International Journal of System Dynamics Applications
Volume 9 • Issue 2 • April-June 2020

Modeling the Complexity of Road Accidents Prevention:
A System Dynamics Approach

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ABSTRACT

Simplistic representations of traffic safety disregard the dynamic interactions between the components of the road transport system (RTS). The resultant road accident (RA) preventive measures are consequently focused almost solely on individual/team failures at the sharp end of the RTS (mainly the road users). The RTS is complex and therefore cannot be easily understood by studying the system parts in isolation. The study modeled the occurrence of road accidents in Uganda using the dynamic synthesis methodology (DSM). This article presents the work done in the first three stages of the DSM. Data was collected from various stakeholders including road users, traffic police officers, road users, and road constructors. The study focused on RA prevention by considering the linear and non-linear interactions of the variables during the pre-crash phase. Qualitative models were developed and from these, key leverage points that could possibly lower the road accident incidences demonstrating the need for a shared system wide responsibility for road safety at all levels are suggested.

KEYWORDS

Causal, Complexity, Loop Diagrams, Non-Linear, Road Accidents, System Dynamics, Transport System

INTRODUCTION

Computer simulation provides a powerful tool that can be used to model and understand complex systems from the macro systems level to the micro genetic level. The application of System Dynamics (SD) has grown extensively and the availability of a variety of more sophisticated simulation software has significantly expanded the role of simulation in research, policy making and operational decisions (Greasley, 2017; Abar et al., 2017; Maani & Cavana, 2007, Zelinka & Amadei, 2019). Azar (2012) describes System Dynamics as a powerful methodology and computer simulation modelling technique for framing, understanding and discussing complex issues and problems in business, ecology, medical and social systems, engineering to mention a few. Computer models are used extensively in many areas of systems management to provide insight into the working of a system. This is particularly useful when the system is complex and/or when experimentation is not possible such as the road transport system (Urban et al., 2017; Pierce et al., 2019). SD has been used in a number of public transportation systems (Bajracharya, 2016; Elkady et al., 2016; Spichkova, 2016).

Bajracharya (2016) in a study to understand the public transportation system in Dubai used the System Dynamics approach and found out that it was challenging to motivate individuals to change from private car transport to public transportation. Elkady et al. (2016), in a study to investigate the effect of vehicle dynamics on collision of vehicles used 2 models. The first model demonstrated

DOI: 10.4018/IJSDA.2020040102

vehicle body crash parameters and the second model aimed to predict the effect of vehicle dynamics control system (VDCS) which showed that the VDCS can positively affect the crash characteristics and improve occupant behavior. Spichkova (2016) in a study to understand the dynamic decision-making system for public transport routes which focused on environmental, societal, spatial planning and optimization for smarter cities and user satisfaction for passengers and drivers. Cruz-Cantillo (2014) built a system dynamics model for the forecasting, prioritization, and distribution of critical supplies during relief operations in case of a hurricane event, while integrating GIS information. The model was used to for decision making, simulation of the behavior of key variables, estimate the supplies needed and the routes to use for delivery of supplies.

SD has been used to analyze traffic management aspects including safety improvement (Shire et al., 2018), traffic safety policy (Goh & Love, 2012), the underlying causes of organizational accidents (Goh et al., 2010a; Goh et al., 2012), and combat vehicle accidents (Minami & Madnick, 2009). Sterman (2000), Cooke and Rohleder (2006) and latterly Goh et al. (2010a) have advocated for the introduction of Systems thinking to the analysis of major accidents.

Morrison et al. (2003) summarized numerous traffic safety interventions that can be utilized, for example, motorcycle helmets and seatbelts, raising minimum drinking age above 18 years, traffic-calming engineering measures, speed camera, public lighting, random breath testing, enforcement and graduated licensing. The decisions to implement these traffic safety interventions are often based on public health analysis, and impact assessments or cost-benefit analysis (CBA) of road transport safety initiatives (Goh et al., 2010b). Road accident prevention has to be considered in a holistic and/or systemic manner, taking into account all other components of the road transport system (RTS) in order to make publicly rational decisions (Cochran & Malone, 2005). However, publicly rational decisions for the RTS cannot be easily determined due to its complexity. In its simplest form, the RTS can be described by its essential components: vehicles, drivers and the road infrastructure (Brett et al., 2010). However, this limited system exists within the larger social, business, government, and natural environmental contexts (Toleman & Rose, 2008). These elements include policies from different levels of governments, funding and pricing systems, legislated requirements, and many diverse expectations, amongst other things. The RTS is essentially a large ‘open’ system with lack of clear boundaries. All stakeholders of the RTS can impact on the system simultaneously, but none has direct control of the entire system. Furthermore, the RTS has a range of goals to satisfy and a rational decision is inherently difficult (Brett et al., 2010).

