Safety Science 92 (2017) 298–301

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Special Issue Article: Cycling Safety

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

Torkel Bjørnskau *

Institute of Transport Economics, Gaustadalleen 21, NO-0349, Oslo, Norway

ARTICLE INFO

Article history:
Received 3 March 2015
Received in revised form 3 August 2015
Accepted 17 October 2015
Available online 2 November 2015

Keywords:
Cyclists
Cars
Yielding
Crossing
Interaction
Game theory

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.

* Tel.: +47 91152549.
E-mail address: tbj@toi.no

http://dx.doi.org/10.1016/j.ssci.2015.10.007
0925-7535/

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.

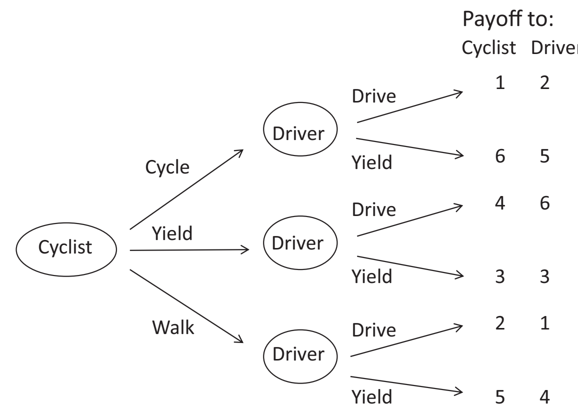

Fig. 1. The "Zebra Crossing Game", in extensive form with ordinal valuations of outcomes: 6 > 5 > 4 > 3 > 2 > 1.

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.

In this game we assume perfect information; i.e. that both the driver and the cyclist know each other's preferences over the different outcomes, that they can observe each other's moves, and that they know where in the decision tree they are. Thus, for example, the cyclist knows that the worst outcome for driver is to hit him when he walks over the zebra crossing.

The standard solutions in game theory are those of Nash equilibria. A Nash equilibrium is a combination of strategies that are such that no actor has any incentive to act otherwise given the other actor's choice. In this game, there are two Nash equilibria: Cycle/Yield (6,5) and Yield/Drive (4,6). If the cyclist cycles over the crossing, the best choice for the car driver is to yield and if the cyclist yields, the best choice for the driver is to drive. The outcome Walk/Yield (5,4) is not a Nash equilibrium; given that the driver yields it is better for the cyclist to cycle than to get off and walk.

According to the traffic rules, there are two solutions here, either the cyclist yields and the driver drives, or the cyclist walks and the driver yields. However, as mentioned, the solution Walk/Yield (5,4) is not a Nash equilibrium and accordingly not a stable solution according to game theoretic reasoning. The solution Yield/Drive (4,6) is a Nash equilibrium, but not a perfect equilibrium (Selten, 1975), and thus not a stable solution. The only stable solution in the game is Cycle/Yield (6,5) which is also a perfect equilibrium. In order to identify this as a perfect equilibrium solution to the game we can adopt so-called backward induction, i.e. we reason backwards from the different outcomes to what strategies the players would adopt in order to realize the best solution to themselves.

Thus, the cyclist may reason as follows; according to the rules, I must either give way or get off and walk over the zebra crossing. If I give way, the driver will drive, and the outcome will be Yield/Drive (4,6). This is a solution according to the rules (and Nash equilibrium), but the cyclist can achieve a better outcome by choosing to get off and walk over the zebra crossing instead. The cyclist has the first move in the game and knows that the car driver will yield if he walks over the crossing, and thus the outcome will be Walk/Yield (5,4). This is also a solution according to the traffic rules, but it is not an equilibrium solution. Given this outcome, the cyclist may reason as follows: given that the driver yields, it is better both for me and for the driver that I cycle over the zebra crossing instead of walking. The solution Cycle/Yield (6,5) is preferred also by the car driver to the solution Walk/Yield (5,4). Accordingly, based on game theoretic reasoning we would expect the solution to be that cyclists cycle over the zebra crossings while cars yield, contrary to what the traffic rules prescribe.

Based on this reasoning, and in light of the then recent changes in give-way rules in Norway, Bjørnskau predicted in 2001 that "in a few years the normal practice will be that drivers yield to cyclists at zebra crossings" (Bjørnskau, 2001). The aim of this study is to assess whether actual road user behaviour reflects this prediction, i.e. is better predicted by game theory rather than the prevailing traffic rules. A more general aim was to assess the usefulness of game theory as a tool to help understand road user interactions that do not always accord with the law.

