Systems Analysis of Commercial Motorcycle Service Safety Problem in Nigeria

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ABSTRACT

The use of motorcycles for carrying passengers for a fee (commercial motorcycles) has been suffering from serious safety challenges over the years in Nigeria. Policy measures developed to address this problem have not been very successful. This paper looks at the safety problem and presents an illustration of how a model (a system dynamics model) of the safety problem was formalised. The results obtained from model runs reveal how the model developed offers an opportunity for policy makers and stakeholders to better understand the structure and the dynamics of the safety problem. It also indicates that something can be done to improve safe driving behaviour of the drivers. Particularly, it points out that a mix of measures including improved enforcement of law is one main way by which driver behaviour can be improved. But it also warns that increasing the number of enforcement officers does not improve enforcement in a corrupt environment.

Keywords: Commercial motorcycle, Safety, System dynamics

INTRODUCTION

Commercial motorcycle is the use of motorcycle for carrying passengers for a fare (*1*,*2*) They have become very popular in various countries of the world due to their perceived benefits. These places include Brazil, Indonesia, Thailand, Cameroon, Sierra Leone, and Nigeria. They have the advantage of speed, door to door service and serve narrow roads less accessible to other modes (*3*,*4*). They play an important role in serving the transportation system as gap filler as well as a source of employment for people. Moreover problems such as poorly developed road network, narrow streets, traffic congestions, and poor standard of public transport which are characteristic of many developing countries not only contribute to the rising number of commercial motorcycles but opens up a gap they are fit to fill (*1*,*3*).

In Nigeria, the emergence of commercial motorcycle service is largely attributed to mobility challenges that succeeded the post oil boom economic recession of the 1980s (*5*). Within a short time, it became an important transport in many towns and cities in Nigeria (*6*,*7*,*8*). Its operation however, started to become challenging soon after it emerged as a transport mode in Nigeria (*9*,*10*,*11*). Nevertheless, while the government now regularly comes up with policies on measures to improve this mode's operation, there is still no record of successful regulation of commercial motorcycles in Nigeria today (*12*,*13*). Some of their problems include pollution, criminality, and safety. Their safety problem is however more prominent (*14*). This paper therefore attempts to explain why some of the efforts put up by the government have not been successful in improving safety and what might be done to improve the situation.

The concept adopted is that of system dynamics. This concept shows the connections between the elements of a system. Leverson (*15*) argued that models should not treat just safety events and conditions; rather, the process involved should be treated. This process, according to him, controls a sequence of events and describes system and human behaviour over time. Defining system characteristics based on drivers' characteristics alone without considering the interaction with other system components might make the solution proffered less effective. This paper illustrates this concept.

In the following section, a brief review of the stages involved in data collection and analysis to

obtain a causality diagram known as causal loop diagram (CLD)) is presented. This is followed by a description of the feedback loop in the CLD and how it is reflected in the subsequent model. Section 4 demonstrates the process of translating CLD into mathematical equations while the fifth section conducts some model responsiveness tests. A brief conclusion is provided at the end of the paper.

DATA COLLECTION AND ANALYSIS: THE PROCESS

The data collection method employed is more similar to (*16*) than the GMB method (*17*) in system dynamics modelling. Stakeholders were contacted for semi-structured interviews. The semi-structured interviews involved preparing a few general lead-questions. while other questions raised during the interview resulted from responses to the lead questions. The lead questions included: What are the reasons for the safety problems of commercial motorcycle operation? Why are the problems persisting? What can be done about the problems? In all 25 respondents from seven stakeholder groups participated and granted 13 interview sessions in all. Most of these interviews were audio recorded while others that could not be recorded were documented by hand-written notes. The entire data was transcribed for the ease further analysis. Other written documents such as newspapers reports and literature on commercial motorcycle safety provided information that influenced the researcher's frame during data analysis.

The data collection phase was followed by data coding using Miles et al. (*18*) *causation coding* and Burnard's (*19*) steps for coding interview data. The codes obtained were first sorted into small clusters as a starting point for generating meanings in the analysis. Both (*18*) and (*20*) suggest the use of graphical representations called *causal networks* (causality diagrams) for the outcome of a coding process to support "sense-making". Causal networks are graphical illustrations of cause and effect as they are deduced from the data. They are drawn with the use of arrows and codes. Arrows link codes to one another and indicate how one thing leads to (or is related to) the other. In all, five networks were obtained The causal networks obtained were combine to form a single network. There were redundancies in the form of repetitions that were removed in preparation for the next step in the data analysis process.

