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Game Theoretic Analysis of Road Traffic Problems in Nigeria

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Abstract

Chaotic road traffic situation in most Nigerian and African cities and roads is a nightmare, and a significant proportion of the cost of goods and services is attributed to this. A general feature is that these problems are due to tyranny of small decisions by motorists and some other citizens, hence, traffic problems in Nigeria are analysed in the context of a social dilemma. Game theoretic models based on the famous prisoner/commons dilemma game were used for the analysis. The analysis revealed the mechanism and scientific basis for most traffic problems encountered in Nigeria. Finally, it is suggested that the undesirable equilibrium outcome of the social dilemma could be avoided by using mechanism design and structural changes to the social game to achieve the desired efficient outcome and by so doing increased productivity, reduced accidents, injuries and deaths, and the resultant increased economic growth will be achieved.

Keywords: Game theory; Social Dilemma; Road Traffic; Equilibrium; Mechanism design

Introduction

Social dilemmas are situations in which private interests are at odds with collective interests. This is often referred to as the tyranny of small decisions. Such situations arise because people frequently attach more weight to their short-term selfish interests than to the long-term interests of the group, organization, or society to which they belong. Many of the most challenging issues we face in the world, from the interpersonal to the inter-group, are at their core social dilemmas. Naturally human beings are self centred or selfish. Although the selfish behavioural tendencies of humans are rational, often it is not for the common good of the group, organization or society to which he belongs. For example, although payment of taxes is for the common good of the society, ordinarily a rational human being would want to evade taxes, even though he would like to enjoy public amenities like good roads, pipe borne water, electricity and other public utilities provided by the government. The public goods are non-excludable because whether you pay or you don't pay taxes you still enjoy them.

Social dilemmas describe situations in which the rational behaviour of an individual -defined in pure and simple economic terms - leads to sub-optimal outcomes from the collective standpoint (Dawes, 1980; Kollock, 1998). Researchers frequently use the experimental games method to study social dilemmas in the laboratory. Sometimes the experimental results differ from theoretical predictions (Carmichael, 2005). In fact in an experiment conducted on prisoner dilemma, players were found to cooperate half of the times (Camerer, 2003). An experimental game, which is often simulated with the computer, is a situation in which participants choose between cooperative and non-cooperative alternatives, yielding consequences or outcomes for themselves and others (opponents). These games are generally depicted with a pay-off matrix representing valuable outcomes for participants like money or lottery tickets. Social dilemmas are in fact a "conflict in which most beneficial action for an individual will, if chosen by most people, have a harmful effect on everyone" (Oliver, 1980; Marwell, 1988; Elster, 1989).

There are three main aspects of social dilemma. They include: Tragedy of the commons, prisoner dilemma and public goods dilemma. The concept of social dilemma has been used to explain many phenomena in various facets of life. In 1982, the estuarine ecologist, William Odum, published a paper where he extended the notion of the tyranny of small decisions to environmental issues. According to Odum, "much of the current confusion and distress surrounding environmental issues can be traced to decisions that were never consciously made, but simply resulted from a series of small decisions" (Odum, 1982). Other writers like Odum have applied the concept of social dilemma to problems in many spheres of life. This work is the first attempt to apply this concept to traffic problems encountered in Nigeria and all over Africa.

Most traffic problems in Nigerian cities are due to the tyranny of small decisions by motorists and citizens. Traffic problems results to the following:

- Delayed delivery of goods and services.
- Increased transportation costs.
- Faster depreciation of vehicles.
- Increased environmental pollution.
- Psychological and mental problems etc.
- Accidents.
- Injuries and deaths.

Traffic problems are non-excludable because whether you contribute to it or not you are affected by it in one way or the other. The general effect of these problems is that it affects the economy negatively. The negative effects stems from the fact that the rates of production and delivery of goods are reduced leading to slow rate of growth of the gross domestic products (GDP). Also, the cost of production and delivery of goods and services is increased which reduces the profitability of business enterprises with the attendant reduction in economic growth. In addition to these, accidents, deaths and injuries are of great cost to the economy.

