Navigating Chaos: A Qualitative System Dynamics-based Analysis of Road Safety Challenges for Vulnerable Road Users in a Major Developing City (Kinshasa)

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Abstract: This paper investigates the interaction of the elements of road safety concerning pedestrians and motorcyclists as vulnerable users in the system of the developing city. These cities are characterized by crowded streets, aggressive drivers, and insufficient conditions for traffic safety. The authors employ a qualitative system dynamics approach to clarify the multifaceted problems vulnerable road users encounter.

The findings show that users are much more likely to be involved in accidents and suffer injuries due to a combination of aggressive driving style, road conditions, and traffic management. The use of interviews, observational data, and case studies also depict the realities of the life of pedestrians and motorcyclists, which present an account of their efforts still first-hand. Heretofore, many factors contributed to the increased risk of these road users, such as the absence of pedestrian road crossings, improper placement of traffic signs, poor illumination, and the absence of special motorcycle lanes.

Further, this study examines the broader issues that are part of these challenges, such as socio-economic pressures that make people move by foot or motorcycle, and in most cases, at risk, or lack of governance and policy promoting investment in road safety features. Practically also considered the psychological and social consequences of these hazards, especially for women who are among the most vulnerable users of the transport system. This seeks to understand how fear and stress from hazards impact their commuting patterns and overall quality of life.

The paper's aims include the need for more effective measures such as improving traffic law enforcement, enhancing road facilities, and initiating an education campaign for the masses on road safety. Community participation and engagement through participatory planning is essential in helping design and build safer road environments that are responsive to the needs of vulnerable users. This study intends to explain the relationships among aggressive driving, infrastructure, and user vulnerability, hoping that relevant local authorities, urban planners, and road safety advocates will be informed. The ideas generated are hoped to be beneficial in informing policymaking aimed at designing solutions to common road safety problems such as those faced by developing countries experiencing urbanization. Integrated System Dynamics, a multidisciplinary approach, is helpful for the discourse on circuits and systems, which is relevant to this study.

Key-Words: System Dynamics, COMPRAM, Road Safety, Vulnerable Road Users, Qualitative Analysis.

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1 Introduction

1.1 Overview

Kinshasa, one of the expanding cities of developing countries with a population above 15 million, is waiting for a disaster to happen regarding road safety. Vulnerable road users (VRUs), including people on foot and those on bicycles or motorbikes, are at significant risk due to the absence of the safety features enjoyed by other road users. This group of road users is not only small in stature, which makes them less visible in traffic, but they are also more likely to suffer from severe injuries or death as a result of an impact, [1]. The woes of these VRUs are compounded by the frantic pace of traffic and the poor

quality of roads and services in most parts of the city.

A set of related variables that arise from infrastructural deficiencies of the cities determine how people, in this case, pedestrians, cyclists, and motorcyclists interact within the daily traffic environment. The lack of proper bike or motorrider lanes, the absence of proper pedestrian facilities such as synchronized crossings, and the lack of normal traffic order make life difficult for the vulnerable users of the road. They must weave through congested streets, avoid many dangers scattered through the roads, and confront rivalry among aggressive drivers, making even short trips very risky.

In addition, the socio-economic conditions of Kinshasa force many of its residents to walk, cycle, or use motorcycles as their most utilized means of transport. Such dependence, alongside the poor provision of the city's modes of transport, causes many VRUs to sustain traffic injuries and deaths or accidents. These risks and hazards are associated with many fears and stress, increasing the risk of a good quality of life many city residents enjoy.

This qualitative analysis aims to address these urgent conflicts and seek possible avenues for intervention. Analyzing the experiences of different categories of road user survivors obtained through interviews, observational studies, and case studies. The research presents a rounded perspective of the complex issues the survivors encounter. In addition, the analysis reviews the structural issues that render the present state of safety on the roads a matter of concern, particularly looking at policies and governance issues that facilitate the failure to address the problem effectively.

In order to overcome these difficulties, the research recommends various interventions: enhanced regulation of traffic, adequate planning, design and maintenance of road facilities, and increased public information on the issue of road safety. Additionally, it is emphasized that such strategies should be tailored to the particularities of vulnerable road users (VRUs) and that community and participatory planning should be pursued. In fulfilling these challenges, this study focuses on helping to make cities more safe and inclusive when developing urban areas in growth. Figure 1 shows the Mobility Pyramid and provides context for sustainable urban mobility.

1.2 Problem Statement

Aggressive driving behavior, for instance, excessive speed and unsafe overtaking, increases the risks posed to vulnerable road users to a great extent. The inadequate infrastructure and restricted traffic management measures result in pedestrians, cyclists,

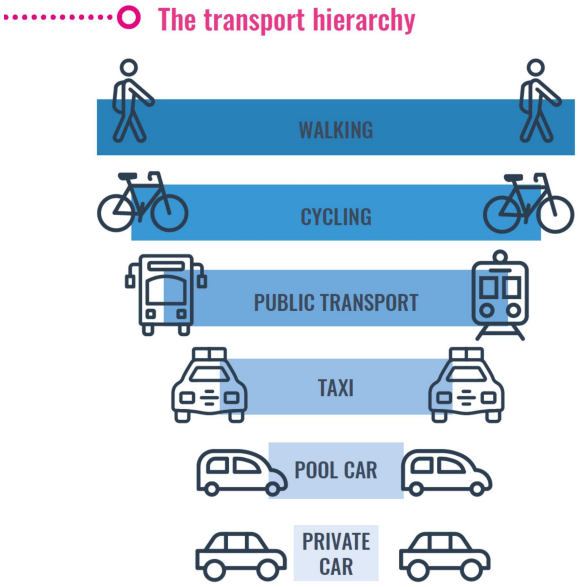

Figure 1: The Mobility Pyramid, illustrating the distribution of efficient and sustainable mobility in a modern, environmentally-conscious city.