The next step was the generation a worded description of all the links present in the causal network. This description helps to provide a story-like account of how and, often, why one cause leads/ relates to its effect. This description is called a “narrative” (*18*). A narrative provides a complete description of a system’s causality relationship as found in the data without including illustrations, examples, and other less important information that make the original data bulky. There are no rules about the starting and end points of the narrative. It is however important that all the links and codes in the causal network are included in the description..

From this narrative, the processes/cycles/dynamics in the system were extracted as summary points. These summary points are what make dynamic hypothesis required for building a (CLD). This summary is different from the narrative in that while the narrative is a story-like description of all the links identified in the data, the summary is a list of bullet points/ statements of the content of the story. The summary identifies processes/ events in the story and why they happen the way they do. More specifically, for the purpose of the development of a CLD, these summary statements describe processes and their feedback loops in a manner that they form a dynamic hypothesis for the problem structure in the system being analysed.

While the process describe thus far is a typical qualitative analysis method found in (*18*), the possibility at this stage to obtain summaries that can form dynamic hypothesis makes the method suitable for adoption in developing conceptual models such as a CLD. One of the dynamic hypotheses generated from this process is labelled *Detection* and is presented below:

> Officers enforce law by detecting and arresting violators but this process is weak (Detection)

THE FEEDBACK LOOP IN THE CLD

Based on the dynamic hypothesis presented above, a balancing feedback loop can be identified. This is shown below.

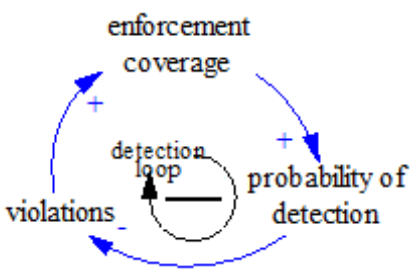

Figure 1: Detection causal loop diagram (19)

In the figure above, three names are used. These are enforcement coverage, probability of detection and violations. **Enforcement coverage** is used to describe the number of police posts mounted on the highway to monitor traffic. **Probability of detection** means the likelihood of a violation committed being detected by

the police. **Violations** are the traffic offences usually committed and for which arrests can be made. From the figure above, it shown that increase in **enforcement coverage** leads to increase in the **probability of detection**. Thus the number of police posts on highways often relates to the level of violation of/ adherence to traffic rules. As the **probability of detection** increases, there is a fall in the number of violations committed by drivers and this can ultimately result in less **enforcement coverage**. This concept is also well established in the theory of deterrence as well as studies on policing and crime (Polinsky and Shavell, 2001; Garoupa, 1997; Chang et al., 2000).

The detection dynamic hypothesis can now be translated into stock and flow diagrams (SFDs). This is represented by three SFDs, based on its structure and feedback loop. These are labelled as **Enforcement coverage**, **violating opportunity**, and risk **perception component**.

The term stock and flow diagram is used in the system dynamics model to represent mathematically CLD. While CLD is a qualitative description, SFD contains mathematical description of the relationships indicated in the CLD. Thus **Enforcement coverage** covers all aspects of recruitment into policing service. **Violating opportunity**, on the other hand measures the cumulative effect of increasing policing as it is expected that the ease of committing a violation reduces with increasing monitoring. The risk **perception component** is essentially an concept to take care of the decision rule guiding enforcement operations. The decision to change the size of the police monitoring per time is treated as a measure of the perception about safety in commercial motorcycle operation. This risk **perception component** indicates that the enforcement system has a floating goal decision rule that guides staff recruitment and layoff decisions. The process of formalisation follows from here.

MODEL FORMALISATION OF THE DETECTION MODULE

In this section, an illustration of how the model is formalised is presented.

