Problems and Externalities of Transport

A system dynamics approach to understanding traffic law compliance problem in commercial motorcycle operation

ITS, University of Leeds

In Nigeria, commercial motorcycle operation is facing a serious challenge with respect to regulation. Policies and other interventions to improve the operation of this mode, in particular with respect to safety, have not been successful mainly due to poor enforcement. For the system to improve, behavioural changes are required from the drivers with regards to adherence to law. This paper uses system dynamics to identify factors that affect drivers' compliance to law and how these factors can be swayed to improve compliance, and thus safety. A causal loop diagram is developed from interview data obtained from a survey conducted with stakeholders in Nigeria and formalised into a quantitative stock and flow model using secondary data obtained from multiple sources. Results from model simulation suggest that the harsh operating condition drivers are subjected to due to their "illegal" operating status contributes to their compliance difficulty. It also found that under a corrupt transport system such as in Nigeria reliance on an enforcement agency alone to improve compliance may not achieve any substantial improvement. This paper concludes by providing some policy recommendations on how compliance can be improved in commercial motorcycle operation. Improving safety enforcement would protect vulnerable road users and provide co-benefits to reduce other externalities of transport, e.g., through stricter adherence to speed limits. These recommendations might also be useful for enforcing emission regulations in future.

1.0 INTRODUCTION

Motorcycle safety is an issue the world over. It is however worse in developing countries. For example, motorcyclists' fatality accounts for about 15% share of total traffic fatality in the United State (*1*). In India and China, the share of total traffic fatality for motorcycles is about 20%; this value is five times higher than their share of total trips. Thus, they are described as the "most dangerous way of getting around" in these countries (*2*). Similarly, they were described as "the most hazardous mode in Taiwan, Malaysia and Vietnam" (*3*).

The situation in Nigeria is not different. Motorcycle transport is responsible for one in five road traffic accident victims in the country (*4*) but accounts for as much as 35% fatality (*5*). Commercial motorcycles are always blamed for this problem (*6, 7*). As a result, a number of attempts have been made to combat commercial motorcycle safety problem. Unfortunately, most of these attempts have been generally unsuccessful (*8, 6*), so its safety problem has remained unresolved. This has led to continuous study on various aspects of motorcycle operation including the characteristics of the drivers in

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general, the characteristics of drivers involved in accidents, and even factors that pre-dispose drivers to accident. But how these characteristics emerge and what their dynamic pattern is has not been as well researched. So it has been difficult to successfully intervene in the factors that pre-dispose the drivers. This paper provides another perspective for understanding possible reasons for this safety problem by exploring the dynamics of the operation of this mode. Factors and processes influencing commercial motorcycle safety problem and their interactions are approached from a systems perspective. This means identifying processes and interactions that lead to the problem. These interactions and processes are modelled through the development of a system dynamics model. The work is part of a broader PhD research project and what is emphasised in the following sections is a portion of the model – driver characteristics sub-model. The results from this sub-model show that simply removing the causal factors for the system problems is not enough to restore the system.

The following section provides a basis for addressing the behaviour of drivers as an important component of safety improvement exercise. This is followed by a brief introduction to system dynamics in section 3. Section 4 presents the model while section 5 discusses the result of policy tests.

2.0 ROAD SAFETY AND THE HUMAN FACTOR

The three broad factors of accident causation are the human, road environment, and the vehicle. Of all these three, human factor is known to be the most significant contributor to accident causation (*9, 10, 11*). Specifically, Davey et al (*9*) noted that the link between, for example, aggressive driving violations and increased risk of crashes has been growing of late. This has, however, been found in some developing countries much earlier (*12*). To deal with this human factor, several studies are being conducted to identify what constitute human factor and how its negative effect can be reduced in the driving task. McKenna, (*13*) identified some earlier approaches including accident proneness, biorhythm, differential accident involvement, etc., many of which have failed to provide reliable or useful information about the human factor causation. West et al., (*11*) identified two other more recent approaches to dealing with human error: studying of accident report to determine causation; and evaluation of driver "performance" to find out features which may be risky in certain circumstances. This second approach is reflected in the concept of driving skills and driving style (driver performance and behaviour respectively) as the two main components of human factor in road safety (*10*). The basis for this is the expectation that it should be possible to improve understanding about human causes of accidents by investigating the variations in driver performance and behaviour and judging what may be related to accident rates (*11*). Ozkan et al. noted that driving style is influenced by motives, attitudes and personality traits while driving skills are related to information processing and motor skills: skills concerns the ability the driver has to control the car; style reflects the habitual modes of operating the car on the road. The variation in these characteristics between drivers has therefore become an important study object.