and motorcyclists encountering daily safety hazards. Addressing these critical issues is imperative for enhancing road safety outcomes in developing urban settings. The lack of safe pedestrian crossings, inadequate signage, and substandard road conditions contribute to an environment fraught with danger, [2]. Our study seeks to understand the experiences of these individuals and identify strategies to improve road safety.

1.3 Relevance and Importance

Understanding road safety challenges in Kinshasa extends beyond the city limits. As urbanization continues worldwide, similar issues plague other developing cities [3]. By examining the experiences of vulnerable road users, we contribute valuable insights to the broader discourse on urban development and transportation planning [4]. Table 1 compares road safety factors between Kinshasa and the global average.

2 Literature Review

2.1 Overview of Existing Research on Road Safety in Developing Cities

Research on road safety in developing cities has gained prominence due to the increasing urbanization and motorization rates [5]. Several studies have investigated factors contributing to road accidents,

Table 1: Comparative Analysis of Road Safety Factors

Factor	Kinshasa (Developing City)	Global Average
Aggressive driving behavior	High	Varied
Road infrastructure quality	Poor	Varies by region
Pedestrian crossings	Insufficient	Varies by city
Signage clarity	Low	Mixed
Vehicle maintenance	Substandard	Varies by country

injury patterns, and preventive measures. Notably, Africa stands out as a region with high traffic fatalities, emphasizing the urgency of addressing road safety in these contexts [6].

2.2 Challenges Faced by Vulnerable Road Users

Globally, vulnerable road users encounter multifaceted challenges, [7]. These include inadequate infrastructure (such as poorly paved roads and insufficient street lighting), lack of safe pedestrian crossings, and limited access to public transport, [8]. In developing cities, these challenges are exacerbated by rapid urbanization, inadequate road design, and insufficient safety awareness programs, [9]. Addressing these issues is crucial for equitable mobility and social justice, [1].

2.3 City-Specific Considerations

Each developing city has unique road safety challenges. For instance:

- **City X**: High population density and informal settlements lead to complex traffic patterns. Pedestrians and cyclists face risks due to inadequate pedestrian infrastructure, [10].
- **City Y**: Rapid motorization and aggressive driving behaviors contribute to road accidents. The lack of safe pedestrian crossings exacerbates vulnerability, [11].
- **City Z**: Poorly maintained roads and inadequate lighting affect road safety for all users, especially at night, [12].
- **City V**: It includes all the negative features of Cities X, Y, and Z, with the crucial absence of significant community awareness programs regarding the road safety of VRUs as shown in Figure 3, [13].

2.4 Impact of Aggressive Driving on Road Safety

Aggressive driving behaviors, such as speeding, tailgating, and road rage, significantly impact road safety, [14]. These behaviors increase the likelihood of accidents, injuries, and fatalities. Figure 2 compares the leading causes of death between 2004 and 2030, while Table 2 summarizes the effectiveness of road safety interventions across different cities. Understanding the interplay between aggressive driving and vulnerable road users is essential for effective safety interventions, [15].

Table 2: Summary of Road Safety Interventions and Their Effectiveness

Intervention	City X	City Y	City Z	City V
Improved pedestrian crossings		×		×
Speed bumps	×			×
Community awareness programs			×	×

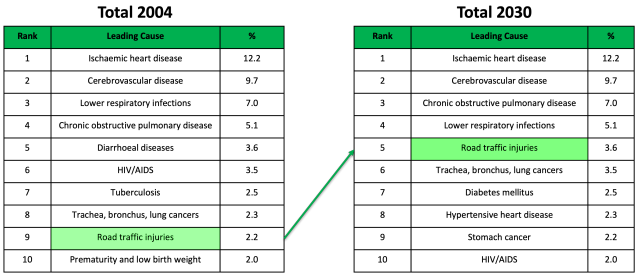

Figure 2: Leading cause of death 2004 and 2030 compared.

3 Methodology

3.1 Introduction to the Qualitative Analysis Approach Adopted

In this study, we employ a qualitative analysis approach to delve into the complex road safety challenges faced by vulnerable road users in Kinshasa. This approach is well-suited for exploring the multifaceted and dynamic nature of road safety issues in a developing city context. Qualitative approaches are valuable in understanding intricacies, contexts, and perspectives that may not be apparent through quantitative methods by getting in touch with the stakeholders, engaging in behavioral observations, and conducting more detailed interviews than the other methods, i.e., [16].