The detection module shows the changes in the number and capacity of traffic enforcement officers. These changes are as a result of the need for more (or less) officers. This part of the model contains the main enforcement agencies' staff, officers who engage in overtime duty, and ad hoc officers who might be recruited from time to time to support the main staff in the enforcement agency. (While there are up to four different enforcement agencies in the study location, their combined effect is considered here). These all add up to make the **enforcement coverage** in the system. A simple formalisation for recruitment is presented in figure 2 below.

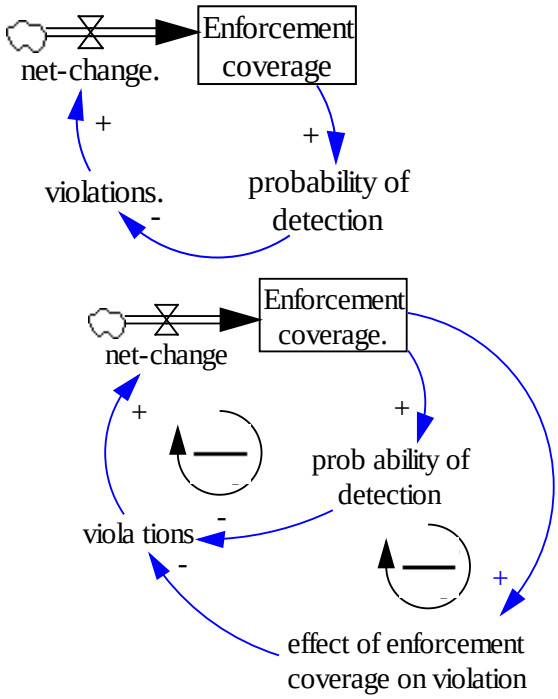

Figure 2:Simplified SFD for enforcement and Extended Simplified SFD for detection loop (Aluko, 2014)**.**

In the qualitative data obtained for this study, respondents estimated recruitment rate within the enforcement system from hindsight. They also noted that officers were usually not enough for full traffic monitoring. As a result, the enforcement system normally recruited ad hoc support as the need arose. This information is employed in the model. Figure 2 shows that **enforcement coverage** is fed by **net-change** (i.e., net change in the number of officers). **Net-change** changes in response to **violations**. As **enforcement coverage** changes, the **probability of detection** of violation changes and this affects **violations**. This is a balancing loop and forms the discussion under the theme **enforcement coverage**.

In addition, **enforcement coverage** usually created an effect. If the **enforcement coverage** increased, then police surveillance would rise; so drivers would have less opportunity to commit violations. This effect of less **violating opportunity** is represented for simplification by the variable **effect of enforcement coverage on violations**. The new simplified description is also shown in figure 2 above. It is the subject of discussion under the theme **violating opportunity**.

Finally, a third unit is added as it provides additional information about enforcement operation.

This third unit is titled **perceptions**. **Perception** refers to the risk perception level amidst commercial motorcycle patrons and the public about commercial motorcycle operation. It was the gauge that mobilised enforcement agency to alter their enforcement coverage.

The three units are now presented.

Enforcement Coverage

This is derived by adopting two stocks to separate steady officers' recruitment from the ad hoc officers' recruitment. These two stocks are **enforcement workforce** and **additional support officers** as shown in figure 3.

Enforcement workforce is the stock of traffic officers recruited steadily on annual (weekly in this model) basis. This rate does not respond to violation; it is a constant rate. The stock of **additional officers' support** is what responds to traffic violation (and the perception about the risks involved in commercial motorcycle service). To capture this response, a floating goal of enforcement system's target level of decorum in traffic operation (**target perception**) is operationalized. Some of the equations are shown below (not all equations can be shown due to word limit):

Enforcement Workforce: is the term used to describe the number of officers in the traffic enforcement division who are the main personnel charged with the duty of traffic law enforcement. It is an accumulation and therefore treated as a stock in the model. Both its initial value and current value are approximate number obtained during the field work exercise. Its equation is given as

$$EW_t = EW_{t(t-1)} + \sum NH_t\,;\; EW_{t(0)} = IW = 20 \qquad (1)$$

where EW_t, the **enforcement workforce**, is the total number of officers in the traffic division, $NH$the**net hire**, is the number of new officers added to **enforcement workforce** each time step. The stock started with an initial value, named here **initial workforce**, of 20. **Enforcement workforce** has the dimension **officer**. The number of new officers added each time step is given as 0.0769, being the approximate value obtained during data collection and the unit of **net hire** is **officer/week**.