2.1 Driver Behaviour

The study of individual difference in accident involvement assumes that different degrees of accident involvement are in part a product of differences in driving style or driving skills as opposed to chance factors (*11*).   But both style and skills are empirically related to each other and interact together to influence crash risk. While it is not clear the extent to which accident liability results from defects in skill or style or some interaction between them, earlier studies focused on improving drivers' performance with little or no attention given to style. But as skills models of drivers' performance were not effective (*14*), findings led to a view that driving style may be more important than skills for an average driver (*11*). This led to a switch to more concentration in driving style (driver behaviour) rather than skills (driver performance). Driver behaviour which reflects driving habit is now in use to estimate the amount of risk a driver accommodates as he uses the roadway.

The interest of the current study is to understand the motivations for the pattern of drivers' behaviour in commercial motorcycle operation and to identify what might be influenced to improve this behavioural pattern, as well as explore how such intervention would perform. In this paper, the use of a system dynamics model is presented as a method to understand commercial motorcycle driver behaviour and determine what factors might be influenced to reduce deviant driving in the operation of commercial motorcycles. The next section provides some information about system dynamics and its use. This is followed by the development of a system dynamics model in section 3. Section 4 discussed the result of the model while section 5 wraps up with a brief summary.

3.0 SYSTEM DYNAMICS METHOD AS AN ALTERNATIVE TOOL

System dynamics (SD) is a computer based modelling approach for analysing and solving complex and dynamic problems. SD is an approach based on system theory and extends cause-and-effect relationships to consider possible feedback effects. The problems addressed by SD are based on the premise that the structure of a system generates its behaviour (*17*). A system is a structure that maintains its existence and functions as a whole through interaction of its components. In this way, a model based on SD organises information by linking the components of the system with one another, and linking the past to the present to show how the present conditions arose. SD is also a useful method in exploring possible scenarios to solve complex real world problems, especially those that involve human behaviour.

The choice of system dynamics method in this research is based on the principle of behavioural adaptation which shows that driver behaviour is in a dynamic state and is influenced by several factors, all of which interact in a complex manner over time. SD

capability to deal with this type of problem is demonstrated in its use in behavioural study in many fields and some of these include (*18* and *19*).

4.0 SD MODEL DEVELOPMENT

The model described in this section considers the pressures that mobilises commercial motorcycle drivers to engage in deviant behaviours. First, the structure of the interacting factors generating the pressure is described. This is followed by the model development.

Before presenting the model it is necessary to clarify the adopted approach. The formulation and the implementation of the model were borne out of pre-modelling engagement with relevant stakeholders in the commercial motorcycle operation in Nigeria. These stakeholders provided the basic information from which the conceptualisation of the system and the formalisation of the model were developed. There was, however no reliable data. Due to the lack of solid data, the calibration of the model was focused on dynamic patterns of observed trends described by the stakeholders. Due to these limitations, the resulting model should be seen as a tool for learning by exploring possible futures by scenario analysis, instead of a solidly calibrated model to predict the implications of certain policies. In this section, driver means a commercial motorcycle driver while trade refers to the commercial motorcycle trade.