Unlike the traditional modeling approaches that emphasize linear cause and effect, SD focuses on internal feedback loops and time delays that affect the behavior of the entire system. The focus on feedback between variables in a system enables a more holistic view of the real world and places emphasis on complex dynamics of real world systems. A holistic approach is needed to model the occurrence of road accidents. Once the model is built, it can be used to simulate the effect of proposed actions on the problem and the system as a whole.

The aim of this research therefore was to carry out a dynamic and non-linear analysis of the occurrence of road accidents on highways in a developing country using the System Dynamics Methodology (SDM) so that various interventions measures and strategies for minimizing the occurrence of RAs on highways in developing countries can be evaluated. Specifically, the study set out to establish the risk factors for road accident causation in developing countries, build qualitative models from which insights for reducing the occurrence of RAs on highways could be generated.

The next section provides a background to the study followed by reviewed literature on the methods and modeling approaches used to study road accident management. This is followed by the methodology used to guide the study, results from the study, a description of the qualitative models and conclusions from the study.

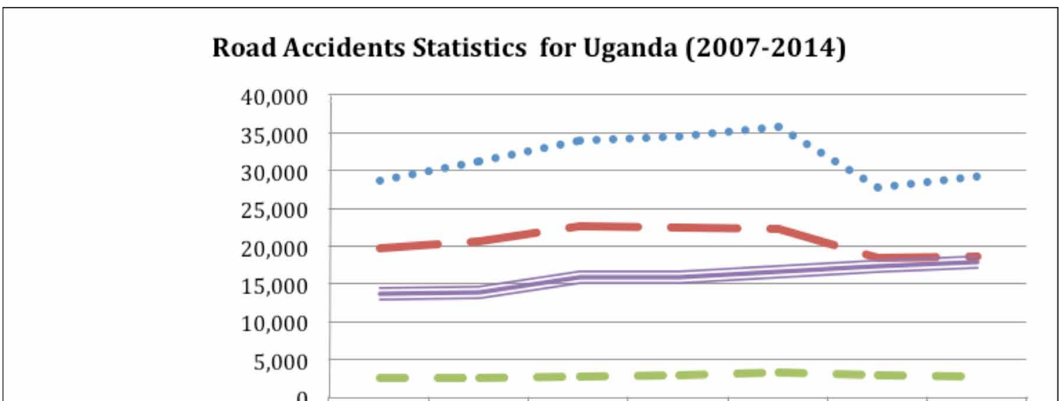
BACKGROUND

According to the Global Status Report on road safety 2018, the number of annual road traffic deaths has reached 1.35 million with road traffic injuries being the leading killer of people aged 5-29 years (WHO, 2018). The burden is disproportionately borne by pedestrians, cyclists and motorcyclists, in particular those living in developing countries. Over the years, at 85% of the global average of 750,000 compared to 15% in high-income countries, Uganda has been one of the low and middle-income countries bearing the heaviest burden of road traffic incidents (RTI). (Balikuddembe et al., 2017). Currently Uganda is experiencing RTI deaths of 28.9 per 100,000 population (Balikuddembe et al., 2017). In Uganda, road accident preventive measures are focused almost solely on failures of operators at the sharp end of the RTS rather than the inadequate conditions present in the system itself. However, the RTS exhibits 'dynamic complexity' (Goh et al., 2010a; Senge, 2006) which arises when actions and consequences are separated in time and causation of consequences involves 'messy' coupling of issues with indistinct root causes. Reductionist modeling approaches fall short in addressing the complexity and non-linearity of the RTS which also involves several stakeholders hence the need to employ systemic approaches like SD.

Each time RA intervention is targeted towards measures that only solve the symptomatic causes at the sharp end, some temporary slight reduction in the occurrence of road accidents may be achieved (this assumes a well-planned intervention). However, the underlying root causes persist and road accidents consistently continue to occur after some time with some drops at some point.

Figure 1 shows data for the road accidents that occurred in Uganda for the period 2007 to 2014 as reported by the Uganda traffic police in its annual crime and traffic road safety report for the year 2014 (Police, 2014). The population for Uganda has been increasing steadily over the years. The number of vehicles involved in accidents increased from 28,517 in 2007 to 19,174 in 2014 as shown. It is possible that this trend prompted various stakeholders to enforce measures targeted towards

Figure 1. Behavior over time - graph for road accidents in Uganda (Police Uganda, 2014)



	2007	2008	2009	2010	2011	2013	2014
Vehicles involved in accident	28,517	31,065	33,931	34,412	35,716	27,648	29,174
Road Accidents	19,867	20,729	22,699	22,461	22,272	18,368	18,686
Road Deaths	2,597	2,488	2,734	2,954	3,343	2,937	2,845
Road Casualties	13,576	13,753	15,829	15,854	16,619	17,283	17,848

promoting road safety more strictly, causing a drop in the number of accidents that occurred during the period 2011 to 2014. The statistics show that the problem still exists and therefore there is need to employ new techniques to understand the problem.