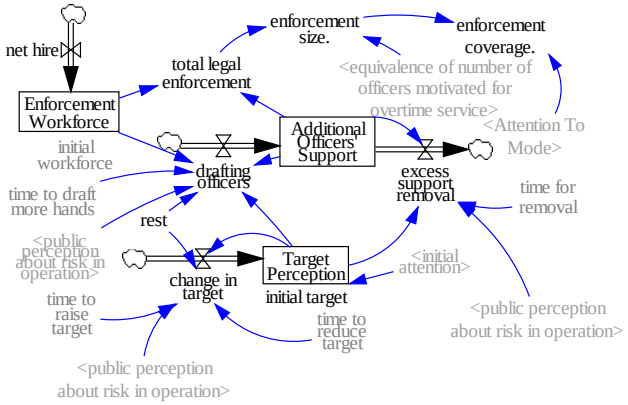

Figure 3 SFD for enforcement coverage(Aluko, 2014)**.**

Additional Officers' Support: this parameter is the number of officers drafted as additional support on secondment basis to assist the traffic enforcement officers. It is treated as a stock and is given by

$$AOS_t = AOS_{t(t-1)} + \sum(DO_t - ESR_t); \qquad AOS_{t(0)} = 0 \qquad (2)$$

where AOS, the **additional officers' support**, is the additional officers provided to support traffic enforcement officers, DO, the **drafting officers**, is the officers drafted for support each time step, and ESR, the **excess support removal**, represents officers removed from the supporting duty when their services are no longer required. The unit of **additional officers' support** is given as **officer.**

Excess support removal: this is the parameter that shows how officers on secondment in the stock of **Additional officers' support** are withdrawn back to their primary duties. It is given by

$$ESR_t = \begin{cases} \frac{AOS_t}{TFR}, & AOS_t > 1 \; and \; (TP_t - PPRO_t) > 0 \\ & otherwise \\ & 0 \end{cases} \qquad (3)$$

where AOS is the **additional officers' support**, TFR, the **time for removal**, is the length of time deemed suitable to have stabilised the traffic system, organise and implement removal of excess support staff and ESR, the **excess support removal**, is the number of officers whose service is no longer required each time period. $PPRO$ is the **public perception about the risk in operation** and TP, is the **target perception**. The unit of **excess support removal** is given as **officer/Week.**

Total legal enforcement: this is a parameter that estimates the total number of officers working legally in enforcement operations. It differentiates between illegal and legal enforcement operations. The

total legal enforcement is the addition of enforcement officers and additional support provided to assist with traffic management, i.e., the sum of **Additional officers' support** and **Enforcement Workforce**

The equation for the model is given as

$$TLE_t = AOS_t + EW_t \tag{4}$$

where TLE is **total legal enforcement**, AOS the **additional officers' support**, EW_t is the **enforcement workforce**. The unit of **total legal enforcement** is given as **officer.**

Violating Opportunity

Violating opportunity is what shows the direct effect of changing **enforcement coverage** on the liberty of drivers to commit **violations**. The effect of increasing number of officers is partly an increase in the number of police posts on the road. An increase in the number of police posts tends to reduce the liberty to commit a traffic violation. The SFD showing this part of the model is presented below with the equations representing it..

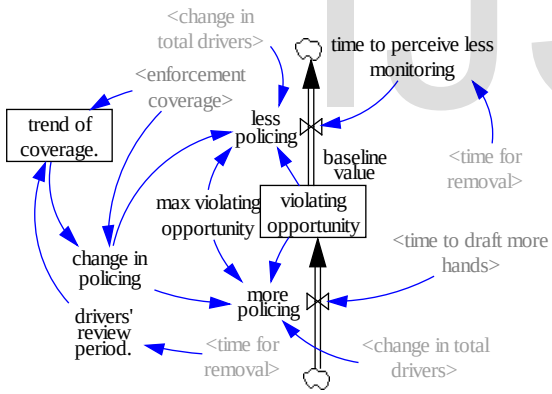

Figure 4 SFD for violating opportunity(Aluko, 2014)**.**

Violating opportunity: This is the effect of increasing the number of police posts on the road. The effect is cumulative and is therefore represented as a stock with the equation below