Transport and logistic is an important aspect of supply chain management. According to Stevenson (2002), American companies in 1993 spent $670 billion-a gaping 10.5 percent of GDP-to wrap, bundle, unload, sort, reload, and transport goods. This is an eloquent testimony of the how much efficient transport and logistics could do to enhance economic growth. Traffic problem in Nigeria could make the cost go up even higher up to 20percent of the GDP.

This paper examines the road traffic situation in Nigeria, establishes the general reasons for the road traffic problems which is most often due to tyranny of small decisions, and modelled the problem in the context of a social dilemma using game theoretic analysis.

Background

Theoretical Background

There are many theories used to analyse and understand the mechanisms and basis of social dilemmas. Such theories include: game theory, evolutionary theories and psychological theories. The basic theory used in studying social dilemma is the game theory. The psychological and evolutionary theories are used as a complementary and reinforcement to game theory. The psychological and evolutionary theories are used to explain why rational agents behave the way they do in social dilemma situations.

Game theory is the study of interaction between rational players where the outcomes depends on the choice of strategy of each player given the opponent's strategies. Game theory is interested in optimising outcomes/payoffs for decision makers in strategic situations. There are many solution concepts in game theory which guides the decision taker in arriving at an outcome that maximizes his utility or at worst makes him better off. The most popular solution concept in non cooperative games is the Nash equilibrium (Nash, 1950). The Nash equilibrium solution concept will guide the prediction of players behaviour in social dilemma models developed in this work.

Studying the circumstances or conditions under which people cooperate might lead to recommendations to solve social dilemmas in society. The literature distinguishes between three broad classes of solutions—motivational, strategic, and structural—which vary in whether they see actors as motivated purely by self-interest (selfish behaviour) and in whether they change the rules of the social dilemma game.

The structural solutions involve changing the structure of the game model used to capture the social dilemma situation. By so doing a new equilibrium point is obtained for the game, and the new equilibrium point will lead to a more efficient outcome. We shall explore the structural solution in all the discussion in this paper.

The Nigerian Situation

In Nigeria controlling road traffic is quite a challenge. Often motorists are faced with chaotic traffic situations. The traffic problems are usually caused by the defective behaviours of motorists, citizens, government officials and law enforcement agents. These defective behaviours include:

1. Driving against the traffic.

2. Following illegal routes.
3. Dropping/picking passengers at unauthorized points along the road.
4. Abandoning broken down vehicles on the road.
5. Buying goods from hawkers without clearing away from the road.
6. Illegal parking of vehicles along the main road.
7. Construction and use of illegal structures for businesses along the main road.
8. Unrestricted use of private cars.
9. Illegal check points mounted by the police and other law enforcement agents etc.

Bad roads which constitute a substantial part of the Nigeria road network are equally a major contributory factor to road traffic problems and defective behaviours by motorists. The Nigerian situation is not different from what obtains in many parts of Africa and most developing countries.

The Model

The model used for the analysis is based on multi-person social dilemma (public goods/commons dilemma). The game matrix in figure 1 shows the common/public goods dilemma model that is used to analyse road traffic problems as a social dilemma.

Here it is assumed that the motorists/citizens are not necessarily opposed to each other. All the actors/parties (groups of motorists/citizens) could either cooperate for the their common good or defect by engaging in activities that is beneficial to them but it is not in the best interest of all the motorists and makes the traffic situation worse off in the long run, while making themselves temporarily better off. This model is suitable for modelling most traffic problems in Nigeria.

Looking at the game matrix in fig. 1, from game theoretic predictions, the equilibrium point is at point D, D. Defective behaviour is the dominant strategy for both players, hence, the game theoretic prediction is that both players would defect. This is a commons dilemma for both parties as they could get better payoffs by cooperating. Hence, it is in the best interest of both parties to cooperate. If both cooperate, each group of motorists gets a payoff of 100. If both defect, each group of motorists gets a payoff of 30.