METHODS USED TO STUDY ROAD ACCIDENT MANAGEMENT

Diverse traditional modeling approaches such as Cost Benefit Analysis (CBA), Public Health Analysis (PHA), Mathematical Modeling (MM) have been employed in accident management. CBA, arguably the most common method used to facilitate transport policy analysis (Haezendonck, 2007) employs costs and benefits of different transport policies in monetary terms and provides quantitative assessment measures to support decision making. Models can be constructed in numerous ways, but for transport safety investigations they tend to be quantitative regressions of related variables (Gokdag et al., 2004; Ma & Kockelman, 2006), epidemiological studies (Marchetti et al., 2009; Naci et al., 2009) or before and after analyses (Passmore et al., 2010; Seethaler & Rose, 2009). The current CBA approaches are static (Schade & Rothengatter, 2003) as they are usually based on relatively simple estimates of parameters.

The Public Health Analysis approach is not only helpful in the analysis of road accident prevention measures, but also provides a framework that guides decision making throughout the entire process from identifying a problem to implementing an intervention (Krug et al., 2000). PHA has been adopted in the creation of awareness among the health professionals about the various modalities available to prevent road accidents as well as inculcate a sense of responsibility toward spreading the message of road safety in India (Gopalakrishnan, 2012)

Mathematical modeling (MM), whose theoretical and numerical analysis provides insight, answers, and guidance useful for the originating application (Neumaier, 2003), has been applied in the road accidents investigation models to investigate the causes and impacts of accidents in the Slovak Republic where the most significant factors mentioned were human behavior factors. Whereas MM is systematic, results can be repeated, and the model can be refined, it is difficult to build a complete model of real-world processes. It assumes a linear sequence of events and several simplifying assumptions have to be made in order to deal with the complexity and non-linearity of socio-technical systems. The road traffic system is complex, requiring a holistic modeling approach which puts into account all variables in their non-linear nature.

MODELING APPROACHES USED TO STUDY ACCIDENT MANAGEMENT

Systemic models have their roots in systems theory. Systems theory includes the principles, models, and laws necessary to understand complex interrelationships and interdependencies between components (technical, human, organisational and management) (Qureshi, 2008). Safety is no longer solely the responsibility of front line operators (e.g. drivers); rather, the responsibility is shared between actors across all levels of the complex socio-technical system (regulators, policy makers, designers, line managers, manufacturers, supervisors, and front line operators). This section highlights some of the applications of systems-based modeling approaches employed in accident management.

The Haddon Matrix

The Haddon matrix is an analytical tool used to identify all factors associated with a crash. It illustrates the interaction of three factors; human, vehicle and environment during three phases of a crash event: pre-crash, crash and post-crash. Once the multiple factors associated with a crash are identified and analyzed, countermeasures can be developed and prioritized for implementation over short-term and long-term periods. The Haddon matrix has been applied in a number of accident analysis projects (Darby et al., 2014; Edmonston & Sheehan, 2005). Evidence from some highly motorized countries shows that this integrated approach to road safety produces a marked decline in road deaths and serious injuries. The Haddon matrix, does not take into account the recurring and feedback behavior of the complex road transport.

The Swiss Cheese Model

The Swiss Cheese Model by Reason's put forward a systems perspective model of human error and accident causation which focuses on the interaction between system wide inadequate conditions and errors (referred to as latent) and their contribution to organizational accidents (Reason, 2000). The model follows the principles of sequential models (Hollnagel, 2004) and the direction of causality in a linear fashion. In addition, the causal links between distant latent conditions (organizational factors) and the accident outcome are complex and loosely coupled (Shorrock et al., 2003). Reason's model shows a static view of the organization; however, the whole socio-technical system is more dynamic than the model suggests (Qureshi, 2008).

Systems-Theoretical Accident Model and Processes (STAMP)

While traditional approaches view component failure as the source of accidents, Systems-Theoretical Accident Model and Processes (STAMP) incorporates dysfunctional component interaction and external disturbances as well (Leveson, 2004). Therefore, accidents occur when there is inadequate control or enforcement of safety-related constraints on the development, design, and operation of the system. Leveson (2004) developed a scheme which captures most control flaws that are broadly, categorized into three: inadequate enforcement of constraints, inadequate execution of control actions, or inappropriate or missing feedback. These flaws can be classified and used during accident analysis or accident prevention activities to assist in identifying all the factors involved in the accident (Leveson, 2004). Leveson (2002) asserts that "the most important factor in the occurrence of accidents is management commitment to safety and the basic safety culture in the organization or industry".

