System Dynamics for a Holistic Management of Road Traffic Congestion – A Comprehensive Overview with Some Selected Simple Use-Cases related to the Town of Kinshasa

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Abstract: This paper examines how system dynamics can comprehensively understand road traffic congestion in developing cities, mainly focusing on Kinshasa. The research investigates the principles of system dynamics and emphasizes its efficacy in analyzing the interrelated factors contributing to congestion. A qualitative methodology examines traffic congestion in Kinshasa, focusing on the interconnections among factors such as inadequate road infrastructure, population expansion, urban planning deficiencies, and road users conduct. The system dynamics framework can include traffic system feedback loops and delays, which most methods ignore. Using real-world scenarios, this paper will demonstrate that system dynamics can diagnose chronic congestion in many urban transport systems. According to the analysis, poor road maintenance, inadequate public transport, and unsafe driving exacerbate congestion. Traffic congestion harms people, businesses, and society, as this paper examines its economic and social effects. The paper includes case studies showing how system dynamics was used to solve multifaceted problems. Different scenarios are prepared to evaluate the effectiveness of improving public transport and deploying other integrated traffic management approaches and essential infrastructure to reduce congestion. These multi-pronged strategies illustrate the transformation challenges urban planners must address to provide integrated and sustainable solutions. This work aids decision-makers and urban developers in integrating system dynamics to control road traffic congestion. The author believes cities should use adaptive models instead of linear ones, which is common in Kinshasa. This paper offers a systematic approach and descriptive methods for developing viable urban congestion and transportation solutions in similar socioeconomic environments.

Key-Words: System Dynamics, Urban Planning, Sustainable Development, Road Infrastructure.

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1 Introduction

Urban traffic congestion is an issue that most of the developing cities all around the world are facing. This is primarily because of the urban population increase concurrent with motorization, which puts much pressure on existing city transportation systems. Traffic congestion has terrible consequences, including increased vehicle emissions, increased travel times, and notable economic loss due to transport and time loss. Factors such as lack of infrastructure, rapid growth of cities, and ineffective traffic management can help substantially decrease traffic in developing countries, [1]. It is evident by the context of cities that understand congestion have a period formulating effective and long-lasting solutions. The reason for this is contingent upon understanding the relationship between constituents of urban traffic frameworks. Some existing models supplement the understanding of urban traffic systems, but they tend to fail; furthermore, they need more understanding of interdependence. There is potential within using system dynamics to assist in modeling systems with these interdependencies. System dynamics help emphasize qualitative aspects that allow for more accurate and effective congestion alleviation strategies rather than treating superficial issues alone, [2].

Kinshasa is an excellent example of the challenges most developing city regions encounter. Kinshasa, which has reached a population of over 15 million, is now one of the largest cities in Africa and is also a core economic region of the DRC. The urban population growth has been massive, and as such, the

pace at which infrastructure has been expanded has yet to keep up, leading to severe traffic congestion and its associated problems, [3]. Kinshasa, a Case for Investment, thus stresses the dire position of urban infrastructure in Kinshasa for effective, comprehensive urban planning and transport system improvements. A declining transport road network, lack of adequate public transport, and poor traffic management characterize traffic blueprints for Kinshasa. However, dealing with the issues facing Kinshasa has provided this study with direction and recommendations for other developing cities facing similar issues.

This research uses system dynamics as a methodological tool to analyze structurally the factors that afflict traffic congestion in Kinshasa. Previous studies have looked at various aspects of traffic management within developing circumstances. Munga and Kasongo, in their study of the dynamic management of traffic in Kinshasa, propose the use of Warning Limits and Inhibit Limits, which are important in predicting and alleviating congestion. Their study aims to address the need for everyday information and adaptive response methods appropriate to the conditions in the local area, [4]. The studies on traffic congestion in Nigeria greatly help from a comparative perspective. Popoola, Abiola, and Adeniji blame traffic congestion on the road network's limited capacity, the roads' underdeveloped condition, and the poor organization of traffic flow. The conclusions stress the need to resolve issues about the existing gaps in infrastructure provision and the restructuring of traffic management systems to tackle congestion, [5].

2 Literature Review

Urban traffic congestion presents a considerable challenge that impedes economic development, exacerbates environmental sustainability issues, and diminishes quality of life, particularly in developing urban areas. Various causative and consequential factors, as well as potential solutions to the issue of car congestion, have been examined through system dynamics modeling in numerous studies conducted in the past. System Dynamics (SD) enables traffic congestion analysis, facilitating improved policy decisions by modeling systems that incorporate time dependence and feedback loops.

2.1 Discuss relevant studies on congestion dynamics in developing cities and the importance of qualitative insights

New cities face numerous traffic-related challenges, such as rapid urbanization, inadequate infrastructure, and a need for more funding for effective urban planning and management. The study "Traffic Congestion on Highways in Nigeria: Causes, Effects and Remedies" identifies key factors contributing to congestion, including inadequate road capacity, substandard road conditions, and ineffective traffic management, [1]. Furthermore, socioeconomic factors, particularly societal growth and urban expansion, contribute to increased competition for road space. The study' Flood Impacts on Urban Transit and Accessibility: A Case Study of Kinshasa' demonstrates the significant role of environmental factors in exacerbating traffic congestion. Inadequate drainage systems and substandard road construction impede efficient urban transportation and obstruct effective traffic management. These studies underscore the importance of comprehensive physical and environmental strategies to mitigate traffic congestion (Table 1).