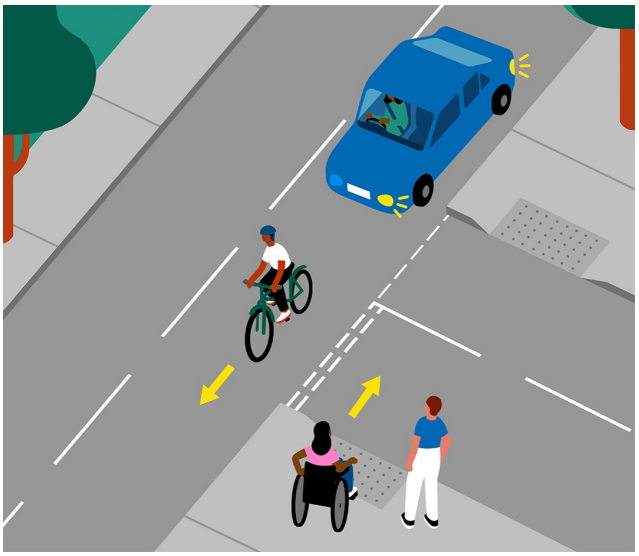

Figure 3: Vulnerable Road User (VRU) Safety

The case study worked with the residents, motor vehicle operators, traffic enforcement officers, and city designers through semi-structured interviews, focus group discussions, and participatory observations to obtain thick descriptions of the views of the varied interests within the communities. Such methodological triangulation contributes to the internal validity of the results as the outcomes are based on several perspectives, and some information is cross-checked and corroborated from different sources [17].

3.2 Explanation of the Inclusion of System Dynamics in the Analysis

In evaluating how to improve our understanding of the qualitative data collected and presented, System Dynamics (SD) modeling is included in the analysis. SD provides a systematic description of the interconnections and the feedback structures in the road safety system, which makes it possible to explain and model complex systems with complex interaction, feedback, and time lag [18].

In defining the SD approach, CLDs and stock-and-flow models depicting the causation and interrelationships among the critical variables, including traffic density, the behavior of road users, the prospects of traffic controls, and the quality of the infrastructure, are developed. This methodology allows for modeling various scenarios and assessing the possibilities of improving road safety through various initiatives [19]. Figure 4 provides a simplified causal loop diagram illustrating the dynamics of road safety in Kinshasa.

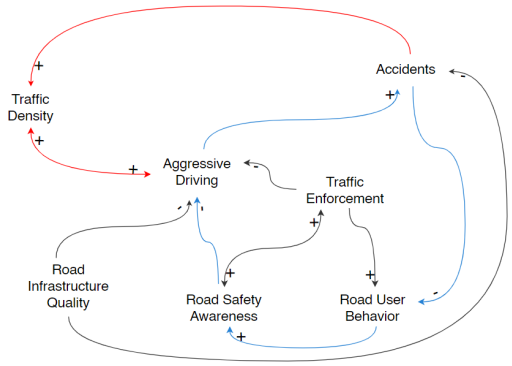

Figure 4: Simplified Causal Loop Diagram of Road Safety Dynamics in Kinshasa

3.3 Overview of the Complex Methodology of COMPRAM and Its Relevance to the Study

In this paper, the authors use the Complex Problem Resolution and Monitoring (COMPRAM) methodology, which shifts from the portrayal of road safety problems as individual concerns to one that roams into broader views encompassing social structures, cultures, economics, and infrastructure systems, [20]. This approach stresses the need to provide a solution step-by-step, modify the responses, and evaluate from time to time.

The COMPRAM methodology consists of problem identification, problem definition, generation of alternative solutions, decision-making, action, and monitoring. Every stage is participative, allowing the sponsored problem–solving process to resolve by taking views from all the relevant actors, [21].

The COMPRAM methodology is appropriate for the road safety challenges in Kinshasa. The study's objectives, which seek to bridge gaps in understanding the complexity of the urban landscape and make usable, evidence-informed recommendations, include incorporating qualitative perspectives, System Dynamics modeling, and stakeholder participation. With the help of the COMPRAM approach, the existing study diagnosed the traffic safety problem and developed and implemented adequate and viable solutions, [22].

The COMPRAM methodology highlights an integrated and participative response to road safety challenges in Kinshasa. In this regard, stakeholders are solicited, such as local authorities, the traffic police, NGOs, and community members involved in workshops, focus group discussions, and other participatory activities. Such a joint effort makes the construction of System Dynamics (SD) models

rational and based on the evidence from the field. Research also utilizes ethnographic fieldwork, semi-structured interviews, and document analysis, which enables researchers to feel the urban spatial setting in the case of Kinshasa. Such exposure helps record road users' behavior, the state of the road and its facilities, the effect of the enforcement of regulation, and other qualitative aspects necessary in SD model construction, [23].

System dynamics (SD) models for examining road safety issues are built using tools such as Vensim or Stella, which incorporate components such as traffic volume, surface conditions, enforcement, and societal perception into the analysis. After creation, these models are tested against past practices and improved through an iterative process with the help of309 the targeted audience, [24]. The applicability of the SD model also allows for scenario exploration, which basically enables the changing of one or more of more than one parameter to see what the result would be. Researchers can test the limits on how plains can be administered in areas like public awareness, campaigns, or the level of enforcement law to identify areas of high leverage that can dramatically bear on achieving better road safety targets. Table 3 outlines the steps of the COMPRAM methodology and its application in this study. This systematic and participatory approach makes it possible to enhance the design of the intervention and its targeted applicability [25].

