How to manage motorway tolls through the Game Theory

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A team led by José Manuel Zarzuelo, Professor of Applied Economics, has applied the co-operative Game Theory to calculating motorway toll charges. The results of the study have been published in the specialised journal *European Journal of Operational Research*. In this study, the authors propose that sophisticated mathematical methods could be used in traffic management.

"Yes, it can be done," explains Jose Manuel Zarzuelo. "In the United States it's been done on public highways; yet in the case of Spain most of the motorways are not public. So the criteria used to manage them are more of a business than of a technical nature. By that, I don't mean that it could be negative; they are criteria that can also be defended. Private companies try to collect more where themost traffic is.

And they do it a bit by rule of thumb, not with studies. For example, they put up a toll charge and wait to see what kind of response they get from the motorists. If the number of motorists falls, for example, they lower the charge again, etc. In the end, the ones that pay the most tend to be the users of stretches which have the most people, which is where the company can make the most profit."

However, the criteria used by the UPV/EHU mathematicians are different. They do it from the point of view of a state body, in which one would want to use criteria based on fairness and equity rather than ones based on economic performance. And for this it is possible to use various methods of calculating the charges based on the co-operative

Game Theory. The Game Theory is the study of optimum strategies applied to a given problem, and co-operative Games are basically games in which it is possible to reach binding agreements.

That branch does not propose a single solution. Firstly, it is possible to apply the Shapley Value. It is a fairly simple solution in its approach: each stretch has a charge, and so the people pay a charge which is the sum of the stretches they use. Secondly, one can apply the so-called Nucleolus. With this method, so that the people who travel longer distancesdo not have to pay an excessive amount, the charge is reduced a little, whereas those who travel shorter distances pay a little more than what the stretches would cost. In this study, the Zarzuelo team used the second method.

The Nucleolus method has already been used in studies of this type. A significant example was the calculation of the charge to use the runway at Birmingham airport. The work dating back to the 1970s is very well known and was a reference for the Zarzuelo team. "In fact, our work is a generalization of that case," says Zarzuelo. "An airport is as if it were a motorway in which everyone joins at the same spot, which is the start of the runway, but they can leave via different places. It depends on the aircraft; if it is small, it takes off sooner, and if it is big, it takes off further on, and each flight pays a different rate to use the runway."

The biggest problem is that it tends to be very difficult to calculatethe Nucleolus method in situations like these, in which it is about favouring the most disadvantaged. As soon as there is a fairly high number of participants —a large number of stretches, in this case— the calculation becomes very difficult. They are calculations within the branch of operational research,and they include starting from ad hoc mathematical models and repeatingthem by means of algorithms until a solution is reached.

"This is designed for motorways," says Zarzuelo, "but it can also be done for sports centres, for example. Or, in general, for public facilities in which it is possible to assign the equivalent of motorway stretches. At a sports centre, the equivalent of the stretch could be the squash court, the sauna or any other service. Apart from a flat rate, people would have to pay an amount for the stretches they use. But for the people who use the gym a lot, a slightly lower charge than the sum of the stretches can be calculated, precisely because it is used a lot."

The work ends with an approximate comparison between the rates for the AP68 motorway between Bilbao and Zaragoza in 2007 and the ones that could be obtained using the Nucleolus method, where it can be seen, among other things, that the Nucleolus would reduce the toll for users travelling long distances. The work has also inspired other similar studies." Some Dutch people, after reading about our work, replicated it for motorway networks, in other words, imagining that the motorway had branch roads. In our case, the motorway is only one line. At the end of the day it is a tree-shaped structure."

Provided by Elhuyar Fundazioa

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