4.1 Model Structure and Characteristics

Information obtained from the stakeholders was coded and used to generate a causal network (not included in paper). This network is a summary of the operation of commercial motorcycle as understood by the stakeholders. A reflection upon this network identified the following concepts, amidst others, about the system:

1. The trade is lucrative and so more and more people are joining as drivers; but this rapid growth is causing increasing competition in the trade
2. Expensive motorcycle acquisition options make joining the trade easy but generates a repayment pressure; this pressure influences drivers' behaviour

The causal network indicated that drivers' population growth is supported by the awareness that drivers perceive the trade as lucrative. There is the indication that individuals with no means of livelihood can join the trade and thrive. Also drivers make above the national minimum wage from the trade and this is confirmed in the literature (*20, 21*). In addition, unlike most other informal trades, commercial motorcycle trade does not require long apprenticeship or training. This is the reason why people from various other trades switch job to commercial motorcycle trade on full time or part time basis.

Furthermore, it also emerged that the availability of motorcycle hire purchase and motorcycle rent options for prospective drivers make joining the trade a lot easier for many who cannot afford the cost of a motorcycle (*22*). These options are relatively expensive. Nevertheless people take them based on the awareness that commercial motorcycle trade is lucrative and drivers actually become owners after a relatively short time of about a year. This structure thus shows that increase in the number of motorcycles on hire purchase and rent is an important influencing factor in the determination of the number of commercial motorcycle drivers.

But this increasing number of drivers results in competition for picking passengers which affects drivers' income. Malstein's (*7*) study supported this effect of growing population when he found that drivers were willing to pick passengers for lesser amount than they would have otherwise taken due to rising competition. This has an implication on how drivers work. For example, to make a desired target amount, drivers might have to work more than they would otherwise do. Arosanyin et al. (*23*) found that drivers' average working period was as high as 13 hours a day (with half of drivers on expensive repayment options – motorcycle rent).

In addition, drivers who join the trade through these expensive routes (motorcycle hire purchase and motorcycle rent) need to make payments for the cost of the motorcycle and raise enough for their livelihood. The stakeholders all agreed that this is another reason why some drivers work more and are more pre-occupied with what they want to make (when compared with others who own their motorcycles). Since more work is done to earn more money, drivers are pushed to work more (thereby increasing their average daily working time) in other to realise a desired target. This push, termed earning pressure, results from the desire to meet up with a hypothetical target income set by drivers as well as the increasing competition for passengers. This pressure is a major motivation influencing driver aberrant behaviour in the trade. Unfortunately, the current system of enforcement is not able to match the problem. Notwithstanding, as drivers reach their desired target income, the perception that commercial motorcycle trade is lucrative is maintained – all at the cost of excessive work and high risk behaviour. So the population of drivers keep increasing, howbeit, under intensely increasing earning pressure. This description is shown using a causal loop diagram in the figure below.
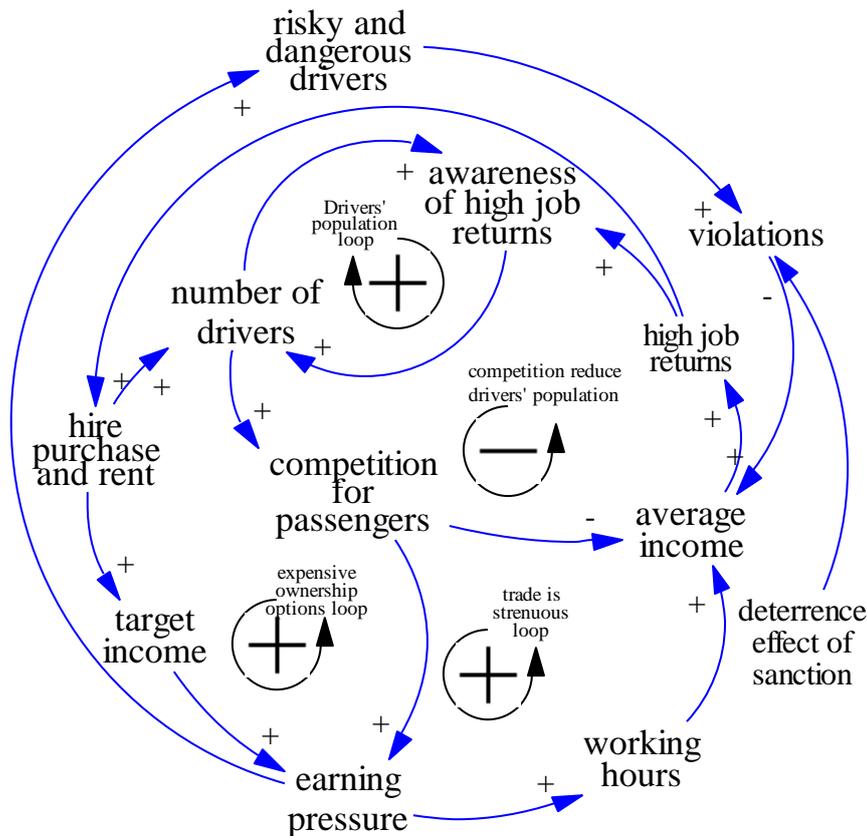
FIGURE 1 Causal loop diagram of system interactions.