Table 1. Causes of Traffic Congestion in Kinshasa, [3]

Causes	Percentage
Poor road conditions or lack of roads	43%
Bad driving habits	20%
Police officers	9%
Mismanagement of priorities	6%
Lack of pedestrian crossing	4%
Religious events	4%
High number of taxis and buses	4%
Accidents	2%
Arbitrary parking on public roads	2%
Broken down vehicles on the road	2%
Incomprehension between drivers	2%
Motorcycles	1%
Misuse of sirens	1%
Untrained drivers on the road	1%
Unknown reasons – We come out of traffic jams without knowing the cause	1%
Violation of highway code	0%

Numerous studies have examined traffic congestion in various Nigerian cities. A GIS assessment conducted in Akure identified key factors contributing to congestion in the area, notably the rapid increase in motorization rates, insufficient advancements in the transport system, and illegal roadside parking practices. The analysis indicated the

need for an advanced TIS to monitor road congestion and collect essential data, [6]. Factors such as population growth and urban development exacerbate these challenges by increasing the demand for road space. Table 2 provides an additional illustration.

The residential estates surrounding Abuja, located near state offices, experienced significant congestion during peak hours, particularly at 8 am and 6 pm rush hour, [7]. Traffic flow in Lagos, especially on Mondays, must be clearer of parked taxis, potholes, and the unpredictable presence of buses, [8].

Table 2. Causes of Traffic Congestion on Highways in Nigeria, [1]

S/N	Causes	n1	n2	n3	n4	N	R.I.I	Rank
1	Poor driving habit	106	114	43	12	275	0.785455	6
2	Poor road pavement	119	115	36	9	279	0.808244	2
3	On-going construction activities	61	107	82	26	276	0.683877	16
4	Poor road network	102	121	40	13	276	0.782609	7
5	Inadequate road capacity	123	114	28	11	276	0.816123	1
6	Poor parking habit	105	112	51	10	278	0.780576	8
7	Lack of parking facilities	83	103	66	24	276	0.72192	15
8	Lack of road furniture	85	105	67	22	279	0.726703	14
9	Too many taxis/buses	67	66	105	44	282	0.638298	19
10	Poor traffic control management	120	93	43	16	272	0.79136	4
11	Poor drainage system	117	94	61	6	278	0.789568	5
12	Presence of heavy trucks	102	92	67	13	273	0.758212	12
13	Excessive speeding	64	81	93	33	271	0.662362	18
14	Poor design junctions/round-about	109	99	59	14	281	0.769573	11
15	Frequent use of sirens	22	54	130	60	266	0.535714	24
16	Lack of effective mass transit	51	84	91	46	272	0.628676	20
17	Malfunctioning vehicle	65	93	76	41	275	0.665455	17
18	Poor weather	41	58	118	45	262	0.590649	22
19	Religious/special event along the road	110	108	32	26	276	0.773551	10
20	Work zone	40	81	113	40	274	0.610401	21
21	Slow driving	43	64	101	62	270	0.581481	23
22	Accidents on the road	113	131	10	27	281	0.793594	3
23	Lack of pedestrian facilities	92	99	63	20	274	0.739964	13
24	Lack of overhead bridges/fly-overs	120	88	49	21	278	0.776079	9

2.2 Provide an overview of existing literature on road traffic congestion and System Dynamics modeling

Both a coherent and structured understanding of urban complex systems such as traffic congestion can be modeled using System Dynamics (SD) modeling. Feedback loops and delays that complement each other over time are what System Dynamics (SD) models resort to in order to showcase the relationships that exist within a given system or model. This kind of mechanism enables constructive analysis of different models' interrelations or interventions and their effects in the foreseeable period.

The study "Dynamic Management of Traffic Congestion – Case Study in Developing Countries" offers proof of the feasibility of the system dynamics modeling in Kinshasa. Congestion in Kinshasa has been predicted and managed through the use of models that combine Warning Limit (WL) and Inhibit Limit (IL) indicators, which the authors present, [3]. The SD model benefits policymakers in terms of development planning as they integrate and connect other pioneering solutions and local conditions specific to traffic problems.

The problem of traffic congestion in developing cities has been studied from the perspective of its spatial organization with a particular focus on the necessary qualitative information needed to get to the core of the problem. The "Democratic Republic of Congo Urbanization Review" reviews urbanization patterns and their consequences for transport in Kinshasa. Amongst other things, the review of (in particular emphasizing) physical planning for urban centers and an adequate provision for mass transit systems are crucial in reducing congestion, [4].

The "Urban Transport Master Plan's Project in Kinshasa City" aims to enhance urban movement in Kinshasa in a more organized way. The enhancement plans include providing more road space, constructing depots, and providing advanced traffic control systems, [5]. The research shows that traffic congestion can best be tackled through a combination of infrastructural growth, policies and plans, and behavior change strategies.

The major developmental frameworks and approaches used in the study of the failure of the urban transportation system are varied and diverse due to the heterogeneity of urban areas. The implicit and explicit feedback loops and nonlinear interrelationships, which are characteristics of urban traffic systems, are related and analyzed through System Dynamics modeling.