Rasmussen's Socio-Technical Framework (RSTF)

Rasmussen adopted a system-oriented approach based on control theoretic concepts and proposes a framework for modeling the organizational, management and operational structures that create the preconditions for accidents. Rasmussen's framework for risk management has two parts:

Structure and Dynamics

The structure hierarchy states that accidents are caused by decisions and actions by decision makers at all levels, and not just by the workers at the process control level. Lin (2011) used the Rasmussen's socio-Technical Framework for safety management and risk modeling in the aviation, as a complex, hierarchical system in the Netherlands.

Critique of the Reviewed System-Based Modeling Approaches

Although these systemic techniques do provide a deeper understanding of how the behavior of the entire system can contribute to an accident (Salmon et al., 2012; Arnold, 2009), various studies suggest that there are more resource intensive and require considerable amounts of domain and theoretical knowledge to apply (Ferjencik, 2011; Johansson & Lindgren, 2008). Methods currently employed to model the occurrence of RA have been successful in addressing challenges of a single RTS component at a time, in isolation of the other components; which undermines the interactions and interdependences between technological, social and organizational subsystems, which, actually are responsible for the resulting visible outcomes of the RTS. Therefore, the evaluation of current modeling approaches that can possibly be employed in accident management is henceforth considered with utmost importance.

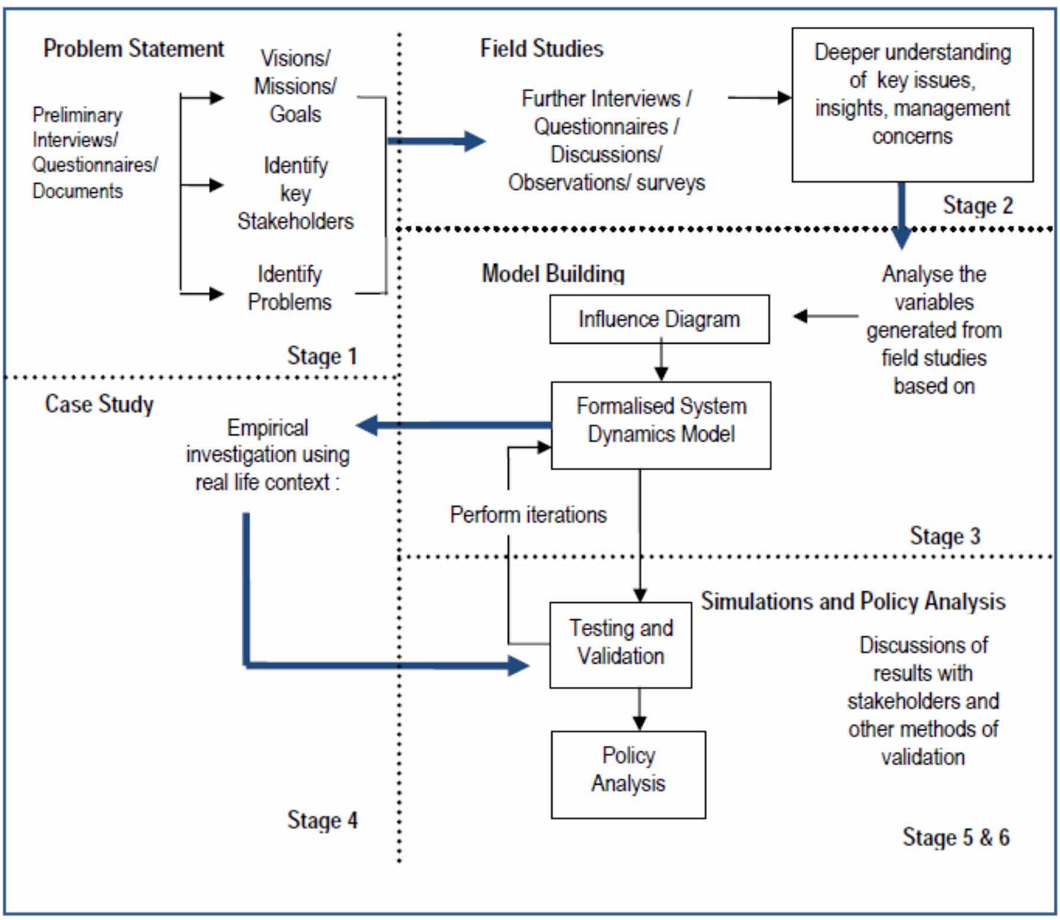
Following a critical evaluation of various modeling approaches applicable in the RTS domain, this research opted to employ SD because of its completeness as a research methodology and its unique features. First and foremost, it is underpinned by the systems theory meaning that it considers the performance of the system as a whole. Systemic models view accidents as emergent phenomena, which arises due to the complex interactions between system components that may lead to degradation of system performance or result in an accident. Secondly, SD takes into account the feedback interactions that occur within complex systems and time delays that affect the visible outcomes of the system.

