycle over the zebra crossing (and risk a collision) (b); or (c) force the drivers to yield by dismounting and walking over the zebra crossing (c). The approaching driver has two choices: drive on as the law suggests (x) or give way to the cyclist (y). The solutions prescribed by the traffic rules are a/x or c/y. However, on applying game theory to this situation, it can be shown that neither of these solutions are in perfect equilibrium, and the game theoretic solution to the game is in fact b/y, i.e. that the cyclists cycle over the zebra crossing and the cars yield, contrary to what the traffic rule prescribes. Thus, according to game theoretic reasoning one would expect the normal solution in road traffic to be that drivers yield to cyclists in zebra crossings.

In order to test this, we studied crossing behaviour at three zebra crossings, two crossings where cyclists approached from the pavement and one crossing where cyclists came from a combined cycle and walking path. We found that rather than aligning with traffic rules, the actual crossing behaviour aligned with the solution generated by game theory. The results show that game theoretic modelling can be a valuable tool to understand road user interaction. Better understanding and ability to predict road user interactions could help to improve traffic safety.

1. Introduction

Infrastructure and rules for cycling differ greatly between countries. Some countries like the Netherlands and Denmark have built dedicated lanes and tracks for cyclists, to separate them from motorized traffic. In other countries, cyclists share the separated areas with pedestrians.

In Norway, the normal solution is a combined cycle/pedestrian lane, separated from motorized traffic. Mopeds and motorcycles are not allowed to enter these lanes. Cyclists are also allowed to cycle on the pavements in Norway. Since cyclists are allowed and expected to share the same areas as pedestrians, road-crossing areas (e.g. zebra crossings) are also shared. However, the rules concerning the right of way at such crossings are different for cyclists and pedestrians. Pedestrians have the right of way at zebra crossings and cars must yield. For cyclists this is not the case; if they cycle over the zebra crossing they must yield to crossing cars. However, if they get off the bike and walk, they are considered as pedestrians and the cars must yield.

The give-way rules for cyclists in Norway were changed in 1998. Before that, the right-hand rule applied for cyclists approaching a road from a crossing pavement. That is to say, if a cyclist approached a crossing from the right-hand side, the driver had to give way, regardless of whether the cyclist approached from a pavement or road. In addition, vehicles wanting to turn had to give way not only to oncoming traffic, but also to cyclists coming from the right from a pavement and going straight over the intersection. Accordingly, in many cases cars had to give way to cyclists in zebra crossings before the law was changed. After 1st of May, 1998 the give-way rules became stricter for cyclists. From then on, cyclists were obliged to give way to cars when crossing the road from the pavement, whether they approached from the right or left on any type of crossing. In zebra crossings, however, they can still gain right of way by dismounting and walking over the road.

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2. The use of game theory to study road user interaction

Game theory is used to model and analyse situations in which people interact, and where the actors involved are influenced by the outcome of their interaction (Hamburger, 1979). The interactions between people are modelled as a game in which it is assumed that every actor plays a part to influence the result, but that no actor can single-handedly determine the outcome. The essence of game theory is that each actor must consider that other actors will influence the outcome, and thus each actor must decide what to do based on predictions of what other relevant actors will do. Furthermore, each actor must realize that the other actors will make their decisions based on similar considerations. This "symmetric" decision problem is essential in game theory.

Traditionally, game theory has been based on very strict assumptions of rationality and information. It is assumed that all players know the "rules of the game", i.e. the number of actors in the game, the possible actions or strategies each actor may choose, and even how different actors value different outcomes. In addition, all actors are assumed to be rational in the sense that they have the cognitive (and mathematical) skills necessary to calculate an optimal strategy, which may be to choose alternative a with probability p, alternative b with probability q, and alternative c with probability $1 - (p + q)$. Such assumptions of rationality and information seem unreasonable when we are concerned with the decisions people make in road traffic. When road users interact in traffic, decisions will normally have to be made quickly, and thus there will be important limitations on the actors' cognitive capacities.

During the last 40 years, much work has been done on repeated games and on games where the actors play sequentially, i.e. on models with a dynamic element (Axelrod, 1984; Kreps et al., 1982; Selten, 1975; Sugden, 1986). In such models, the assumptions of information and rationality are often less strict, and researchers consider the possibility that actors learn through their experience in the game which actions or strategies are most successful. Such models can both be models where the same actors play some game sequentially or models where some constituent game or static game is played for a repeated number of times by the same actors (super-games), or models where the same game is played repeatedly but where the actors involved change over time (compound games). Such dynamic models, where the assumptions of information and rationality are not so strict, are the game theoretic models with the greatest potential to study road user interaction.