Research goes beyond a single methodology and employs qualitative and quantitative approaches to analyze traffic congestion. Qualitative approaches involve looking at interviews/surveys and enable a better understanding of the population's behavior and socioeconomic relations. The work entitled "Traffic Congestion on Highways in Nigeria: Causes, Effects and Remedies" employed structured questionnaires to collect primary data through road users' chauffeurs, patronizers, and traffic officers. From the study results, the role of bad driver behavior and ignorance of the masses in traffic issues is worthwhile in combating traffic congestion, [1].

Quantitative models use relationships between traffic data and various parameters in the frame of statistical and mathematical models to yield traffic simulations. Furthermore, integrating qualitative aspects into quantitative analysis frameworks improves the precision and contextual understanding; thus, the problem itself is better assessed.

2.3 Review theoretical frameworks and methodologies used in analyzing urban transportation systems

Traffic engineering problems and their corresponding solutions aimed at curtailing the volume of bottlenecks may be identified through pre-existing material, surveys, and data collection. One common rush hour problem in all cities of the world is slow traffic movement during peak hours, and various reasons lead to slow traffic movement all across the globe. The primary issues in Pakistan and India were governmental inaction and insufficient decision-making processes, [9]. According to research in Peru, the primary factor was the low number of public transportation users considering using private vehicles as a general norm, [10]. Moreover, in Nigeria, a lack of road networks was pointed out as another significant factor, [1], [11]. People in central London rely too much on cars, which explains why cross-traffic jams are frequent even with buoys of several constant features, then freeze traffic loading on cars as one melee branch, [11].

This connotation can also mean that the coordination of basic plans to control congestion in a region should not be based on a single, careful plan designed to cover all regions. System Dynamics Models (SDM) and Casual Loop Diagrams (CLD) approaches are very effective in understanding and analyzing urban traffic systems' dynamic behavior. The approach generally combines variables such as the volume of vehicles, road capacity, traffic flow and vehicles, driver behavior, and even feedback systems depicting the relationships of the variables. By effectively simulating various scenarios, system dynamics models help predict specific traffic control schemes' long-term impacts while revealing important factors that would enable constructive action.

The study **Dynamic Management of Traffic Congestion: A Case Study In Developing Countries** shows cases of application of system dynamics modeling in traffic management. The authors make a model using Warning Limit (WL) and Inhibit Limit (IL) indicators to predict and manage traffic congestion in real-time. The model's efficacy is in the case studies conducted in Kinshasa with a view of even broader applicability in other urban centers such as [3].

Real-time dynamic approaches encompass the measurement, detection, communication, information transfer, and information control to predict and reduce traffic congestion, [12]. These features of these methods include the application of technology and artificial intelligence to enhance responsiveness and adaptability. The literature concerning dynamic traffic assignments brings forth the drawbacks of static techniques and the benefits of using some contemporary techniques of real-time data utilization, [13].

Reasonably, several research studies have confirmed the efficacy of sensor-based technologies in predicting and controlling traffic congestion. Machine learning models relying on sound sensors have been installed to monitor traffic congestion by actively scanning sounds made by moving vehicles, [14]. Another specific study examined the issue of possible AI applications for estimating traffic congestion, including the advantages and disadvantages of different models, [15].

The current state of research devoted to traffic congestion and System Dynamics modeling contains a good deal of relevant knowledge about the problems of urban transport management, especially in the context of developing countries. Their combination of qualitative and quantitative approaches allows specialists to elaborate robust models encompassing key aspects and feedback loops relative to the contributing factors of traffic congestion. The investigation of this category emphasizes the significance of a multi-target approach, which includes investment in infrastructure, policy measures, and changes in behavior to address traffic congestion effectively.

3 Methodology

3.1 System Dynamics Approach and Its Suitability for Modeling Complex Urban Systems

The main objective of this research is to emphasize the importance of using policy design frameworks based on the principles of systems dynamics and the problems of decision-making in social planning. Aspects of System Dynamics are particularly pertinent and recommended in planning scenarios that tend to fall within the domains of wicked problems- largely unstructured, complex, poorly understood, and have many and often conflicting decision criteria or goals, [16]. In combining these two schools of thought, practitioners of the discipline will be forced to take a more holistic and holistic perspective of the issues under consideration. Formulating public policies based on SD principles may assist in better decision-making regarding urban sustainability policies that many scientists highlight. In its place, society becomes the principal actor. System Dynamics (SD) models foster the ability to simulate different scenarios, thereby providing urban planners or policymakers with tools to consider the future consequences of their

policies and decisions, [17]. In the context of SD in urban traffic management, the model traffic volume, road network, and public transport are interlinked, thus aiding in understanding how changes in one component can have widespread effects on the whole system.

3.2 Developing a Qualitative Understanding of Road Traffic Congestion in Kinshasa

The study used a literature review, interviews with relevant actors, field visits, and data collection as part of the road traffic congestion in Kinshasa. The approach aimed to analyze the complex factors influencing congestion change in a rapidly growing city experiencing severe infrastructure problems.

3.2.1 Literature Review

The literature review focused on the issue of traffic congestion in developing countries and cities, including Kinshasa. This review aims to identify the common factors contributing to congestion, evaluate the effectiveness of various approaches for congestion relief, and highlight existing information gaps, [1], [4]. The results offer insights that establish a fundamental understanding and conceptual framework for analyzing the contextual issues arising from traffic situations in Kinshasa.