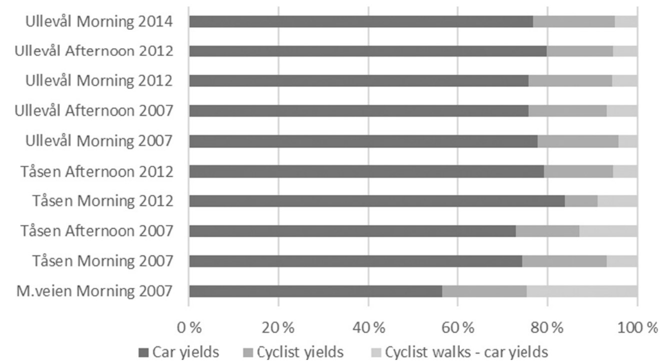

Fig. 2. Results of observations of yielding behaviour in three different zebra crossings in Oslo during morning and afternoon traffic in different years. Per cent.

4. Method

Registrations of real-life encounters were carried out at three different zebra crossings in Oslo, Norway, at three different periods in time, in 2007, 2012 and 2014. The crossings and registration times were as follows:

A. Nordbergveien/Kaj Munks vei – Rolf Wickstrøms vei ("Tåsen") in April 2007 and May–June 2012.
B. Sognsveien/Ring 3 ("Ullevål") in April 2007, May–June 2012 and September 2014.
C. Maridalsveien ("M.veien") in May 2007.

Crossings A and C are zebra crossings, where cyclists and pedestrians cross from the pavement. Crossing B is a combined walk/cycling path crossing Sognsveien marked with zebra stripes.

Data were collected by manual registrations based on observation. All registrations were made by the author and took place during rush hours, i.e. in the morning (08:00–09:00) and in the afternoon (16:00–17:00). The registration periods varied from 20 min to 1 h. Only cases where one or both of the interacting cyclists and car drivers had to yield were registered. If cyclists approached as a group or in a queue, only the first cyclist was registered. The reason for this was that if a driver had stopped for one cyclist he would normally remain stationary for an immediately following cyclist. Thus, a new case was only registered if the distance to the subsequent cyclist was 5 m or more. In addition, we omitted cases if a pedestrian crossed the zebra crossing at the same time as a cyclist. We registered both the yielding party (driver or cyclist) and whether cyclists got off and walked. In the latter case, car drivers always yielded.

Table 1
Results of observations of yielding behaviour in three different zebra crossings in Oslo during morning and afternoon traffic in different years. Per cent.

	C M.veien	A Tåsen				B Ullevål				
	Morning	Morning		Afternoon		Morning			Afternoon	
	2007	2007	2012	2007	2012	2007	2012	2014	2007	2012
Car yields	56.6	74.1	83.9	72.7	79.3	77.8	75.9	76.9	77.8	79.8
Cyclist yields	18.9	19.0	7.1	14.3	15.2	18.1	17.2	17.9	18.1	14.7
Cyclist walks – car yields	24.5	6.9	8.9	13.0	5.4	4.2	6.9	5.1	6.9	5.5
N	53	58	56	77	92	72	54	39	87	272

5. Results

The results are presented in Table 1 and Fig. 2.

6. Discussion

The general picture is quite clear: car drivers give way to cyclists at zebra crossings, contrary to traffic rules. This seemed to be a very widespread and stable solution in two of the three zebra crossings investigated. In the third, at M.veien, a greater share of cyclists got off and crossed as pedestrians. It is not surprising that M.veien differs from the two other locations, since it is located in an urban, gentrified area in Oslo where many young people move around on skateboards, bicycles, as pedestrians etc. The cyclists here are typically urban cyclists without much equipment, often cycling at low speeds, which may make it easier to get off and walk. The crossing behaviour here also tends to be more "chaotic" than at the other two study sites, which are both located on a cyclist "highway" running parallel to a ring road around the city (Ring 3), dominated by "transport" cyclists with helmets and other cyclist equipment (jackets, shoes, etc.).

The Zebra Crossing Game is a type of Leader-game where the first mover has a clear advantage. Here it is assumed that the cyclist has the first move, which is decisive for the solution in this game. If modelled with car driver as the first mover, the outcome will be that he drives and the cyclists yields. As we have seen, this solution is also experienced in real-life interactions, but it occurs much less often than the solution we have identified. In other countries, similar situations may have very different solutions, due to different traffic cultures and thus different preferences in the game. An important point is that drivers in Norway must yield to pedestrians at zebra crossings, and are strictly penalized in the case of a collision with a pedestrian. Accordingly, a very important driving force in this game is the opportunity for cyclists to become pedestrians and thus force car drivers to yield. Their ability to use this role transformation as a credible threat is of course dependent on the speed and distances of the actors involved when a cyclist and a car approach a zebra crossing. Sometimes the car driver manages to reach the crossing just in time to gain a "first mover" advantage whereby he can safely pass without risking hitting the cyclist. He may even speed up to obtain such an advantage. However, the results of the registrations suggest that this happens rarely.