Road traffic interaction is an obvious arena where such models ought to be relevant. Dynamic models have the potential to improve traffic safety by improving our understanding of road user interactions, as well as our ability to predict them. However, game theory has not been used much in road traffic research, with a few exceptions (Bjørnskau, 1994; Bjørnskau and Elvik, 1992; Elvik, 2014; Prentice, 1974). Nevertheless, examples from road traffic are very often used in the game theoretic literature (Binmore, 1992; Hamburger, 1979; Schotter, 1981; Sugden, 1986). The game theoretic model that is most often used to describe road user interaction in the research literature is "Leader" (Bjørnskau, 1994; Rapoport, 1967), also named as "Cross-roads" by Sugden (1986). The "Zebra Crossing Game" presented below is a variant of the classic Leader game.

3. The "Zebra Crossing Game"

The Zebra Crossing Game model presented in Fig. 1 is a game theoretic model where the actors are supposed to move sequentially and where both parties know the other parties previous moves in the game. Thus, the model is presented in so-called extensive form in order to capture this dynamic aspect of the game. In the game only ordinal values are assumed, i.e. the actors rank the different outcomes from 6 to 1, where 6 represents the best outcome and 1 represents the worst outcome. Thus, it is not possible to compare the utilities for drivers and cyclists in the game and the valuation of the utility derived from the different outcomes may vary between different actors. However, it is assumed that the ordinal preferences capture how both drivers and cyclists normally rank the different outcomes.

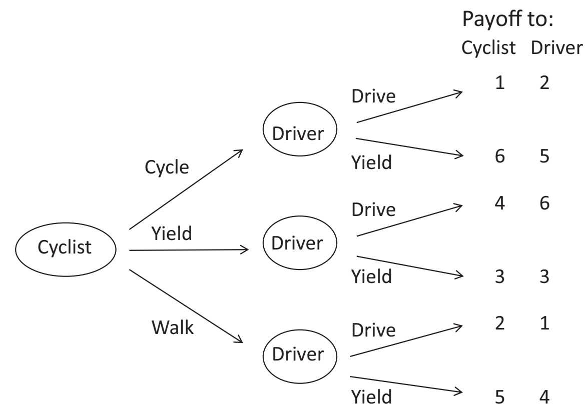

Fig. 1. The "Zebra Crossing Game", in extensive form with ordinal valuations of outcomes: 6 > 5 > 4 > 3 > 2 > 1.

In the Zebra Crossing Game depicted in Fig. 1, the cyclist has three options; (a) he can cycle over the zebra crossing, (b) he can yield to crossing cars or (c) he can get off the bicycle and walk over the zebra crossing. The car driver has two options, to drive or give way. In the model, it is assumed that both parties prefer solutions where they can continue to move to solutions where they have to wait. It is also assumed that collisions represent the least desirable solutions for both actors.

The best outcome for the cyclist (6) is when he can continue cycling over the zebra crossing and the crossing driver yields. The second best outcome (5) for the cyclist is when he gets off and walks over the crossing and the driver yields. This is considered a better outcome than when the cyclist yields to the driver (4). A worse outcome results when both yield (3). This is bad for both actors because then no solution is reached and they need to negotiate again in order to settle the game. The worst outcome for the cyclist is when he cycles over the crossing and the car does not yield resulting in a collision (1). To the cyclist this is worse than if he walks over the crossing and the car drives (2). In the latter situation, the driver has broken the traffic rules and therefore it can be expected that he will receive better compensation than if he had cycled, since in that case he was the one breaking the traffic law.

The best outcome for the driver is when he can continue unhindered i.e. the cyclist yields (6). The second best outcome for the driver (5) is that he yields and the cyclists cycle over the zebra crossing. This is considered better for the driver than if the cyclist gets off the bike and walks over the zebra crossing (4) since the latter takes more time. As mentioned, the situation in which both cyclist and driver give way is considered a bad outcome (3), since it does not resolve the game. The worst outcome for the driver is when he drives and hits a person walking over the zebra crossing (1). In that case, the driver will be at fault, receive a harsh penalty and lose his driver's licence. If the driver drives and the cyclists cycles over the zebra crossing, the resulting outcome is also bad (2), but not as bad as the previous one since in this case the cyclist will have violated the law and be responsible for the collision.

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