3.2.2 Stakeholder Interviews

In Kinshasa, the researchers conducted semi-structured interviews with several stakeholders, including government officials, transport authorities, public transport operators, and ordinary residents. The interviews rendered crucial qualitative information regarding causative perceptions of traffic jams, reasons for the infrastructural and regulatory gaps, and mitigating alternatives. The information collected through these interviews helped explain traffic situations and the economic characteristics of the people of Kinshasa Traffic.

3.2.3 Field Observations

The real-time observation was also made at key traffic hotspots in Kinshasa to understand peak congestion patterns and evaluate drivers behaviors. The direct observations were essential and included the search for chronic problems such as chronic constraints, nonoptimal timing of traffic signals, and other effects of informal transport services. The primary data was critical in pinpointing the reasons behind the operational deficiencies that increase congestion, [4].

3.2.4 Data Collection

A detailed data collection plan was developed using manual vehicle counts, video recordings, and existing traffic control systems. This approach resulted in a complete set of data with the computed vehicle counts, average rates, average times spent on travel for congestion, and even distribution on the days of a week. The derived empirical data formed the basis of the SD model, from which simulation validation and calibration were performed, [1].

3.2.5 Qualitative Analysis

Stakeholder interviews and field observations formed the basis of theme analysis for the qualitative data collected. The approach was to identify recurrent themes and noteworthy patterns to deepen the understanding of the causes of traffic congestion in Kinshasa. These insights guided the formulation of the SD model, especially those regarding identifying critical variables and configuring feedback loops representing the dynamic nature of the system, [3].

3.3 Data Collection Methods, Stakeholder Engagement Processes, and Model Development Procedures

3.3.1 Data Collection Methods

- **Manual Counting**: Traffic volumes were systematically recorded at essential intersections and significant road segments during peak and off-peak periods. In this respect, it helped to evaluate the traffic volume in the specified locations, which helped pinpoint congested areas and allowed for the adjustment of traffic models.
- **Video Recording**: At critical traffic intersections, cameras were placed strategically to record vehicle movement continuously. After that, the video footage was examined to evaluate movement patterns, vehicle composition, and traffic density. This approach thoroughly understood traffic patterns, emphasizing problems such as unauthorized parking and pedestrian obstructions.
- **Traffic Monitoring Systems**: Monitoring systems such as inductive loop sensors and GPS data from public transportation fleets were integrated to remove the bias created by manual counts and video recordings. By incorporating this modern data into the evaluation, the precision of the traffic dynamics analysis was heightened.

3.3.2 Stakeholder Engagement Processes

- **Interviews and Focus Groups**: Various key stakeholders, such as policymakers, transportation planners, community representatives, and public transportation operators, were involved in the focus groups and interviews. The aim of conducting such

sessions was to collect detailed information about the problems faced in traffic management, the interventions that are perceived to have been effective in traffic management, and what interventions can be put in place to enable possible development. The qualitative data obtained were essential for understanding the broader socio-political context influencing traffic dynamics in Kinshasa.

- **Public Surveys**: Surveys were sent to a wide range of road users, such as drivers, pedestrians, and people who take public transportation to work, to find out what they thought about traffic congestion and how they experienced it. The surveys gathered much information about people's complaints and hopes for improving city traffic and mobility.

- **Workshops and Seminars**: Workshops were set up to share the first results and get feedback from people who mattered. These workshops also allowed people to share what they knew, which helped everyone understand SD modeling and how it can be used in traffic management. This participation was essential for reaching a consensus on possible solutions and encouraging teamwork to reduce traffic.

3.3.3 Model Development Procedures

- **Causal Loop Diagrams (CLDs)**: Causal Loop Diagrams were used to see how the feedback loops and dependencies work in Kinshasa's traffic system. They helped us figure out the important system variables and how they related to each other, which is what the "Figure 1" shows. Using the CLDs, it was easier to understand the changing cause-and-effect mechanisms that have a bearing on traffic build-up. This also contributed to refining specific intervention strategies.

  Figure 1: This figure presents a conceptual diagram illustrating the System Dynamics model for traffic congestion in Kinshasa. It includes essential components such as road infrastructure, vehicle flow, traffic signals, and feedback loops capturing driver behavior and policy interventions.

- **Stock and Flow Diagrams**: Stock and flow diagrams were made to figure out how to measure the critical factors and show how the traffic system changes over time. These pictures show significant stocks, like the number of vehicles and flows and the rates at which traffic comes in and goes out. See "Figure 2" for an example.