4.2 Model Description

The description in section 4.1 is summarised in figure 1 above. Four feedback loops are identified to describe the system interaction. These interactions are developed into mathematical equations and presented in this section. However, a few assumptions are made. First drivers are categorised into three groups based on their driving experience, earning capacity and target income. The first group are new drivers who are less than a year in the trade. Many drivers in this group join the trade through expensive motorcycle acquisition means and are under pressure to pay back within a short time. Yet they have less capacity to earn than the experienced drivers. The literature supports this, showing that experienced drivers earn more than new drivers (*20, 21*). The second group are those who have just graduated from the process of learning the trade; this group does not have any repayment to make. But they have become used to working under pressure and set high target income. This second group have an average experience of four years in the system. The third group are the more experienced and relaxed drivers who work rather smartly than under pressure. The sum of the three groups of drivers makes the total drivers. These three groups are identified for the purpose of generating a representative driver which is an average for all drivers. Thus,

aside these three distinctions, all other characteristics in the model are that of the average of all the drivers rather than treating each group differently.

The first equation is for the growing number of drivers and is given by:

$$ND_t = (1 - EIS_t) * (1 + EAO_t) * GR * TD_t * \left(1 - \frac{TD_t}{CC_t}\right) \tag{1}$$

This is the estimated number of drivers joining the trade on a weekly basis. This is treated as a logistic function to make up for new drivers joining and leaving as well as to fit the growth pattern indicated by stakeholders. ND stands for new drivers, EIS stands for effect of income shortfall, EAO stands for the effect of alternative ownership options, GR stands for growth rate, TD stands for total drivers, and CC stands for carrying capacity. This equation shows that the number of new drivers (ND) joining the trade decreases with decreasing drivers earning relative to their target (denoted as effect of income shortfall (EIS)). It increases with increasing availability of options for acquisition of motorcycle (i.e., effect of alternative ownership options (EAO)). This parameter, EAO, also takes care of the expensive hire purchase and rent options. The growth rate is a constant chosen to fit the model to data as nearly as possible while the total driver is the sum of all stocks of the three drivers' groups in the model. By developing this equation in this manner, it is able to account for the awareness of the trade's high job returns. The unit is driver/Week.

Competition for passengers is treated as an effect on the total income that a driver earns. It is taken as a function of driver population's density. Its maximum effect is however set to a third of the drivers' population density. It is given by:

$$ECI_t = MEC * DPD_t \tag{2}$$

EC is effect of competition on income, MEC is maximum effect of competition, and DPD is drivers' population density. The value for MEC is taken as 30%. It is arbitrarily assumed that the maximum level of competition should not require more than a third of a driver's income. Values from the literature have been found to be as much as about 20% (*7*).