METHODOLOGY

System Dynamics Modeling (SDM) was found to be most suitable for holistic modeling of complex socio-technical systems such as the as the Road Transport System. The researchers employed the Dynamic Synthesis Methodology (DSM) that was developed by Williams (2000) and revised by Rwashana et al. (2009) shown in Figure 2. DSM follows six stages namely; problem statement, field studies, model building, case study, simulations and policy analysis as shown in the figure and the details of what happens in each state are explained later in this section.

DSM allows the integration of theoretical concepts and structuring of parts and elements of a process over time in such a manner to form a formal functional entity, underpinned by synthesis as philosophy of science (Williams, 2004). DSM is grounded on well-tested and developed theoretical anchors and builds on an existing epistemological philosophy of science in the acquisition of knowledge

Figure 2. Dynamic synthesis methodology (Rwashana et al., 2009)



(Rwashana et al., 2009). DSM combines two powerful research strategies; System Dynamics and case study research methods (Forrester, 1994). Case studies are used to collect on-site information from the current system owners and user requirements and specifications in the natural setting. This paper presents the work done in the first three stages of the DSM.

Stage 1

Preliminary interviews were used to find out more about the context of the problem. Owing to the complexity of the problem, the following stakeholders were identified; traffic police, roads construction authority, vehicle manufacturers, transport regulatory agencies/institutions, legislators, judicial officers, prison officers, operators of driving schools, education institutions as well as the various categories of road users. The boundary of the research was determined with four categories of stakeholders. Table 1 shows the four categories of stakeholders that were selected for the study and the roles they play in accident management.

Stage 2

Field studies were used to determine the full range of activities, challenges and opportunities associated with the occurrences of RAs. The field studies were necessary in generating data for better understanding of the problem. Different data collection instruments were designed and control measures (reliability and validity testing) were used to ensure the collection of high-quality data.

Purposive sampling was used to select 9 administrators and/or policy makers in different institutions working to reduce the occurrence of road accidents in the country including traffic police, Uganda National Road Safety Council, Uganda National Vehicle Licensing Board, Road Safety Department of UNRA; who, had a lot of data and knowledge about the occurrence of road accidents. Convenience sampling was used to select respondents travelling in passenger service vehicles (PSVs) and salon cars. The simple random sampling method was used to select vehicle drivers and traffic police officers. One hundred and fifteen (115) questionnaires were distributed to three categories of respondents (vehicle drivers, passengers and regulators of the RTS and law enforcers). Focus group discussions with different RTS stakeholders in groups of 5-10 members were used to collect information from cyclists and pedestrians.

RESULTS

The raw data from field studies summarized and analyzed by cross tabulation analysis using Microsoft Office Excel 2007 pivot tables from which key variables and their relationships were identified.

Table 1. Key stakeholders involved in accident management

	Stakeholders	Roles
1	Traffic police	Enforce the laws against traffic criminality.
2	Road users (vehicle drivers, passengers, pedestrians, cyclist of motorized and non-motorized two/three wheelers)	Use the roads in a manner that is safe to themselves and to other road users and in accordance with the policies governing road users.
3	Senior management staff of regulatory agencies/ institutions (Uganda national road safety council, National motor vehicle licensing board)	Regulate and coordinate road safety related functions and activities in various capacities
4	Uganda National Roads Authority (UNRA) staff	Ensure that road safety initiatives are given the right attention they deserve early at the initial stages of planning, engineering and designing of new roads

Later these variables were used in the development of the causal loop diagram (CLD) using Vensim modeling software which was used to analyze the feedback nature of the variables generated from field studies and their interactions.

Questionnaires

Out of a total of one hundred and twenty-six (126) questionnaires distributed, one hundred and fifteen (115) of them were collected back as detailed in the questionnaire survey distribution shown in the Table 2. Table 2 presents the response rates from two categories of respondents; the traffic police officers who are mobile and stationery officers and three categories of road users namely vehicle drivers, passengers in passenger service vehicles and passenger who were found to be using personal / private vehicles.

The aim of these randomly distributed questionnaires was to get views and opinions from operators at the sharp end of the RTS (mainly the RUs) who are on several occasions implicated in many of the accident investigation reports in Uganda. This enhanced a holistic view of the RTS.