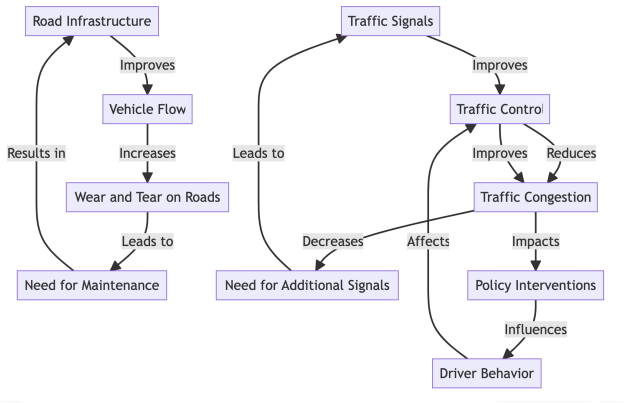

Figure 1: Simplified Causal Loop Diagram for Traffic Congestion in Kinshasa

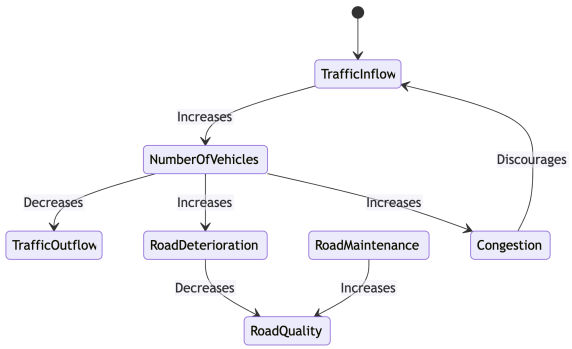

Figure 2: Simplified Stock and Flow Diagram for Traffic System in Kinshasa

- **Simulation and Validation**: Specialized software simulated the model and looked into possible outcomes. The simulation results were checked against real-world traffic data to ensure accuracy and reliability. Changes were made repeatedly during the validation process, considering stakeholder feedback and adding more data as needed.

4 Contextualizing Kinshasa

4.1 Background Information on Kinshasa's Urbanization, Population Growth, and Transportation Infrastructure

With more than 15 million people, Kinshasa, the capital of the Democratic Republic of the Congo (DRC), is one of the most crowded cities in Africa. Rapid urbanization in the city has been caused by both natural population growth and large numbers of people moving from the countryside to the city. This has made urban planning and infrastructure provision very difficult. Kinshasa is an excellent example of the

problems and problems with systems that come with a city overgrowing. It has a lot of sprawling informal settlements and needs more infrastructure and more public services.

The transportation system in the city hasn't changed as fast as its population has grown. The current road demand is too high, and many are in bad shape because they haven't been maintained in years. Private cars, minibuses (which people in Kinshasa call "taxibuses"), motorcycles, and bicycles are the main ways to get around town. Due to the lack of public transport, people are compelled to use private transport, which is often unofficial. Urban planners must reduce traffic congestion by developing alternatives to private transport, particularly by designing robust, comprehensive, and well-integrated urban public transport systems, [4].

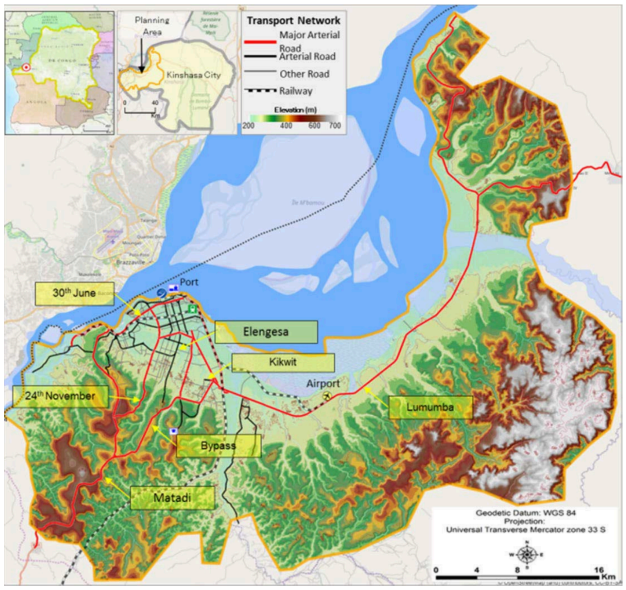

Figure 3: Transportation Network in Kinshasa, [5]

4.2 Unique Characteristics of Kinshasa's Traffic Patterns

Several interrelated but distinct elements affect Kinshasa's traffic pattern. The volume of vehicles on the road has been on the rise, even though fewer people own cars compared to other metropolitan areas, and this has exacerbated traffic problems at the city level. Even though many people travel using public transport or other non-motorized means, the increasing number of automobiles has worsened the traffic problem, [3].

With all the potholes, broken drainage systems, and missing road signs, Kinshasa has a long way to go in reconstructing its roads. Such infrastructural deficiencies create traffic snarl-ups, increasing the risk of collisions and vehicle damage. Worse, unofficial transport providers like minibus taxis and motorcycle taxis are often forced to comply with the law, making the traffic mix more volatile and dangerous, [2].

Several gaps in the planning and control of the public transportation systems in Kinshasa need to be improved, as illustrated in Figure 3. The public transport fleet comprises overcrowded, poorly serviced minibusses that need to follow the route and schedule. This increases the traffic congestion as more and more workers use private or semi-private means to reach their places of work. In addition to this, there needs to be adequate pedestrian infrastructure, such as pedestrian crossings and walkers. This makes it dangerous for pedestrians to move around and adds to traffic problems because they have to share the road with cars, [4].

4.3 Key Challenges and Factors Contributing to Road Traffic Congestion

A multitude of interrelated challenges drives the road traffic congestion in Kinshasa:

- **Inadequate Road Infrastructure**: Kinshasa's road network is still not very good and has been ignored for a long time. The current roads aren't designed to handle the amount of traffic, so there are often traffic jams, especially during rush hours. Lack of proper maintenance worsens the traffic problem by creating many traffic jams throughout the city, [1].
- **Rapid Population Growth**: The rapid population growth that the country has been experiencing, along with the continuing flow of migrants into Kinshasa, has been the barrier to slowing down the pace of infrastructure construction, increasing the city's density. The quick increase in the population of cities also puts enormous pressure on the existing congested networks, which causes severe and widespread problems of traffic jams, [4].
- **Informal and Unregulated Transport Sector**: The informal transportation sector, primarily made up of motorbikes and minibus taxis, is subject to very little regulation. However, because there is less oversight in this area, there is more law-breaking, which raises the number of accidents and traffic. Their erratic movements further exacerbate the chaotic nature of traffic congestion, [2].