Similarly, drivers are assumed to set a hypothetical target income which they desire to make to become satisfied in a typical day. This target income is treated in this model as that for a representative driver in the system (an average of all drivers). It is given by:

$$TI_t = \left. \left((NED_t + ED_t) * DCL + (1 - SOD) * AWC_t * AD_t\right) \right/ TD_t \tag{3}$$

TI is target income. NED, ED and AD are the three groups of drivers in the model. NED is New Entrant Drivers, ED Established Driver, and AD is Ambivalent Drivers. DCL is driver's capacity less repayments, SOD is self-owned drivers' repayment factor, AWC is average work capacity, and TD is total drivers. Target income (TI) is the average expected income a representative driver wants to make in the trade on a typical

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day of the week. The new entrant drivers (NED) are those in the trade within their first year. Due to the repayment they have to make, their target is set at the minimum for all drivers, i.e. the value of DCL. The established drivers (ED) are mature drivers who have been in the trade for five years and above. The model conceptualisation shows that this group is more relaxed and don't have high targets. Yet they have high earning capacity. Their target in this equation is also set at the minimum too (i.e., to DCL) since you are not under pressure. The driver's capacity less repayments (DCL) is the minimum capacity in the system - what is left to a driver after paying for the daily instalment cost of the motorcycle. It is therefore the average value of income of drivers less all repayments. This amount is taken as the real income that goes into the drivers' pocket. It is also about the estimated income a prospective driver looks forward to making. The self-owned drivers' repayment factor (SOD) is the average cost of acquiring a new motorcycle, i.e., the amount a driver saves toward replacing his motorcycle to avoid expensive acquisition options. Its value is decided based on the average life of motorcycles in use for this trade as shown in the literature. The average work capacity (AWC) is the average income in the system if there are no repayments for the cost of motorcycles, i.e., it is the income of a driver who is not making repayments. The ambivalent drivers (AD) are those in their second to fourth year; they share the characteristics of the other two groups in the they have the same earning capacity like the established drivers (ED) but they share similar work pressure like the new entrant drivers (NED). Because of their higher working pressure, higher earning capacity and lower repayment, they set higher target income than the other two groups. This equation presents target income (TI) as the average expectation for all the driver groups. But it also shows that the ambivalent drivers (AD) group has higher target than those in the other two groups as described earlier in this section. The units is NGN/(Week*day*driver).

The model shows that the difference between target income and drivers' real income is the shortfall that motivates drivers' behaviour in the system. The assumption is that the pressure under which drivers work lasts long enough to get them used to it. As a result, once a driver has been subjected to pressure as a new entrant driver (NED), he carries this pressure on for years until maturity, taken in this model as about four years. The period under which this happens is the time covered in the group of ambivalent drivers (AD). This shortfall is represented by the following equation.

$$ES_t = \int_0^t (SD_t - LE_t)ds \tag{4}$$

ES is *effect of shortfall*, SD is shortfall deficit, LE is loss of effect. Though this is intended to show a pressure, it is presented in monetary value so that *effect of shortfall* (ES) is the monetary equivalence of the pressure a representative driver is experiencing at a time. The shortfall deficit (SD) is the difference between target income and total income that a representative driver earns. The loss of effect (LE) is used to capture the fact that this pressure diminishes over time until the driver becomes mature. The unit is NGN/(day*driver).

The pressure effect of the shortfall described above is represented by *earning pressure*. The value of this pressure is the ratio of driver's perceived shortfall to the average capacity of the driver. The driver feels this pressure by comparing what he wants to make to what capacity he has to work. So earning pressure is given by

$$EP_t = \left(\frac{TAE_t}{DCL_t}\right) \qquad (5)$$

EP is earning pressure, TAE is target additional earning, and DCL is driver's capacity less repayments. The earning pressure measures the ratio of the pressure represented by *Effect of Shortfall* (ES) to target additional earning (TAE). Target additional earning (TAE) is the value of *effect of shortfall* (ES) at the time the pressure is being considered. The unit of this pressure is dimensionless.