$$VO_t = VO_{t(t-1)} + \sum(LP_t - MP_t); \quad VO_{t(0)} = BV = 1 \tag{5}$$

where VO Is **violating opportunity**. Its unit is **dimensionless**. LP, is **less policing**, meaning that officers' coverage is less than it was previously. MP, **more policing** and it mean that officers' coverage is more than it was previously.BV is the **baseline value** of **violating opportunity** at the start of simulation. It has the value of one to indicate when there was no difference.

More policing and **less policing** are given by the equations

$$MP_t = \begin{cases} \frac{VO_t}{CITD} * \left(\frac{VO_t}{PVO_t}\right) * \frac{(CIP_t - 1)}{TTDM}, & CIP_t > 1 \\ otherwise \\ 0 \end{cases} \tag{6}$$

$$LP_t = \begin{cases} \frac{(1 - CIP_t)}{CITD} * \left(1 - \frac{VO_t}{PVO_t}\right) * \frac{VO_t}{TTPL}, & CIP_t < 1 \\ otherwise \\ 0 \end{cases} \tag{7}$$

whereCIP is **change in policing,** $CITD$ is **change in total drivers**, VO is **violating opportunity**,MVO is **max violating opportunity,**$TTDM$ is **time to draft more hands**, MP is **more policing**, $TTPL$ is **time to perceive less monitoring**, and LP is **less policing.** This formulation shows a logistic function that indicates that additional policing becomes less effective with more officers just as in the law of diminishing returns**.** The unit of **more policing** and **less policing** is **1/Week**.

Perceptions

Moreover, it is shown that enforcement agencies respond to the feelings of the public by trying to maintain a "floating" level of "acceptable" traffic decorum (**target perception**). If this level is exceeded, then ad hoc officers are recruited so as to raise detection level. The formal model shows that the feeling of the public is named: **public perception about risk in operation** and that it determines enforcement system's **target perception**. It also determines the level of attention (**attention to mode**) that is given to motorcycle mode during monitoring. How perception is determined and what it influences are shown in the SFD presented in figure 5.

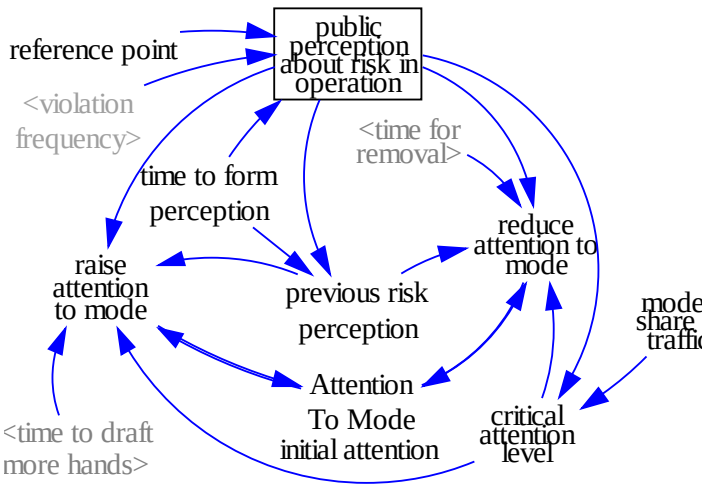

Figure 5 SFD for perceptions components(Aluko, 2014)**.**

Public perception about risk in operation: this parameter estimates public view about the safety performance of commercial motorcycles, particularly with respect to the drivers' aberrant behaviours. It is given as the average value of this perception over some time. But perception is difficult to measure. It is therefore estimated as an index between 0 and 1 using violating frequency as

$$PPAR_t = \sum_{t(t-TTFP)}^{t} \frac{VF/RP}{TTFP}$$

(8)

where $PPAR$ is **public perception about risk in operation**, VF**violation frequency**, RP is **reference point**, and $TTFP$ is **time to form perception**. **Reference point** here takes a value of one, comparing **violation frequency** to an assumed baseline index of one violation per driver. Also introduced in the model is the **previous risk perception** which provides information about what the perception was just before the current perception. The unit of measurement of **public perception about risk in operation** is **dimensionless**

What has just been presented is one of the dynamic hypothesis. The final model is composed of seven dynamic hypothesis in all.