- **Lack of Public Transportation**: Due to the absence of a reliable public transport system, several people are compelled to use their private vehicles or untaxed modes of transport. This reliance increases the vehicle count on the road, which worsens the city's traffic situation. Essential public transportation system minimization impairs the movement of many residents, thus worsening the socioeconomic divide, [4].
- **Poor Traffic Management**: The traffic control situation in Kinshasa needs improvement. The essential infrastructure for traffic management, such as traffic lights, appropriate signage, etc., must be improved, and traffic regulations must be enforced. Because these measures aren't good enough, traffic flows are disorganized and hard to predict, often leading to severe traffic jams, especially in areas with many people, [3].
- **Economic and Social Factors**: The government can't invest in significant infrastructure improvements because it doesn't have enough money. Also, social issues like a cultural preference for owning a private car and opposition to making the informal transportation sector official are big problems that make it hard to use effective strategies to reduce traffic. These economic and social factors make it hard for the city to improve traffic conditions over time, [4].

5 Qualitative Insights and Stakeholder Perspectives

5.1 Findings from Qualitative Data Analysis

Interviews, surveys, and expert consultations with people involved in Kinshasa's transportation ecosystem were used to collect and analyze the qualitative data. The information gathered from these interactions helps us learn more about the real-life experiences of people who use roads, the points of view of people who run transportation systems, and the systemic problems that city planners and policymakers have to deal with. The results show that traffic jams are a big problem affecting daily life and the economy. As shown in Table 3, most of the people who answered have been stuck in traffic, and many spend more than three hours a day stuck in traffic. This information clarifies the importance of having reasonable traffic management solutions right away, [3].

The polls pointed out certain days when traffic is especially bad, like Mondays and Saturdays when people drive to and from work and there are religious events. Poor road conditions, not following traffic rules, and insufficient public transportation options are some of the main reasons for so much traffic.

Table 3. Overview of Time Spent in Traffic Congestion

Time Spent	Percentage of Respondents
Less than 1 hour	59%
1-2 hours	20%
2-3 hours	8%
More than 3 hours	13%

5.2 Stakeholder Perspectives on Congestion Issues

Stakeholders, such as government officials, transportation authorities, public transit operators, and residents, had a range of opinions on the problems caused by traffic. They think the main reasons for traffic jams are the bad condition of the roads and the crazy way people drive in the city. Many people rely on their cars because there isn't a reliable public transportation system, [2]. This makes traffic worse.

Stakeholders have suggested that some possible solutions are to improve the infrastructure of roads, make traffic laws stricter, and add more public transportation options. Everyone agrees that much money must be spent on maintaining roads and improving public transportation to reduce traffic, [4].

5.3 Common Themes, Feedback Loops, and Causal Relationships

Some of the main ideas from the qualitative research are that roads need to be better maintained and traffic laws need to be strictly followed. One of the identified feedback loops is the link between the state of the roads and how people drive. Bad roads make people drive more erratically, which makes traffic worse. Another feedback loop involves public transportation. When there aren't enough options for public transportation, more people use their cars, which makes the roads even more crowded, [1].

The analysis also showed that there were causal links. For instance, the lack of infrastructure for pedestrians causes problems between pedestrians and cars, which slows down traffic. In the same way, not having enough traffic lights and not having enough maintenance on them means that traffic flows freely, which often leads to traffic jams.

6 System Dynamics Model Development

6.1 Translating Qualitative Insights into a System Dynamics Model

The SD modeling technique allows a qualitative representation of the system to be transformed into a quantitative system that shows the dynamics and interactions of its components. The first step in addressing this task is to define the key assumptions and their interdependencies through literature, experts, and personal experience. The aim is to construct a CLD that depicts the cause-and-effect relationships and the feedback loops regarding traffic congestion. Engaging with the stakeholders, conducting surveys, and reviewing plenty of literature on driving behavior, road situation, and road policy management have all informed these rich snapshots, [1].

6.2 Construction of Causal Loop Diagrams and Stock-Flow Diagrams

The CLD diagram, which depicts the causal factors associated with traffic congestion, must be drawn to develop the SD model. From Figure 4, it can be seen that higher traffic volumes lead to deterioration in congestion, the impact of which is a decreased flow of traffic and increased travel time. The positive and negative feedback loops that govern the system's dynamics over time are brought out in these pictures, [3].