Table 3: Steps of the COMPRAM Methodology and Their Application

COMPRAM Step	Application in the Study
Problem Identification	Identifying key road safety challenges in Kinshasa.
Problem Structuring	Mapping the complex interactions among road safety factors.
Generation of Solutions	Developing potential interventions based on stakeholder input.
Decision-Making	Selecting the most feasible and impactful solutions.
Implementation	Applying the selected solutions in pilot areas.
Monitoring	Continuously assessing the impact of interventions and making necessary adjustments.

4 Study Area and Data Collection

4.1 Detailed Description of the Chosen Third-World City (Kinshasa)

Kinshasa, the capital city of the Democratic Republic of Congo, portrays a vivid picture of a quite drastic and growing Urban center with an approximate population of over 15 million people. The city is situated in Kinshasa, among Africa's largest cities, and is crucial for preserving its political and economic growth and cultural enlightenment. Nonetheless, the accelerated rate of urban population has dramatically exceeded the advances in critical infrastructural development, resulting in many severe problems, especially regarding the road safety of vulnerable road users such as pedestrians, cyclists, and motorcyclists, [3].

The road system of Kinshasa is comprised of paved and unpaved roads, some of which are in poor condition and need to be better maintained. The widespread potholes, ineffective drainage, and missing road signs reflect a chronic lack of infrastructure maintenance, worsening the already high safety risks for VRUs, [26]. The city suffers from high traffic congestion, especially at peak times, worsened by aggressive driving behavior and the high level of formal and informal public transport traffic, [27]. All these factors combine to create an environment where road safety is grossly undermined, and focused actions must be taken to protect the most vulnerable in society.

4.2 Identification of Specific Areas with Congestion, Aggressive Driving, and Poor Road Conditions

A comprehensive survey was conducted across various districts of Kinshasa to identify areas most affected by road safety challenges. Key areas identified include:

- **Gombe**: The central business district is known for its high traffic density and significant congestion during work hours.
- **Kintambo**: A residential and commercial area with notable instances of aggressive driving and poor road maintenance.
- **Masina**: An area with a high population density, characterized by numerous informal settlements and poorly maintained roads.
- **Matete**: Known for its bustling markets and frequent traffic jams, compounded by aggressive driving and inadequate infrastructure.

These areas were selected based on preliminary observations and reports from local traffic authorities,

highlighting the urgent need for targeted interventions to improve road safety, [28].

4.3 Methodology for Data Collection: Interviews, Surveys, and Observations

The study adopted a mixed-methods approach to comprehensively capture the dynamics of road safety challenges, as outlined in Table 4. This methodological framework involved the following components:

- **Interviews**: Semi-structured interviews were conducted with a range of critical stakeholders, including traffic police officers, local government officials, and representatives from non-governmental organizations focused on road safety. These interviews provided invaluable qualitative insights into the systemic issues that underpin road safety challenges, such as governance gaps, infrastructural limitations, and enforcement inefficiencies. The study managed to unearth the situational contexts and constraints on efficient road safety measures by interacting directly with stakeholders, [8].
- **Surveys**: Structured questionnaires were distributed to households in the designated study areas to assess residents' experiences and perceptions regarding road safety. Such investigations sought information on the number of intersection accidents, a general account of why there was a road safety problem, and what could be done to improve this situation. The quantitative data derived from these surveys were useful in validating the interview results and pointing out common patterns affecting road safety measures, [2].
- **Observations**: During the investigation, direct field observation was programmed in time and place to record how the users of the road network behaved, the condition of the road, and the general traffic situation. Such observations required comprehensive field notes and photographs, which were used to corroborate the data. As such, the observations assisted in capturing behaviors and conditions and provided a tangible setting, which helped further comprehend the determinants of the road safety problems, which were not easy to trace through interviews or questionnaires [9].

Figure 5 provides a geographical context of Kinshasa and highlights the key areas involved in the study, and Figure 6 illustrates the distribution of responses from the survey conducted among residents. Figure 7 depicts the observed road conditions and traffic behaviors, complementing the data collection process.

Table 4: Summary of Data Collection Methods

Method	Description
Interviews	Conducted with key stakeholders to gain qualitative insights.
Surveys	Distributed to residents to gather quantitative data.
Observations	Direct observations of road user behavior and road conditions.

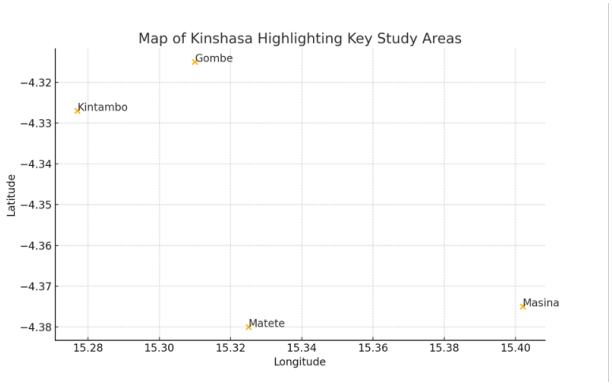

Figure 5: Map of Kinshasa Highlighting Key Study Areas

5 Road Safety Implications

5.1 Qualitative Analysis of Challenges Faced by Vulnerable Road Users

Across urban areas in Kinshasa, vulnerable road users such as pedestrians and motorcyclists face many challenges, which include aggressive driving and poor infrastructure. A qualitative analysis based on stakeholder interview data and observational evidence suggests that the absence of pedestrian crossings at intersections, poor functional road signs, and insufficient lighting expose these road users to greater danger, [12]. Pedestrians are often forced to cross busy roads without safe corridors, whereas motorcyclists have to jostle with other more oversized automobile edges, which increases their risk significantly [29]. Table 5 summarizes the key challenges identified by vulnerable road users based on qualitative data.