Non excludability implies that if there is defective behaviour, defection continues as long as the traffic continues to move. If both parties want to maximize their payoffs, their dominant strategy is to engage in defective behaviours. In the long term this often leads to traffic deadlock or near deadlock situations. These deadlock situations are a frequent feature of traffic situations in Nigeria of which the author has been trapped in it several times.

The game above is symmetric because it is assumed that the two groups of motorists get the same payoff. Since the game is symmetric, the generalized payoff structure is shown in fig. 2.

Government officials and political office holders often flout traffic regulations in Nigeria and many African countries. In this situation, the traffic dilemma becomes asymmetric as shown in fig. 3.

The defective behaviour by one group of motorists/citizens constitutes a trigger strategy and the grim outcome of such a strategy is for the cooperating party to defect forever. The theoretical prediction is supported by my observation of what happens in practice. In many traffic problems that I noticed throughout Nigeria, I found out that once a group of motorists/citizens engages in defective behaviours, the cooperating groups most of the time respond by starting their own defective behaviour. This is akin to tit for tat behaviour in prisoner dilemma. The outcome of such grim strategy is usually traffic deadlock or near deadlock situations. This model is characteristic of many traffic problems in Nigeria some of which I have earlier mentioned.

Finite Repetition

Finite repetition occurs when the cause of the traffic build up is expected to last for a definite time period. For example it could last few or several days. The cause of the build up could be: broken down vehicle expected to be taken off the road within days, bad portions of the road which are expected to be repaired within days etc. in this scenario, motorists expect to meet the same situation for a definite/finite number of times.

If the game in fig. 1 is repeated a finite number of times, and assuming a stage game G, where G (T) is played T times; in this case we assume the game is repeated two times. According to the theory of finitely repeated games (Gibbons, 1992), the payoff structure for the game could be represented by a single payoff matrix representing the possible payoff from the two stages, which is the sum of the payoff from each stage other than the first stage added to the original payoff matrix. In this case we assume the payoffs for the parties in each stage is 30, 30. Hence, the payoff structure in fig. 4.

Looking at the game matrix in fig. 3, from game theoretic predictions, the equilibrium point is at point D, D. Defective behaviour is the dominant strategy for both players, hence, the game theoretic prediction is that both players would defect.

The Nash equilibrium of the one short game in fig. 1 is the same as the Nash equilibrium of the two stage game in fig. 3. This corroborates the following folk theorem for finitely repeated games: “A finitely repeated game has a unique sub-game perfect Nash equilibrium which corresponds to the Nash equilibrium of the one short on which the repetition is based”.

The implication of this is that if the traffic situation occurs in finite number of times. Defective behaviours would still be the dominant strategy. This fact is consistent with my observation of the traffic problems in Nigeria.

Infinite/indefinite Repetition

Indefinite repetition occurs when the cause of the traffic build up is expected to last indefinitely. The cause of the build up could be: bad portions of the road which are not expected to be repaired anytime soon, illegal structures along the main road, perennial illegal parking of vehicles etc. In this scenario, motorists expect to meet the same situation indefinitely.

If either or both group of motorists engages in cooperative behaviours and the game repeated indefinitely/infinitely, capturing the situation mathematically as a repeated prisoner dilemma repeated indefinitely we have:

$$EPO_{coop} = a + aP + aP^2 + aP^3 + ... + aP^n + ...$$

$$EPO_{coop} = \sum_{n=0}^{n=\infty} aP^n = \frac{a}{(1-P)} \quad \text{......................(1)}$$

Here:

P Is the probability that the game continues.

EPO_{coop} Is the expected payoff from cooperation.

If some group of motorists/citizens engages in cooperative behaviour and the other group engages in defective behaviours, the cooperating group might retaliate by defecting. This TIT for TAT behaviour results to deadlock or near deadlock situation. Capturing the situation mathematically as a repeated prisoner dilemma repeated indefinitely we have:

$$EPO_{defect} = c + dP + dP^2 + dP^3 + ... + dP^n + ...$$

$$EPO_{defect} = c + \sum_{n=0}^{n=\infty} dP^n = c + \frac{dp}{(1-P)} \quad ....(2)$$

Here:

EPO_{defect} Is the expected payoff from defection.