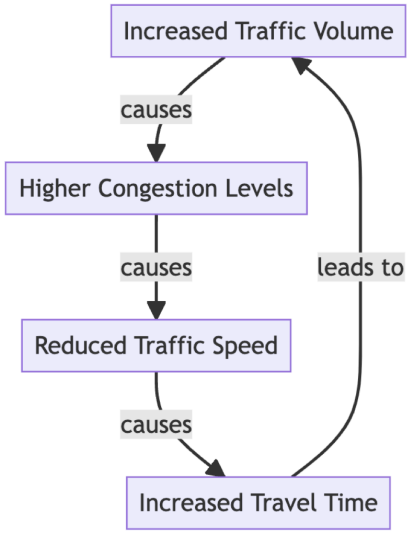

Figure 4: Causal Loop Diagram for Traffic Congestion Dynamics

A stock-flow diagram (SFD), which displays information in greater detail and with more figures, is developed from the CLD. Stocks, accumulations (such as the number of cars on the road), flows (such as the number of cars coming and going), and auxiliary variables (which influence these flows) are all included in SFDs. In traffic congestion, stocks could refer to the quantity of vehicles on a particular road segment. In contrast, flows would refer to the velocity vehicles enter or exit this segment, [2].

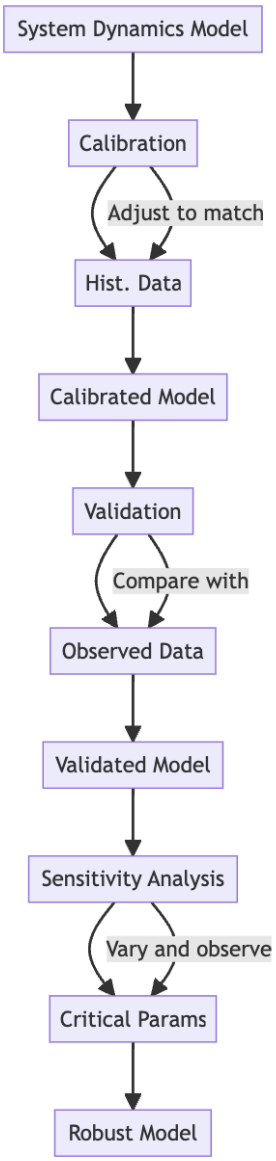

Figure 5: Validation of System Dynamics Model for Traffic Congestion

6.3 Model Calibration, Validation, and Sensitivity Analysis

The SD model is confirmed to be reliable and robust by the existence of the calibration, validation,

and sensitivity analysis. This ensures that the model replicates the actual system accurately. It guarantees that the model is capable of yielding correct results. For example, in Figure 5, an attempt at model validation is carried out. Other model testing techniques include the traffic and congestion prediction level and the model's verification, [4].

A sensitivity analysis examines the model's response to changes in key parameters. The analysis identifies parameters that strongly influence the model's behavior by systematically varying them and observing the changes in the model outputs. This activity is also concerned with preparing for the possible effects of various traffic management measures and constructing effective strategies under these conditions, [5].

7 Analysis of Congestion Dynamics

7.1 Present Results from the System Dynamics Model Simulations Under Different Scenarios

The System Dynamics (SD) model was employed within multiple scenarios to simulate traffic conditions in Kinshasa and analyze how the various factors affected movement within the area. These scenarios involved changing the level of traffic, improving the existing facilities, and employing various traffic management techniques. These results proved that increasing traffic volume tends to worsen congestion, causing longer time spent in traffic and slower traffic speeds. Nonetheless, it has been proved that well-planned road infrastructure, good traffic flow management, and control measures, such as simultaneous well-functioning computerized traffic systems, can reduce traffic bottlenecks and facilitate easier movements.

7.2 Identify Key Drivers of Congestion, Critical Feedback Loops, and System Behavior Patterns

The simulations found several significant causes of Kinshasa's traffic:

- **Traffic Volume**: It was primarily the high traffic volume that caused congestion, which supports the findings of related studies done in Nigeria, [1].
- **Road Conditions**: Poor road conditions and insufficient road capacity contributed significantly to congestion.
- **Traffic Management**: Ineffective traffic management practices were critical factors, such as inadequate traffic signal timings and lack of real-time traffic information.

Critical feedback loops identified include:

- **Reinforcing Loop**: Increased traffic volume leads to higher congestion levels, reducing traffic speeds and increasing travel times, contributing to further increases in traffic volume.
- **Balancing Loop**: Implementation of infrastructure improvements and effective traffic management can counteract the reinforcing loop by reducing congestion levels and improving traffic flow, as shown in "Figure 6."

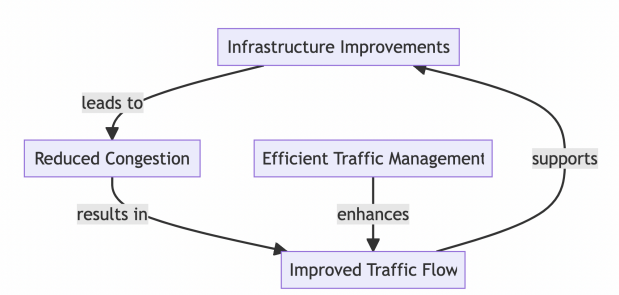

Figure 6: Balancing Loop in Traffic Congestion Dynamics

System behavior patterns observed include:

- **Peak Hour Congestion**: Significant congestion during peak hours, with traffic speeds dropping drastically.
- **Non-Linear Responses**: Small infrastructure or traffic management improvements can lead to substantial congestion reductions due to the system's non-linear nature.

7.3 Discuss Implications of Model Findings for Understanding Congestion Dynamics in Kinshasa

The results of the SD model are significant for understanding and dealing with traffic in Kinshasa. "Figure7" shows that finding the key drivers and feedback loops helps us fully understand the problems that cause traffic jams. This knowledge can help people develop targeted solutions to reduce traffic.