Interview Guides

In order to tap into the wealth of knowledge of some stakeholders of the RTS, two categories of interview guides (one category was meant for traffic police administrators and the other for makers of RTS policies) were designed. The stakeholders who were interviewed included in particular those holding administrative positions working to reduce the occurrence of RAs in Uganda. Table 3 provides a summary of the nine (9) administrators and / or policy makers who participated in the interviews. The respondents represent four organizations namely Uganda Traffic Police, Uganda National Road Safety Council, Uganda National Vehicle Licensing Board and the Road Safety Department of the Uganda National Road Agency (UNRA).

Focus Groups

The focus group guide was used as the main method and was used to collect data from cyclists and pedestrians. Discussions with different RTS stakeholders in groups of 5-10 members were conducted. Table 4 presents the distribution of the groups that were engaged in the focus group discussions, the number of respondents and the meeting place where the discussion was held.

Documentary Review

Desk research, particularly from online secondary sources was used to collect historial data.

Table 2. Categories of respondents to the questionnaire

Category of Respondents	Specific Kinds of Respondents	Population Surveyed	Survey Response	Percentage Survey Response (%)
Traffic police officers	Mobile & stationary police officers	31	28	90.3
Road Users	Vehicle drivers	25	22	88
	Passengers in PSVs	42	39	92.9
	Passengers in non PSVs	28	26	92.9

[Source: Primary data]

Table 3. Category of respondents to the interview guides

Targeted Group	Name of Institution	No. of Respondents Interviewed	Purpose of Interviews
Administrators and/or policy makers	Uganda Traffic Police	3	To probe for in-depth qualitative information in an interactive, flexible and adaptive description of activities, challenges, problems and opportunities.
	Uganda National Road Safety Council	2	
	Uganda National Vehicle Licensing Board	2	
	Road safety department of UNRA	2	

[Source: Primary data]

Table 4. Categories of respondents who participated in focus group discussions

Category of Group	Total No. of Respondents Met in Group(S)	Place of Discussion(S)	Purpose of the Discussion
Passengers in PSV	06	In a bus travelling along Iganga-Kampala highway.	To explaining findings that appeared conflicting and to explore how they felt about the occurrence of RAs in Uganda and why.
Cyclists of motorized two wheelers (mainly boda boda cyclists)	28	Mainly at boda boda stages along Masaka-Kampala highway	
Pedestrians	14	At a zebra crossing on Iganga road	
PSV drivers	07	Kyengera taxi park	

[Source: Primary data]

Analysis

In the first phase of analysis, raw data from field studies was summarized and analyzed by cross tabulation analysis using Microsoft office excel 2007 pivot tables. Key variables and their relationship were identified and used to develop the causal loop diagrams (CLDs).

The second phase of analysis involved the building of a qualitative feedback structural model using the descriptive field study results with the help of CLD. The CLD was developed using Vensim modeling software and was used to analyze the feedback nature of the variables generated from field studies and their interactions.

Table 5 presents the summary of the variables that are associated with accident management generated from the analysis of literature and the field studies. They are categorized as: personal issues, institutional issues, vehicle characteristics, road issues, road accidents and data handling and general issues.

QUALITATIVE MODELS OF THE ROAD TRANSPORT SYSTEM

The variables and their relationships shown in Table 5 were used to the build the causal loop diagrams (CLDs) presented in Figures 3-6. CLDs are composed of variables and influences (links). An influence has direction shown by an arrow and polarity which shows the direction of influence which is same (+) or opposite (−) direction as the influencing element. Additionally, feedback loops occur when arrows connect a variable to itself through a series of other variables. There are two types of feedback loops that are expressed in CLDs namely reinforcing and balancing loops as illustrated in Figures