5.2 Exploration of the Impact of Poorly Maintained Roads and Potholes on Safety

The road security index in Kinshasa can be attributed to the condition of the road network. For instance,

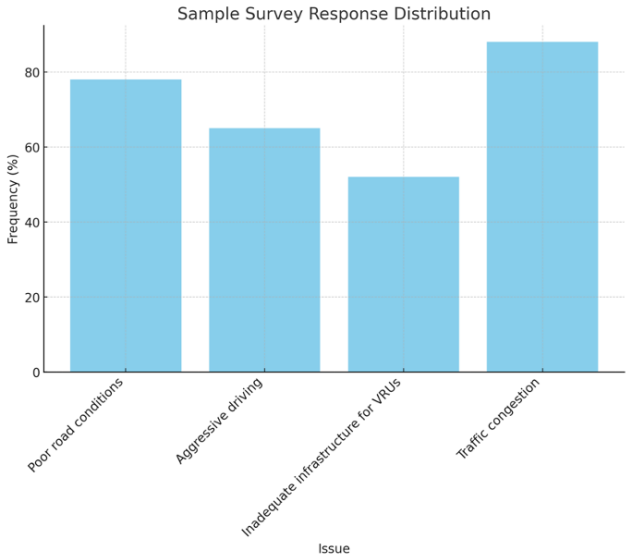

Figure 6: Sample Survey Response Distribution

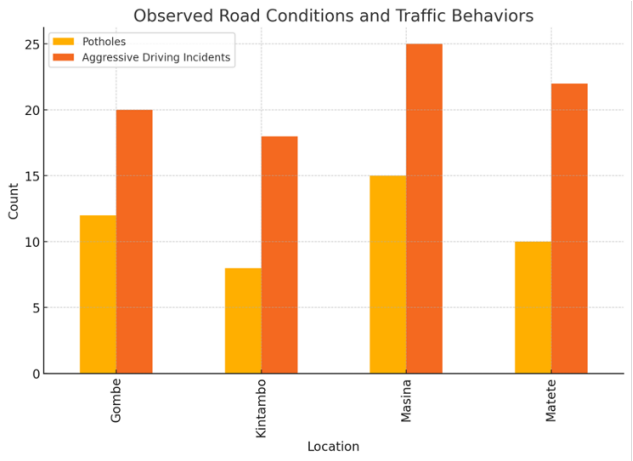

Figure 7: Observed Road Conditions and Traffic Behaviors

poorly constructed roads with a fair amount of potholes pose a risk to whatever category of foot users on the road. These potholes enable vehicles to swerve and cause unintended collisions with pedestrians and bikers, as a result, [6]. On top of that, the conditions of road infrastructure observed here can get worse, damaging the vehicle and paralyzing it much more, creating yet another layer and dimension of road hindrance and danger, [15].

The study, [30], shows a relationship between the number of severe potholes on the road and a more significant number of accidents. Krol, who conducted his research on schools, identified that road maintenance as a predictor of accident rate explained it well by stating that the more maintained a road is, the less prone it is to accidents, [31]. It also

Table 5: Key Challenges Identified by Vulnerable Road Users

Challenge	Description
Lack of Pedestrian Crossings	Pedestrians are often required to navigate congested roads without designated safe pathways, placing them at significant risk.
Inadequate Signage	Poor visibility or the complete absence of road signs leads to increased confusion and a higher likelihood of accidents.
Poor Lighting	Insufficient lighting conditions, particularly during nighttime, exacerbate the risks faced by road users, making navigation hazardous.

demonstrates the need for regular maintenance and quick improvements of roads to increase road security and environmental factors, reducing the dangers to other road users, [32]. Table 6 details the impact of various road conditions on overall safety.

Table 6: Impact of Road Conditions on Safety

Road Condition	Impact on Safety
Potholes	Increased vehicle damage, swerving, and accidents.
Poor Maintenance	Higher incidence of accidents and vehicle breakdowns.
Inadequate Drainage	Increased risk of accidents during rainy seasons.

5.3 Identification of Patterns and Trends in Aggressive Driving Behaviors

The city of Kinshasa is grappling with a variety of challenges related to road safety. Such challenges can be traced to reckless driving behaviors that include excessive speed, maneuvering in an inconsiderate manner, and failure to follow road signs and signals, [14]. Examination of the traffic observations and interviews of road users suggest that reckless driving is largely a result of intense traffic-related stress in most cases coupled with slight enforcement of the traffic regulations, [11]. These observations highlight a more significant structural problem where poor governance enables bad driving practices as the rule rather than the exception.

A recently conducted survey published in 2021, [33], established that such aggressive driving behaviors are, however, common among a quarter of the entire population of drivers reviewed. Survey

results also showed that many proxies viewed aggressiveness as a self-imposed time constraint. Hence, there is a need for better traffic management and enforcement direction, [2]. Figure 8 illustrates the incidence of aggressive driving behaviors observed in Kinshasa. This need to aggressively breach the persistent traffic quagmire is a revealing shortcoming of infrastructural inadequacy, providing no options to motorists. Table 7 outlines the patterns of aggressive driving behaviors identified in the study.