Putting infrastructure improvements in key areas at the top of the list and using intelligent traffic management systems are two ways to reduce traffic jams, [5], greatly. Policies that try to lower the amount of traffic, like encouraging people to use public transportation and limiting car use during rush hours, can also help manage congestion, [3].

In addition, the model's simulations emphasized the importance of traffic control as it considers the

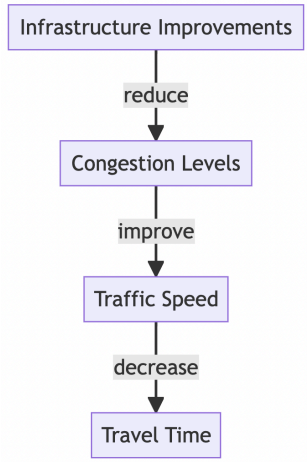

Figure 7: Impact of Infrastructure Improvements on Congestion

interrelation between different parts of the whole. Such a thinking pattern may lead to finding better and more sustainable solutions to the traffic problems of Kinshasa and similar cities, [2].

8 Policy Implications and Recommendations

8.1 Policy Interventions and Strategies Informed by System Dynamics Modeling Insights

System dynamics modeling makes understanding and dealing with the complicated problem of traffic jams easier. This method lets policymakers simulate different situations and guess what will happen with different actions, which helps them make smart choices. System dynamics can show how changes in traffic flow, the number of vehicles, and the availability of public transit all work together over time to affect congestion levels.

8.2 Recommendations for Mitigating Road Traffic Congestion in Kinshasa

8.2.1 Infrastructure Investments

- **Road Expansion and Maintenance:** To ease traffic, smart investments in expanding the current road network and ensuring that existing infrastructure is regularly maintained are essential. Increasing the capacity of roads helps them handle more traffic, and keeping them in good shape prevents traffic jams that happen when roads get worn down. There is evidence that saying that improving infrastructure is important for reducing traffic is true, [18].

- **Advanced Traffic Management Systems:** Using advanced traffic management technologies, like adaptive traffic signals and real-time traffic monitoring, can improve traffic flow and reduce delays. These systems use data-driven insights to change signal timings and handle traffic incidents on the fly, which improves traffic conditions overall, [19].

8.2.2 Public Transit Improvements

- **Development of Efficient Mass Transit Systems:** Building a reliable and effective mass transit system with buses and light rail is necessary to reduce the number of private cars on the road. Public transportation can help reduce traffic and improve mobility by giving people an affordable and useful alternative to driving their cars, [20].

- **Integration of Multi-Modal Transport:** Promoting smooth transitions between different types of transportation, like buses, trains, and bikes, can improve public transit and get more people to use it instead of their cars. Coordinated schedules, unified ticketing systems, and well-designed transit hubs that make switching between modes easier can help make this happen, [21].

8.2.3 Demand Management Measures

- **Congestion Pricing:** Putting congestion pricing in cities with much traffic can make people less likely to drive their cars during rush hours, lowering overall traffic volume. Many cities have used this method successfully, leading to big traffic drops, [22].

- **Promotion of Active Transport:** Creating infrastructure friendly to pedestrians and bike lanes can help reduce the need for motorized vehicles by promoting active transportation modes like walking and cycling. In addition to making traffic less of a problem, active transportation is good for public health and the environment, [23].

8.3 Potential Challenges and Trade-offs

Some things could be improved by putting these strategies into action in Kinshasa. Infrastructure projects take a lot of time and money and need support from politicians and the public. Getting people to agree with changes like congestion pricing and transit systems can be challenging because people who are used to how things are done may be annoyed or unwilling to accept the new ways of doing things, [8].

There are also notable trade-offs, such as weighing short-term cost issues against long-term gains. Unintended consequences, such as urban sprawl

caused by infrastructure improvements, could outweigh the benefits of reducing congestion in central areas, [24].

Kinshasa is in a position to devise plans to help manage the pressure on road networks and enhance mobility and sustainability within the city's transport system by undertaking these challenges and utilizing the experience it acquires through system dynamics modeling.

9 Conclusion

This research suggests that Kinshasa traffic jams can be better understood and managed with the assistance of System Dynamics (SD). The interrelated nature of congestion problems is manifested when examining a combination of factors such as road infrastructure, urbanization, and driving behavior. The SD method outlines important feedback loops, explaining the increasing congestion and suggesting efficient measures for relieving traffic stress, such as improving public transport and introducing new traffic management technologies.

Real-time in-person interaction with the people, such as stakeholders, and their first-hand observation act as crucial contextual information, which improves the model, thereby allowing the development of more appropriate and practical solutions. The research findings propose that effective charging policies be instituted, adequate public transport be implemented, and proper investment be channeled to road infrastructure.

This research does raise issues such as getting early commitment to support new ideas and limited funds. However, it stresses the importance of using a complete strategy to reduce traffic. By looking at the economic and social aspects of traffic management, Kinshasa can progress toward creating a long-lasting and effective system for moving around the city. This study aims to help policymakers and urban planners develop long-term solutions to traffic problems in Kinshasa by moving away from static, linear analyses and toward dynamic, all-encompassing models. This will help them plan to reduce traffic and improve people's ability to move around and their quality of life.

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