Table 5. Summary of the variables used in the causal loop diagrams

Theme (Owner)	Variables Associated With Road Accidents Identified	Source/ Reference	Observed in Field Studies (Y/N)
Personal issues	Driving experience	Field study	Y
	Fatigue	Field study	Y
	Driver's age	Field study	Y
	Health condition	Literature	N
	Over speeding	Field study	Y
	Urgency	Literature	Y
	Distance driven	Field study	Y
	Ability to read and understand road signs	Field study	Y
	Drunk driving	Field study	Y
	Level of formal education	Field study	Y
	Body alcohol content	Literature	Y
	Corruption	Field study	Y
	Understanding of systemic failures in accident causation	Field study	Y
	Probability of being distracted	Field study	Y
	Compliance to TRSLR	Field study	Y
	Safe and good driving practices	Field study	Y
Institutional issues	Quality of sensitization and awareness campaigns	Literature	Y
	Corruption	Field study	Y
	Enforcement facilities	Field study	Y
	Level of enforcement of TRSLR	Field study	Y
	Intensity of public sensitization and awareness campaigns' about road safety	Literature	N
	Amount of funds available	Field study	Y
	Number of enforcement personnel	Field study	Y
	Reinforcement	Literature	N
	Remuneration of enforcement personnel	Field study	Y
	Quality of vehicle inspection	Field study	N
	Vehicle inspection	Field study	Y
	Effectiveness of policies made	Field study	Y
	Quality of policy analysis	Field study	N
	Gazetted speed limits	Field study	Y
Vehicle characteristics	Vehicle safety	Field study	Y
	Safer vehicle fronts	Literature	N
	In car safety technologies	Field study	Y
	probability of vehicle equipment failure	Field study	Y
	Speed control gadgets e.g. speed governor	Field study	Y
	Age of vehicle	Field study	Y
	Mechanical condition of the vehicle	Field study	Y
	Severity of vehicle-pedestrian crash		
Road issues	Number of lanes	Field study	Y
	Road size	Field study	Y
	Road maintenance	Field study	Y
	Probability of runoff crashes	Field study	Y
	Size of medians	Literature	Y
	Probability of head-on crashes	Field study	Y
	Intensity of traffic guidance	Field study	Y
	Probability of intersection crashes	Field study	Y
	Speed humps & bumps	Field study	Y
	Availability of medians	Literature	Y
	Probability of vehicle-pedestrian crash	Field study	Y
	Presence of side-walk ways	Field study	Y
	Presence of round – about	Field study	Y
	Presence of traffic lights at junctions	Field study	Y
	Gazetted speed limits	Field study	Y
Road accident data handling	Quality of data analysis	Field study	Y
	Quality of data storage materials	Literature	Y
	Completeness of data collected	Field study	Y
	Quality of data stored	Field study	Y
	Competency of data handling personnel used	Literature	N
General	Public understanding of TRSLR (Traffic and Road Safety Laws and Regulations) and safety practices	Field study	Y
	Actual number of accidents occurring	Field study	Y
	Risk of accident occurrence	Field study	Y

3-6. Reinforcing loops denoted by R represent a growing action where each action adds to another and may be referred to as virtuous cycles when they produce desirable effect or vicious cycle when they produce an undesirable effect. Balancing loops also known as neutralizing loops, denoted by B apply where there is an attempt to solve a problem or achieve a goal. The CLDs showing the various components of the road transport system are discussed in this section.

Road Safety Aspects

Figure 3 shows the road safety aspects that are associated with the management of accidents. The causal loop diagram has 4 balancing loops (B1-B4). The goal of Loop B1 and B2 is directed to reducing over speeding which promotes the probability of run off crashes (B1) and intersection crashes (B2).

Loop B1

Over speeding promotes the increase in the probability of run off crashes which increases the risk of accident occurrences. This enhances the need to have road expansions which in turn reduces over speeding. Gazette speed limits, speed humps and bumps as well as paying the right attention to traffic guidance during road expansions can lower over speeding thereby lowering the risk of occurrence of an accident.

Loop B2

Similarly, over speeding promotes the increase in probability of intersection crashes thereby increasing the risk of accident occurrence resulting in the increase in road expansions which in turn reduces over speeding. The presence of traffic lights and roundabouts lower the probability of intersection crashes.

Loop B3

The goal of B3 is lower the risk of accident occurrence. Increased road expansion lowers the risk of accident occurrence which increased increases the road expansion, thereby resulting in a balanced loop.

Loop B4

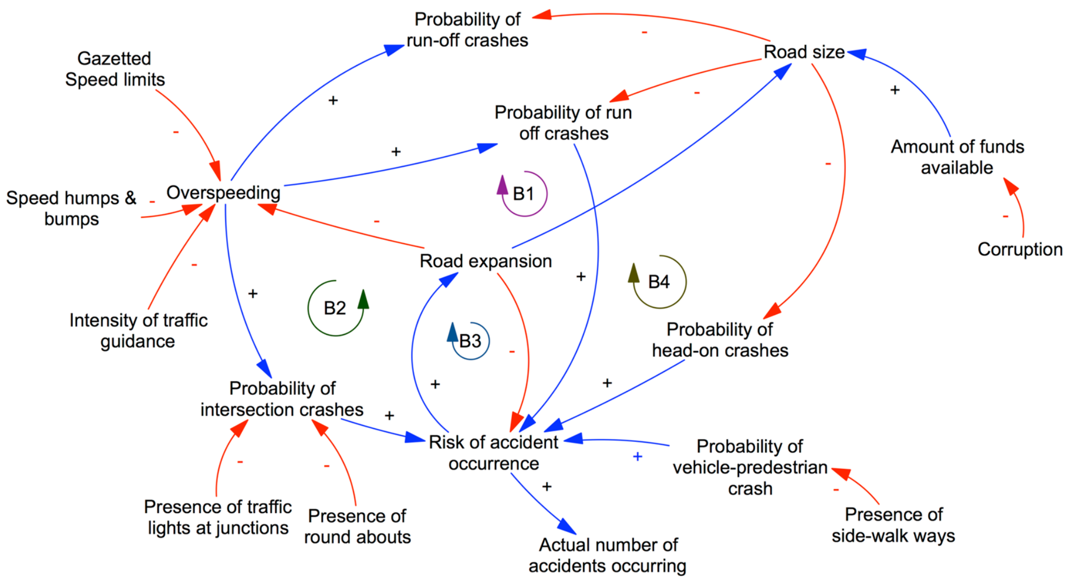
An increase the road size lowers the probability of head on crashes which in turn reduces the risk of accident occurrence. An increase in risk of accident occurrence enhances the need to have road expansions which increases the road sizes. However, corruption reduces the funds available for road construction which when increased significantly contributes to the size of the road.