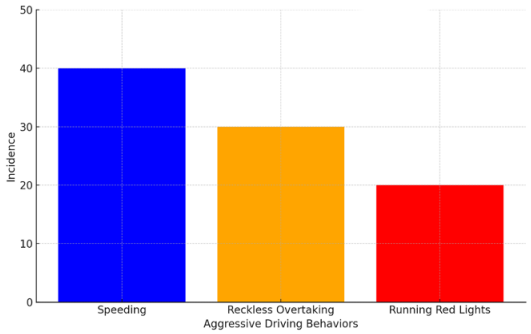

Figure 8: Incidence of Aggressive Driving Behaviors

Table 7: Patterns of Aggressive Driving Behaviors

Behavior	Description
Speeding	Exceeding speed limits, particularly in congested areas, thereby increasing the likelihood of collisions and endangering vulnerable road users.
Reckless Overtaking	Engaging in unsafe overtaking maneuvers on busy roads, often disregarding oncoming traffic and road safety conditions.
Ignoring Signals	Disregarding traffic control devices, such as traffic lights and stop signs, which contributes to chaotic traffic conditions and heightened accident risks.

6 System Dynamics in Road Safety

To tackle road safety issues in Kinshasa – a city on the move – in a more effective way entails abandoning traditional traffic management paradigms and embracing more multifaceted approaches. The complexity of studying road safety problems is well illustrated by the application of System Dynamics (SD), a valuable tool thanks to its complex applications. This section discusses the complexities of road safety, looking at the balancing and reinforcing loops that push the escalation of aggressive driving and cognitive perceptions of lacking road safety for the exposed users, [17].

6.1 Application of System Dynamics Principles

System Dynamics (SD) is an integrating and synthesizing methodological perspective utilized to examine complex systems' evolution over time. It is through these generic concepts of stocks, flows, feedback loops, and time delays that SD encompasses the temporal features embedded within road safety systems. In the specific context of Kinshasa, system dynamics explored how multiple aspects: driver, roads, administration, and education are integrated into affecting the overall road safety situation, [18].

6.1.1 Stocks and Flows in Road Safety

In the SD framework, stocks describe accumulations within the system, such as the number of aggressive drivers and the level of road accidents, while flows describe the rates of such stocks over time. Some aspects, such as enforcement level, road works, and public information campaigns, influence these flows, [19]. These stocks and flows help us understand the consequences of working on one portion of the system in terms of broader road safety processes in the context of the system.

Inadequate enforcement and bad road conditions, for instance, can cause the stock of aggressive drivers to go up. On the other hand, the flow of this stock can be controlled through the improvement of enforcement mechanisms or increased road maintenance, thereby lowering the levels of aggressive driving behavior. It is also essential in addressing the risk factors associated with road traffic management and safety policies in Kinshasa, [5]. Figure 9 illustrates the stocks and flows involved in the road safety system.

6.1.2 Feedback Loops and System Behavior

Feedback loops pertain to the principles governing System Dynamics by defining the cause-and-effect cycles within a given system. This can be elaborated by differentiating two main types of loops–reinforcing (positive) or balancing (negative) loops. By way of illustration, within the road safety issue in Kinshasa, the limited enforcement may aggravate drivers' aggressiveness, increasing the rate of accidents, which compromises road safety enforcement even further, [20]. On the contrary, much safer driving behaviors might result from more robust enforcement measures intended for aggressive driving in the first place, [11].