MODEL RESPONSIVENESS TESTING

A way to demonstrate the usefulness of the model developed is to undertake tests that check the responsiveness of its outputs to interventions. Three different parameter values are changed at the end of the simulation period (15 years) and their impact on the system, run over a period of additional 10 years (to make 25 years) is discussed. These tests include:

a. Increase enforcement coverage by doubling recruitment rate
b. Increase prosecution rate
c. Combination of changes to ownership options and prosecution rate

First, the base line scenario is presented below in figure 6 below

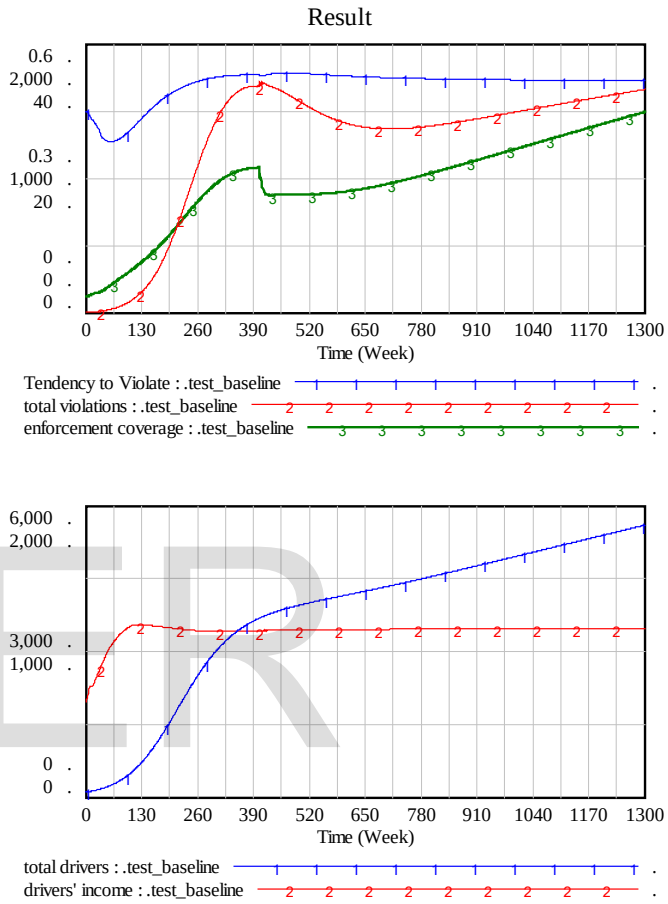

Figure 6 Baseline scenario for some model parameters (Aluko, 2014)**.**

Figure 6 shows the base line scenario as obtained from the model. In the first of the two diagrams, the blue line labelled "1" represents **tendency to violate**, the red line labelled "2" represents the **total violations** while the green line (labelled "3") in the figure represents **enforcement coverage**. This simulation period covers 25 years: 15years into the past (between 1997 and 2011) and 10years into the future, taking the year 2011 as the reference point. The graph shows that drivers' **tendency to violate** remains high past the first 15 ending at 0.52 unit. Similarly, the **total violations** committed in the system continue to rise after a dip that followed aggressive enforcement. **Total violations** ended at 1674 violations/week-day while **enforcement coverage** ended at 30.24 officers. The number of drivers grew to about 5598 drivers while

their income ended at about NGN1158 (about £4) per day.

Increase Enforcement Coverage By Doubling Recruitment

What is considered here is a policy to increase the number of enforcement officers by increasing hiring rate. In this test, the hiring rate is doubled at the end of the first 15 years of the model run. To run this test, some equations were modified/ added