As previously mentioned, the model shows that it is this pressure that influences the behaviour of the drivers and causes high risk behaviour (aberrant behaviour) noticed amidst the drivers. This behaviour is formalised and represented by the equation:

$$TTV_t = IT(0) + \int_0^t (TG_t - TL_t)ds; IT(0) = 0.45 \qquad (6)$$

TTV is *tendency to violate*, IT is initial tendency, TG is tendency gain, and TL tendency loss. *Tendency to violate* is a measure of a representative driver's attitude towards high risk behaviour. Its measurement it formalised to range between zero and one. Model conceptualisation shows that these high risk behavioural actions are all punishable by law and similar thing was noted by Abane (*12*). The initial tendency (IT) is an arbitrary value given to *tendency to violate* (TTV) at the start of the simulation. It is used to show that the private motorcycle owners who initiated the trade were previously violating too since the system was not previously violation-free. Tendency gain is a measure of the effect of sanction on drivers while tendency loss is a measure of the benefit from this high risk behaviour. The relationship in this behavioural measurement follows the theory of deterrence (*23, 24*). The unit of *tendency to violate* is dimensionless.

Finally, the effect of enforcement operation is added to the equation by include the capacity of enforcement officers. It is this capacity that determined the probability of arrest for unlawful behaviour as well as the cost of violation such that the deterrence effect of sanction is created. Denoted by *enforcement coverage*, this effect of enforcement operation is given by the following:

$$EC_t = ES_t * ATM_{j,t} \qquad (7)$$

EC is *enforcement coverage*, ES is enforcement size, and ATM is attention to mode. *Enforcement coverage* represents the ability within the enforcement system to deal with the traffic. *Enforcement coverage* is used to measure the level of the physical presence enforcement officers create to drivers. It is a function of both the population of enforcement officers (known as enforcement size in this model) and the level of attention enforcement operation is committing to commercial motorcycle mode

(attention to mode). Attention to mode is a measure of the concentration committed by officers to dealing with commercial motorcycle problems relative to their share in traffic.

5.0 MODEL RESULT AND DISCUSSION

5.1 Calibration and Validation of Model

As earlier noted, the challenge being addressed here is that of availability of reliable quantitative data for a rigorous quantitative analysis. Since such data is not available, two parameters described by stakeholders were used as a guide for model calibration: *tendency to violate* and the total number of drivers (not included due to space limitation). In addition to these a number of other validation steps were conducted as suggested by Sterman (*17*): the initial conceptual model was used to conduct boundary adequacy test, using respondents familiar with the mode's operation; all model parameters have real life meanings. The dimensional consistency test was also conducted. Similarly, different integration methods and time-steps were used to test model sensitivity and to check for strange model behaviour.

5.2 Scenario Testing

This paper goes a step further here to check the effect of some policy intervention on the system described in section 4. As previously noted, two major factors contributes to the pressure within the system: expensive repayments and competition. An attempt is therefore made to check if removing these influences would change the behaviour of the drivers. In addition, an attempt is made to check what the effect of increasing sanction would be on the behaviour of the drivers. In all, these three policy measures are tested for and the result is discussed below.

5.3 Result and Discussion

The model is developed for a period of 15 years (780 weeks) and scenario testing extends this period by additional five years, making it 1040 weeks in all. The outcome of the simulation is now discussed with graphical illustrations.
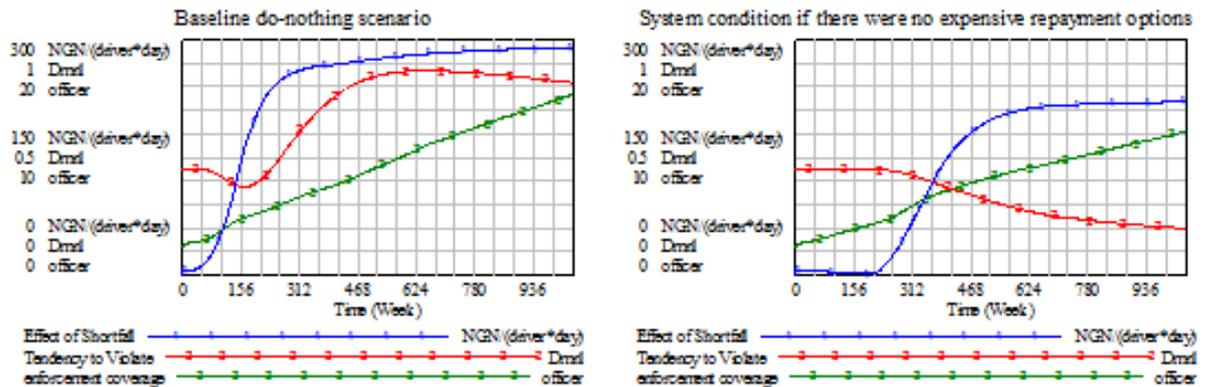
FIGURE 2 Baseline and no-repayment scenarios.