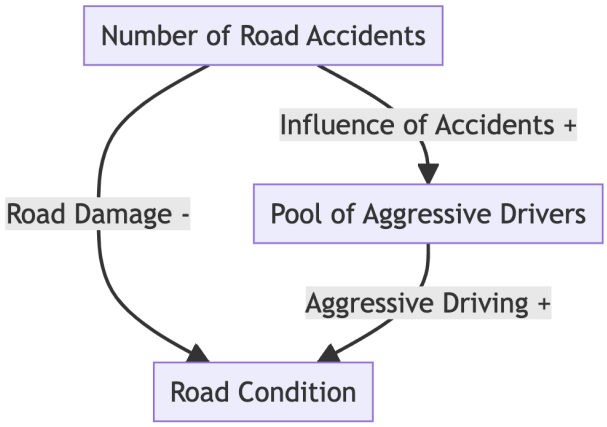

Figure 9: Stocks and Flows in Road Safety

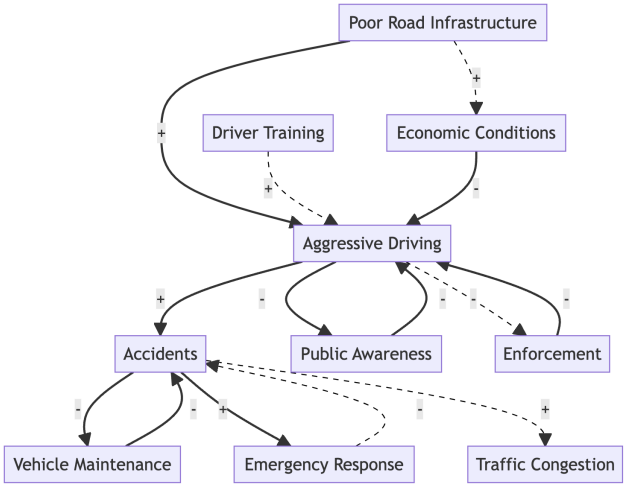

Figure 10: Detailed Causal Loop Diagram for Road Safety in Kinshasa

For example, a reinforcing feedback loop may commence with a deteriorating road surface, which increases drivers' irritation and ultimately leads to aggressive driving practices. Such practices raise the accident potential, which then causes even more roadway destruction, and indeed, there is a feedback loop of decreasing safety and quality of transportation systems, [34]. An example of a compensatory balancing loop might include strict enforcement of traffic management measures that discourage aggressive driving, reduce accidents, and slowly enhance road surfaces through time, [2].

6.2 Analysis of Feedback Loops and Causal Relationships

In order to get a deeper understanding of road safety behaviors and attitudes in Kinshasa, it is relevant to pinpoint and examine the underlying feedback loops and causal links that define the system. In many instances, these relations account for why some interventions to improve safety are successful while others do not appear to work, [22].

6.2.1 Causal Loop Diagrams

In system dynamics, CLDs are useful in communication and learning processes from graphical modeling perspectives. A focus of attention is the constructed causal loop diagram (CLD), which explains the various feedbacks in the Kinshasa case. This designated CLD specifies the system's configuration in Kinshasa wherein aggressive driving, enforcement, roads, and the public interact, [19]. Figure 10 illustrates the detailed causal loop diagram for road safety in Kinshasa.

6.2.2 Feedback Loop Examples

- **Reinforcing Loop (R1)**: The absence of good roads also leads to increased vehicle destructive behavior and driving troubles, which motivates aggressive driving since the desire is to complete the rough surfaces in the shortest time possible. This increases the rate of accidents, which leads to a depletion of road conditions and a continuation of the cause, [3].

- **Balancing Loop (B1)**: Stricter enforcement of traffic rules likely moderates aggressive driving tendencies by making aggressive driving prone to getting caught. Then, there will be fewer accidents, which will help protect the roads and foster higher levels of traffic compliance and, therefore, road safety [2].

Table 8 lists the key variables considered in the system dynamics model, and Table 9 describes the feedback loops identified in the model. Table 10 summarizes the impact of different road safety interventions.

Virtues rooted in reasoning are preserved in Society Dynamics through the understanding of road safety in Kinshasa. However, it emphasizes various aspects responsible for the city's existing traffic challenges. Focused on such structural feedback and causal linkage analysis, the practitioners can construct frameworks to achieve targets intended to constrain aggressive driving and improve the characteristics of the roads. It is particularly crucial in the context of fast-growing cities to consider such a systematic perspective when actively seeking measures to improve the safety and efficiency of road traffic, [4].

Table 8: Key Variables in the System Dynamics Model

Variable	Description
Traffic Density	The level of congestion on the roads.
Aggressive Driving	Frequency of Aggressive Driving Incidents.
Road Infrastructure Quality	Condition of the road network.
Accidents	Number of road accidents.
Traffic Enforcement	Effectiveness of Traffic Law Enforcement.
Road User Behavior	Compliance with Traffic Regulations.
Road Safety Awareness	Public awareness about road safety.

Table 9: Feedback Loop Descriptions

Feedback Loop	Description
Reinforcing Loop (R1)	Poor infrastructure → Aggressive driving → Accidents → Poor infrastructure.
Balancing Loop (B1)	Enhanced enforcement → Reduced aggressive driving → Fewer accidents → Better infrastructure.

7 Using Causal Loop Diagrams (CLDs) to Derive Stock and Flow Diagrams

Causal Loop Diagrams (CLDs) are illustrative and explanatory frameworks that can facilitate understanding the feedback aspects intrinsic to complex systems. Causal Loop Diagrams depict interrelationships between variables in a cause-effect fashion, enabling an analysis of the system to identify feedback loops that are called reinforcing (positive) and balancing (negative) loops, [17]. Nonetheless, more than the structure of causal loop diagrams (CLDs) alone, it is needed to illustrate the accumulations, or stocks, present in a system and the flows and processes that alter these stocks within CLDs. To improve comprehension of feedback mechanisms within the system, SFDs can be transformed into CLDs. This seeks to enhance the construction and coordination of system components over time through inter-system flows, thereby improving the comprehension of road safety system dynamics, [18].

Table 10: Impact of Road Safety Interventions

Intervention	Impact
Increased Enforcement	Reduces aggressive driving and accidents.
Improved Infrastructure	Enhances road safety and reduces vehicle damage.
Public Awareness Campaigns	Increases compliance with traffic laws.

7.1 Steps to Convert a CLD to an SFD

7.1.1 Identify the Stocks

Stocks represent quantities built up in the system and have people's efforts embedded in them—resources, populations, or any countable quantities that could increase or decrease. In the context of the road safety CLD, stocks could be, for example, the number of traffic accidents, the traffic level, or the quality measure of the roadway, [24].

7.1.2 Determine the Flows

Flows are any changes occurring in stocks that will either increase or decrease. Identifying such flows is necessary to comprehend the processes that bring about the accumulation or dissipation of the stocks in the system under study. In the road safety CLD, for example, the flow could be the frequency of accidents sustained during road usage or the rate at which the road structure worsens or is enhanced, [19].