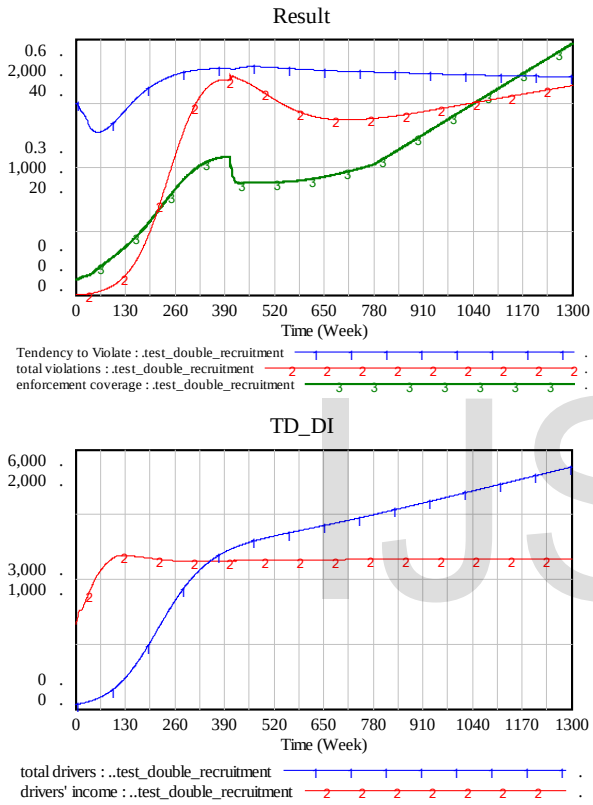

Figure 8 Model behaviour under a test to increase enforcement coverage(Aluko, 2014)**.**

It shows that **tendency to violate** does not significantly change as it moves from 0.52 to 0.51 unit. Similarly, **total violations** only slightly falls from 1679 to 1649 violations/week-day. This result is at variance with (*24*) findings which shows significant improvement in rate of violation when enforcement coverage was increased. This difference is accounted for by the corrupt practices of the officers that make deterrence ineffective. (*25*) observe that the presence of corruption in traffic enforcement has motivated the complete removal of officers by the central government rather than increasing their number. This result is nevertheless similar to the explanation by (*26*) when they show that raising fines (in this case probability of apprehension) could be counterproductive in deterring violations in a situation where corruption is widespread. ([1] Probability of apprehension relates to enforcement coverage. As shown by (*28*), both fines and probability of apprehension are "substitutable" in maximising "social welfare" which is the *tendency not to violate* in this model).The number of drivers under this condition rises to 5598 drivers (similar to baseline) and their income is similar to baseline too at NGN1158. Thus it can be said that improved *sanction* is not the same thing as increasing the number of enforcement officers working on the road. This seems to be the current misconception where increasing the number of enforcement officers is expected to improve sanctions. But the corruption in the system prevents this improvement. This illustrates a *fix that fails archetype* (*27*).

Increase Prosecution Rate

This policy assumes that corrupt practices in the enforcement process are almost removed. To run this test, the equation for **prosecution rate** in the model is altered

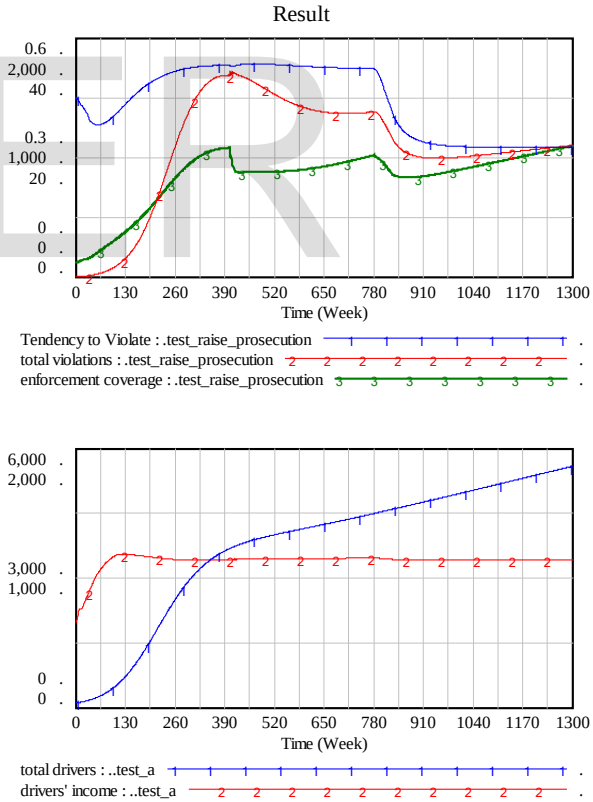

Figure 10 Model behaviour under a test to raise prosecution rate(Aluko, 2014)**.**