What is first shown in figure 2 is baseline model result to compare the patterns of changes in three selected parameters of the system: *Effect of Shortfall* (in blue colour and labelled 1); *Tendency to violate* (red and labelled 2); and *enforcement coverage* (green and labelled 3). As previously described, the *effect of shortfall* represents the cumulative effect of working under pressure in monetary terms for each driver. This pressure translates into risk-taking behaviour and is measured by a driver' *tendency to violate*. The term *enforcement coverage* represents the capacity of enforcement officers under the various scenarios. In relative term, the left-hand graph in figure 2 is used to describe the current situation and the likely trend over the next five years. It shows that *effect of shortfall* keeps rising and approaches almost 300 units (about a quarter of a driver's income). But *tendency to violate* peaks and falls slightly to 0.8 as *enforcement coverage* increases (a measuring index of 0 to 1 is used). *Enforcement coverage*'s increase is steady as it rises to about 15 units (about 15% of human resources of the police traffic unit).

In the right-hand graph of figure 2, a different scenario is shown. Supposing the system characteristics were the same as in the left-hand graph but there were no expensive motorcycle acquisition options, what the system would look like is shown in figure 2 (right). Relative to figure 2 (left), the *effect of shortfall* delays over a long time before it starts to rise and stops at about 220 units (compared to 300 in the other graph). *Tendency to violate* improves and falls to about 0.2 units (compared to 0.8 in the other case) after a small rise in *enforcement coverage* at about week 260. Similarly, the *enforcement coverage* required in the system is lower at 12 units compared with 15 units in the left hand graph scenario.
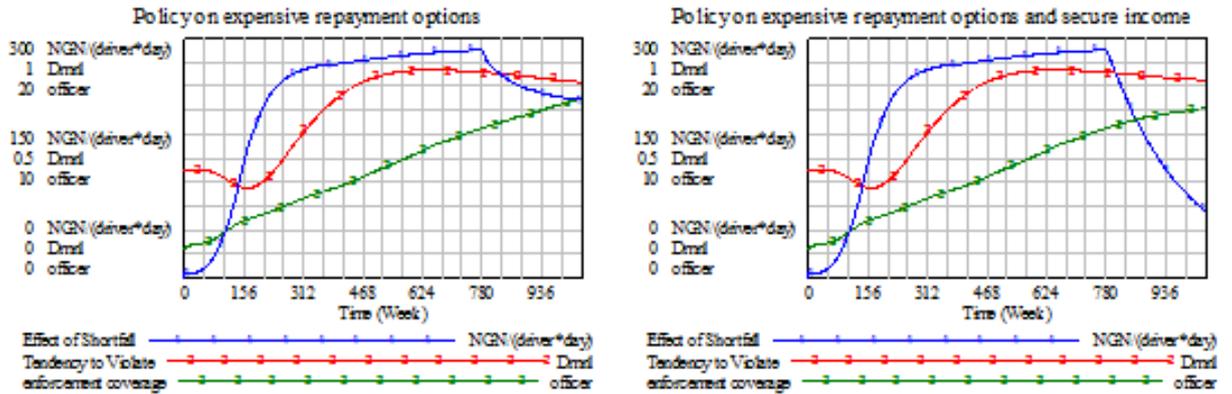
FIGURE 3 Policy scenarios on repayment and secure income.