7.1.3 Map Feedback Loops

Aspects of feedback embedded in the CLD must be converted to the different interactions between stocks and flows in the SFD. Positive feedback loops amplify change, whereas negative feedback loops tend to moderate change, [22].

7.1.4 Establish the Relationships

Establish the links between stocks and flows in mathematical terms or logic. This entails explaining the dependency of the rate of flow upon the other elements within the system, [18].

8 Case Study: Detailed Causal Loop Diagram for Road Safety in Kinshasa

The CLD in the figure illustrates various consequences for road safety in Kinshasa. Relevant ones include economic factors, road networks, driver education, vehicle servicing, road rage, road traffic accidents, road traffic, emergency assistance, law enforcement, and social awareness (Jennings et al., 2015). The Causal Loop Diagram (CLD) successfully illustrates such relationships targeting various aspects

of road safety in Kinshasa by depicting how a lack of good road infrastructures leads to aggressive drivers, causing more car accidents, thus increasing road unsafe conditions.

To start building a Stock and Flow Diagram (SFD), the dominating stocks and flows of this CLD ought to be determined first:

8.1 Stocks

- **Accidents**: Denotes the total number of road collisions that have occurred through time under the system and is a pertinent measure of road safety.
- **Traffic Congestion**: Reflects the extent to which network congestion is felt by road users and its effect on the behavior and mobility of road users.
- **Road Infrastructure**: Assets are denoted by the state and the characteristics of the physical intensity of road networks, which incorporates both physical degradation and maintenance.
- **Public Awareness**: Indicates the level of public awareness regarding road safety practices, influencing driver behavior and compliance.
- **Aggressive Driving Incidents**: Captures the frequency of aggressive driving behaviors exhibited by road users, significantly contributing to unsafe road conditions.

8.2 Flows

- **Rate of Accidents**: Driven by factors such as aggressive driving behaviors, inadequate road infrastructure, and driver education and enforcement deficiencies.
- **Rate of Traffic Congestion**: Influenced by the number of accidents, road capacity, and the quality of road infrastructure, which collectively determine the level of congestion.
- **Infrastructure Deterioration**: Affected by economic conditions, the intensity of road usage, and maintenance practices, leading to either improvement or decline in infrastructure quality.
- **Public Awareness Campaigns**: Shaped by initiatives from government authorities, enforcement agencies, and resource allocation towards educating the public on road safety.
- **Aggressive Driving Increase**: Influenced by poor road conditions, inadequate enforcement, and socio-economic pressures, resulting in a higher prevalence of risky driving behaviors.

8.3 Recommendations for Policy Changes, Infrastructure Improvements, and Driver Education

- **Policy Changes**: Implement stringent traffic regulations and enhance enforcement mechanisms to deter aggressive driving behavior and foster compliance and discipline among road users; there is a need to enhance the penalties for the violators and announce their activities through sociometric devices or advanced surveillance systems, [29].
- **Infrastructure Improvements**: Restoration and management of Typhorian roads are coupled with the sufficient installation of sign boards and improvement of light components in regions prone to accidents. Such infrastructural improvement is critical in enhancing road safety and minimizing accidents, [15].
- **Driver Education**: The driving force behind this campaign is that pedestrians, cyclists, and motorists should be educated to respect traffic regulations and understand the implications of reckless driving and the benefits that arise with order in the streets. Education is crucial for changing the perceptions and attitudes of drivers and other road users and building the road safety culture, [9].

9 Conclusion

This study closely examines the realities of aggressive driving, the deficiency of road infrastructure, and the countervailing positionalities of certain road users in Kinshasa. In so doing, the research aims to assist decision-makers, city planners, and road safety campaigners in identifying the problems and proposing the appropriate measures that may help improve road safety in developing urban areas. Road safety in Kinshasa's context can be adequate for other growing urban conurbations affected by densely populated urban site expansion. There is a need for changes in the structure of thinking with regards to the order of changes in the systems where enhancement of infrastructure, change of policies, and increasing level of information amongst the people on the changes – processes needing to be interlinked: to achieve safer road environments for all road users.

The research emphasizes the role of risky driving behaviors in combination with poorly built roads, which pose higher risks to pedestrians and cyclists. To resolve these overlapping dangers, the study proposes advancing fundamental traffic control measures, expanding the road system to accommodate all users safely, and promoting public

interest education campaigns focused on safety on the road.

In addition, the paper asserts that urban development should include road safety as an area of interest for urban planners, as road safety should be considered throughout road network planning, development, and expansion processes. Policymakers are also encouraged to put legislative frameworks in place to assist these safety measures, such as enhanced traffic violation penalties and safe, constrained driving programs.

The transformation of behaviors of road users, however, relies heavily on the education of the public aided by sustained campaigns. Such cultural changes, based on promoting sharing road space and exercising respect amongst all road users, would reduce road accidents and death over the long term. Infrastructure development complemented by policy support and an active Yellow Page population education program would be the best intervention mix for improving road safety in Kinshasa or other urban environments.

Last, the work brings out the multifaceted strategies to tackle the road safety problems in such developing cities, underscoring the fact that such roads are not just meant for individual use but instead, many people have a significant stake; hence, all arms of the society harnessing their efforts is required.

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