The graph of the simulation outcome is presented in figure 10. As shown in the figure, raising the rate of prosecution reduces **tendency to violate** better than other tests, lowering it to 0.32 unit. But the number of violations does not come down significantly. **Total violation** in the system is as high

as 1118 violations/week-day only slightly down from 1674. Looking through the model shows that though drivers have lower desire for violating, they have more pressure to commit violations. In addition, the floating goal structure of the enforcement system results in a lower level of **enforcement coverage** being 22.19 officers under this test unlike 30.24 in the baseline case. This must be contributing to the high number of violations too. Finally, number of drivers under this condition is slightly lower than the baseline case of 5598 at 5587 drivers and their income is close to baseline case of NGN1158 at NGN1139

Test Combination: Changes To Ownership Options And Prosecution Rate

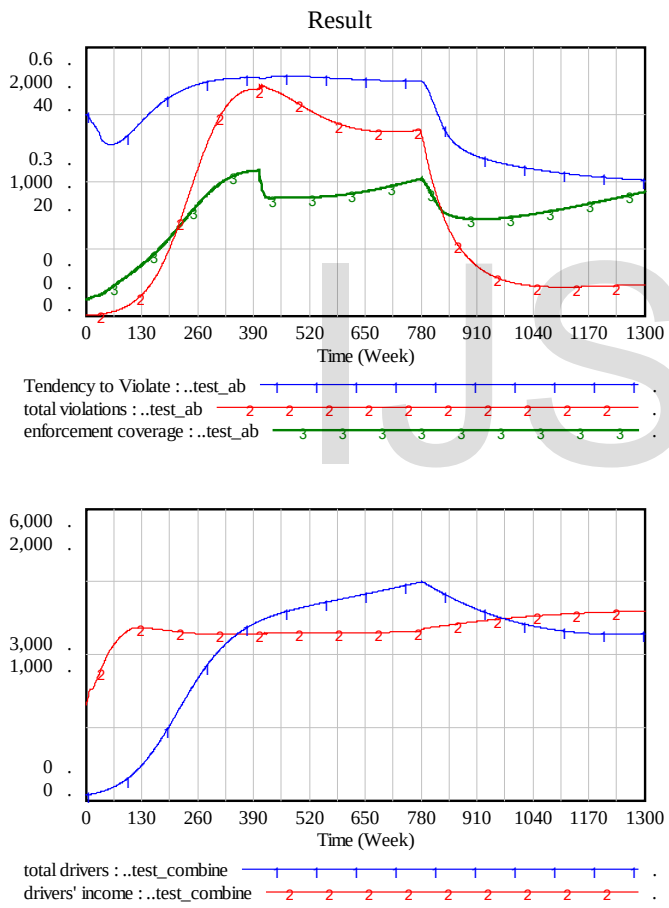

Figure 11 Model behaviour under test to raise prosecution rate and to remove expensive ownership options(Aluko, 2014)**.**

Figure 11 which is a combination of policy to raise prosecution and policy to remove expensive repayment option is shown to give the best outcome of the five future behaviour tests. It shows **tendency to violate** and **enforcement coverage** to be better than others at 0.30 unit and 21.10 officers respectively. It also shows total violations to reduce to 231.7 violations/week-day. However, the number of drivers under this condition falls to 3412 drivers (lower than the baseline case of 5598) and their income is slightly higher than baseline case of NGN1158 at NGN1297. This shows how leverage can be achieved by a combination of policies.

CONCLUSION

In this paper, a model of the safety problem of commercial motorcycle operation described has been demonstrated to offer improved understanding about the safety problem through its potentials for adaptability for testing various policy options. More specifically, the model responsiveness tests undertaken show that the expensive initial motorcycle acquisition method is one of the major causes of the system problem: when this condition was removed in a model run, all the problems reduced. It also shows that improved *sanction* can improve *driver behaviour*. Finally, it points out that a good leverage can be attained by a combination of measures in managing commercial motorcycle safety problem.

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