Since a reasonable decision rule for the players would be to cooperate if $EPO_{coop} > EPO_{defect}$ or:

$$\frac{a}{(1-P)} = c + \frac{dp}{(1-P)} \quad ....(3)$$

Rearranging (3) leads to:

$$\frac{a-c}{d-c} < P \quad ....(4)$$

The derivation above is a proof of the Friedman's theorem which states that "for any prisoner dilemma where the equilibrium payoff is d where d<a, if the discount factor is sufficiently high or close to 1 there exists a sub game perfect equilibrium where the payoff is equal to a" (Gibbons, 1992).

At critical value of the probability denoted by P^* we have:

$$\frac{a-c}{d-c} = P^* \quad ....(5)$$

If there are severe penalties for traffic offenders or in situations where the numbers of bad roads, illegal parking of vehicles, illegal structures along the road etc, which often cause traffic problems, are greatly reduced, the value of the critical value of probability P^* will be low so that the probability of cooperative behaviours is high. We shall discuss this in detail in the next section.

Results and Discussion

It is been shown that traffic problems in Nigerian cities could be modelled and analysed in the context of social dilemma. Small decisions, taken by motorists and citizens, which though rational do not take into account the overall interest of the all motorists and other citizens. Consequently, over time the road traffic reaches a deadlock or near deadlock situation.

One big question therefore arises. How can this disastrous outcome be avoided? As I have mentioned earlier, one method of solving the problem of social dilemma is through structural change to the underlying game. A very good structural solution approach which could be used to solve social dilemma problems is the adoption of mechanism design. Mechanism design is increasingly being used by social choice planners to obtain desirable outcomes that would improve social welfare. In this context using mechanism design, the principal (government regulator), would design a mechanism which would make it in the best interest of the players to cooperate and hence a most efficient outcome is obtained.

One method of changing the structure of this social dilemma game is by punishing severely defective behaviours which motivates motorists/citizens to cooperate. A regulator such as government could be used to achieve this. This scenario changes the game structure to a non commons dilemma as shown in fig. 5.

As shown in fig. 5, the dominant strategy equilibrium point is (C, C). Hence, it is favourable to both parties to cooperate.

In furtherance of our discussion on structural changes to games, consider the game matrix in fig. 6.

The change of P^* from 0.5 in fig. 6 to 0.333 in fig. 7 means that if the game structure in is changed to the structure in fig. 7, it is easier to achieve cooperation among the parties in fig. 7 if the game is repeated indefinitely.

One way to achieve is to put measures in place which would minimize drastically the possibility of traffic build up hence, reducing the incentive to defect. Such measures include: destruction of illegal structures along the road, dismantling illegal check points, prompt removal of broken down vehicles, prompt fixing of bad portion of road etc. Punishing motorists that leave their broken vehicles on the road would help in prompt removal of broken down vehicles. Making officials responsible for road maintenance leave up promptly to their responsibilities would drastically reduce number of un-repaired failed portions of the road.

In continuation, other measures that could change the game structure include: building of strong good roads and elimination of illegal parking of vehicles which reduce the possibility of traffic build up. This motivates motorists to engage in cooperative behaviours. This is because good roads and elimination of illegal parking of vehicles reduce the marginal payoffs to defective behaviours in traffic situations.

Similarly, improving public transportation system by making it attractive to middle class and upper middle class commuters would reduce the use of private cars as a means of transportation to workplaces. This is because the incentive of using them would be reduced under the circumstance.

In the same vein, provision of good parking spaces in cities will discourage illegal parking of vehicles along roads and alley ways thereby motivating motorists to engage in cooperative behaviours.

Furthermore, the Nigerian government should as a matter of urgency eliminate/remove all illegal check points where law enforcement agents extort money from motorists. These check points often cause traffic problems, accidents, injuries and deaths. Check points on the highway should be mounted only where it is absolutely necessary to do so. The law enforcement agents should engage more in patrols instead of mounting illegal checkpoints under the pretext of fighting and controlling crime when in actual fact the real purpose is to extort money from the public.