Figure 3 shows the behaviour of the three elements for two different scenarios. In the left-hand graph of figure 3, a policy instrument to stop expensive repayment option at week 780 (after 15 years of commercial motorcycle operation) is adopted. As can be seen from the graph, this policy leads to a reduction in the *effect of shortfall*, meaning a fall in the pressure a driver works under. But this did not result in any significant reduction in the tendency of the driver to violate. The implication of this is that all the gain of removing this pressure is internalised by drivers such that the policy does not change their behaviour. This may be partly due to the fact that behaviour does not change easily especially when there are no deterrence measures attached to the policy. The second graph in figure 3, the right-hand graph, tests multiple policy measures. In this case, two measures are combined together in the policy: removal of expensive repayment and securing drivers' income. Securing drivers' income is achieved by reducing the effect of competition to near zero, say by making stringent registration requirements for drivers. This leads to more fall in the work pressure, i.e., the *effect of shortfall*. But these two measures combined do not bring any significant change to *tendency to violate* either. These findings may not be a "common sense" without the help of a model. The use of a model to test these policies therefore helps to see what is not easily obvious.
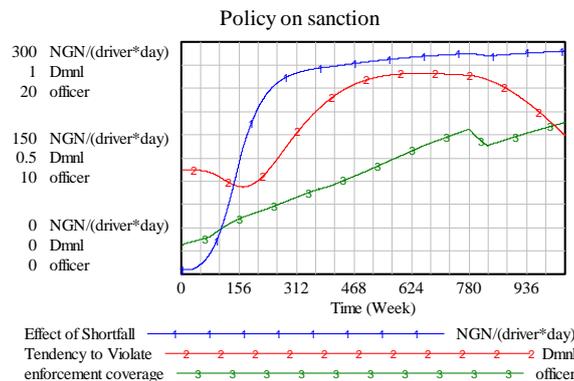

FIGURE 4 Policy on improved sanction.

The last test conducted is the effect of improved sanction on the behaviour of drivers. This measure is shown to have the most significant impact on the behaviour of drivers

by lowering *tendency to violate* from about 0.8 unit to 0.6 unit. This thus reinforces similar studies on driver behaviours (e.g., *18*) that show that improvement in enforcement is very important to deterring aberrant behaviour amidst drivers. In addition, the graph shows that this improvement is achieved without necessarily reducing drivers' work pressure. Moreover, it is achieved by less *enforcement coverage* of about 13 units (which is less than 15 units and 16units in the two scenarios in figure 3).

However, the challenge with many poor developing countries is how to improve the rule of law and to make sanction more effective. This cannot happen simply by increasing *enforcement coverage*. An alternative method of implementing sanction that is more effective than increasing the number of traffic police officers should be considered. For example, drivers' unions are known to be very powerful in coordinating their members (25). Using them as internal guard for the drivers and offering incentives for doing well might be a better alternative to increasing the number of traffic police officers.

CONCLUSION

This paper reports an exploratory model of drivers' behaviour using system dynamics. While the entire model could not be included due to space, the complex dynamics of interactions within the operation of commercial motorcycle has been pointed out. The scenarios tested show that some policy measures would not work, at least in the short run even when they look sensible on face value. This capability of system dynamics to conduct exploratory analysis despite limited data is note-worthy. It is therefore recommended for policy makers in developing countries, especially where there are no sufficient quantitative data.

One important pointer from this analysis is the need to improve enforcement operations. However, many developing countries have problem with corruption which make enforcement operations ineffective. Anbarci et al., (*26*) stressed this and noted that some countries have completely removed all officers in their enforcement agencies and replaced them. There is however no guarantee that such drastic step would work. More research will be required to assist policy makers in dealing with the problem of corruption with a view to improving traffic safety. A suggestion raised in this study is to use the drivers' union as a guard for the drivers. How this would perform is not certain yet either.

Finally, this model is exploratory in its current form. More calibration is necessary to improve the quality of the outcome generated by the model. This can be by expert judgement, Delphi method or even through a combination of quantitative and qualitative data collection methods. This will be the future direction of the study.

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