The normal course of action in the Zebra Crossing Game is that both the cyclist and the driver reduce speed, and that the cyclist crosses before the car. Thus, they are aware of each other and they interact actively. In many such cases, a cyclist's reduced speed may be interpreted to the driver as a kind of threat that if the driver does not signal that he will give way, the cyclist may get off the bicycle, "forcing" the driver to yield. The fact that a stable proportion of 5–10 per cent of the cyclist choose to get off and walk, may contribute to keeping drivers constantly aware of this option, and thus aware of the logic of the game.

Thus, quite often in these interactions, the cyclists and the drivers communicate and negotiate, and very often car drivers signal clearly to cyclists that they will give way, and thus avoid the extra delay involved when a cyclist gets off and acts as a pedestrian. Over time, it seems that the logic of the Zebra Crossing Game has given rise to a norm or informal rule that drivers should yield to cyclists at zebra crossings, and that car drivers behave towards cyclists much in the same way as they do towards pedestrians. To further underpin the results it would be interesting to carry out a survey to the road users about their own motives and reasoning when acting in such situations.

Given the fact that the actual behaviour in these situations are contrary to what the traffic rule prescribes, one could argue that either the rules should be changed or they should be better enforced. However, the Norwegian road authorities have so far made no signs of wanting to change the rules or increase the enforcement. The reason is that the current pattern of interaction ensures that crossings are conducted at low speeds with road users being very much aware of each other, and generally producing quite safe crossings. If cyclists were given the right of way, one could easily imagine that they would cross at much higher speeds, making it difficult for drivers to spot them in time. On the other hand, if the current rules were to be more strictly enforced it would probably lead to protests from road users, who may perceive that the current interaction pattern works quite well. Furthermore, according to the assumptions of the Zebra Crossing Game, to enforce the traffic rules would give a solution neither the cyclists nor the car drivers prefer.

7. Conclusion

We have used game theory to analyse the interaction between cyclists and car drivers at zebra crossings in Norway. Although the formal traffic rule prescribes that cyclist should give way to cars, our analysis suggests that an alternative, negotiated solution in which drivers give way to cyclists will be preferred in reality. Registrations at three zebra crossings in different years reveal that the game theoretic solution in fact is the by far most frequent solution in real life.

The game theoretic analysis presented reveals that game theory can be a fruitful tool to analyse road user interaction. Such models have the potential to improve traffic safety by increasing our understanding of road user interactions, as well as our ability to predict them.

Acknowledgement

The research was supported by The Institute of Transport Economics.

References

Axelrod, R., 1984. The Evolution of Cooperation. Basic Books, New York.
Binmore, K., 1992. Fun and Games. A Text on Game Theory. D.C. Heath and Company, Lexington, MA.
Bjørnskau, T., 1994. Game Theory, Road Traffic and Accidents: A Theory of Road User Interaction. Dr Polit. Dissertation and TØI Report 287/1994. Institute of Transport Economics, Oslo (in Norwegian).
Bjørnskau, T., 2001. Spillet om gangfeltet. Samferdsel 6, 20–21 (in Norwegian).
Bjørnskau, T., Elvik, R., 1992. Can road traffic law enforcement permanently reduce the number of accidents? Accid. Anal. Prev. 24, 507–520.
Elvik, R., 2014. A review of game-theoretic models of road user behaviour. Accid. Anal. Prev. 62, 388–396.
Hamburger, H., 1979. Games as Models of Social Phenomena. W.H. Freeman and Company, San Francisco.
Kreps, D., Milgrom, P., Roberts, J., Wilson, R., 1982. Rational cooperation in the finitely repeated prisoner's dilemma. J. Econ. Theory 27, 245–252.
Prentice, J.W., 1974. The evasive action decision in an intersection accident: a game theoretic approach. J. Safety Res. 6, 146–149.
Rapoport, A., 1967. Exploiter, Leader, Hero and Martyr: the four archetypes of the 2×2 game. Behav. Sci. 12, 81–84.
Schotter, A., 1981. The Economic Theory of Social Institutions. Cambridge University Press, Cambridge.
Selten, R., 1975. Re-examination of the perfectness concept for equilibrium points in extensive games. Int. J. Game Theory 4, 25–55.
Sugden, R., 1986. The Economics of Rights, Co-operation and Welfare. Basil Blackwell, New York and Oxford.