From my observation, indefinite cooperative behaviours are prevalent in government reservation areas and low density areas. Features of these areas include good urban plan, good parking spaces, big roads, absence of illegal structures, absence of illegal check points etc. These features make the incentive to defect very low and cooperation is achieved indefinitely as predicted by game theory. These areas constitute a very tiny percentage of the whole motorable area. As a matter of fact, generally, good urban planning seen in government reservation areas and low density areas encourages cooperative behaviour by motorists and reduces road traffic problems.

In continuation of our analysis, assuming the asymmetric payoff structure in the game matrix in fig. 3 is as shown in fig. 8.

The implication of this is that it is easier for the citizens to cooperate than government officials and political office holders if the game is repeated indefinitely. This explains why government officials and political office holders are often very reluctant to address the issue of perennial traffic problems in Nigeria and other African countries.

Conclusions

The analysis in this work has revealed the scientific basis for most traffic problems in Nigeria. It has shown why politicians and government officials are often aloof to the traffic problems in Nigeria. The first step towards solving the traffic problem in Nigeria is that the government officials and politicians must obey traffic regulations completely and stop bullying other motorists. Government being the regulator should lead by example.

The decisions we make today determines our future well being. A deep understanding of the science of decision making and human judgment, if harnessed properly, will enable us make better decisions for the collective good of the society. Traffic problems affect economic growth and societal well being. If traffic is not properly managed economic growth is hampered and poverty increases. It is therefore in the best interest of individuals and government that chaotic traffic situations are avoided as much as possible all over Nigeria and Africa in general so that the country and the continent continue to thrive and prosper indefinitely. The game theoretic analysis done in this work has given us an insight into scientific reasons for persistent traffic problems in Nigeria and many parts of Africa.

Armed with the analytical tools used in this work traffic problems could be controlled by employing appropriate control mechanisms and problem solutions recommended in this work.

The analysis done in this work will be very useful to game theorists, engineers, economists, management scientists, psychologists and sociologists who are actively involved in the science of decision making and its consequences on the society.

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	D	C
D	60, 60	180, 55
C	55, 180	130, 130

Motorists/Citizens
(Group 2)

		D	C
Motorists/Citizens (Group 1)	D	30, 30	150, 25
	C	25, 150	100, 100

Fig. 1 Traffic Situation as Commons Dilemma

	D	C
D	d, d	c, b
C	b, c	a, a

Fig. 2 Commons Dilemma with Symmetric payoff structure

$c > a > d > b$ $\qquad\qquad$ $c1 > a1 > d1 > b1$

		Citizens	
		D	C
Government officials (Group 1)	D	d1, d2	c1, b2
	C	b1, c2	a1, a2

Fig. 3 Commons Dilemma with Asymmetric payoff structure

$c2 > a2 > d2 > b2$

$c1 > c2$
$a1 > a2$
$d1 > d2$
$b1 > b2$

Fig. 4 Finitely Repeated Traffic Game

	D	C
D	10, 10	75, 40
C	40, 75	120, 120

Fig. 5 Traffic Problem as Non Commons/Public Goods Dilemma

	D	C
D	30, 30	160, 25
C	25, 160	100, 100

Fig. 6 Traffic Dilemma

Here:

$$P^* = \frac{a-c}{d-c} = 0.500$$

Assuming the game matrix in fig. 6 is changed to fig. 7 below:

	D	C
D	20, 20	140, 15
C	15, 140	100, 100

Fig. 7 Traffic Dilemma

Here:

$$P^* = \frac{a-c}{d-c} = 0.333$$

	D	C
D	100, 40	200, 50
C	60, 120	100, 80

Fig. 8 Asymmetric Traffic Dilemma

From equation 5 we have:

$$P_1^* = \frac{a_1 - c_1}{d_1 - c_1} = 0.833$$

$$P_2^* = \frac{a_2 - c_2}{d_2 - c_2} = 0.500$$