Vehicle Safety Aspects

Figure 4 presents the causal loop diagram showing the relationships associated with the vehicle safety aspects and these are presented in five feedback loops; three balancing loops (B5 – B7) and two reinforcing loops (R1 and R2):

- Loop B5 shows that over speeding directly increases the risk of occurrence of accidents and yet on the other hand an increase in risk of accident occurrence lowers over speeding of vehicle;
- Loop B6 shows that intensifying the enforcement of laws against over speeding reduces that vise. And as the over speeding goes down the need to put more efforts on enforcement of laws reduces;
- Loop B7 demonstrates that an increase in vehicle safety reduces the risk of accident occurrence. The risk of accident occurrence reduces over speeding. An increase in over speeding results in the increase in the probability of vehicle equipment failure which lowers the safety of the vehicle;
- Loop R1 describes a positive relationship between the vehicle's mechanical condition and its safety. It depicts that maintaining a vehicle in a good mechanical condition improves its safety and if the safety of the vehicles increases, chances of it getting involved in accidents which are direct consequences of poor vehicle mechanical conditions reduce. That means that to achieve

Figure 3. Causal loop diagram for road safety aspects



long lasting positive results against over speeding, the enforcement of laws against it should never be relaxed even when the initial benefits are realized;

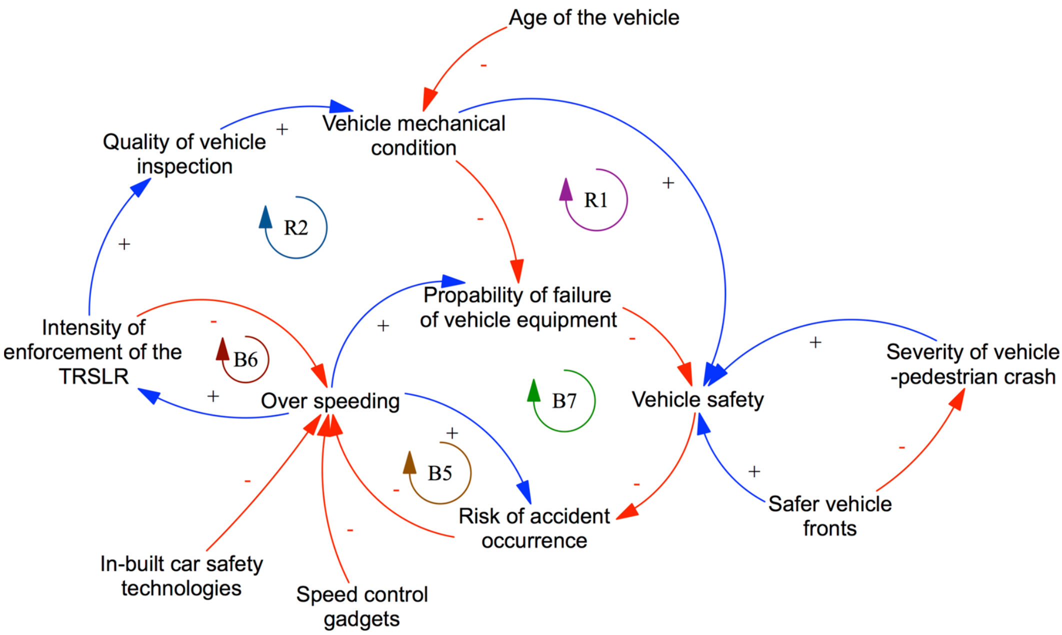
- Loop R2 shows that the quality of vehicle inspection improves the mechanical condition of the vehicle which further increases the vehicle safety thereby reducing the risk of accident occurrence. Lowering the risk of accident occurrence lowers the over speeding. An increase in the intensity of enforcement of TRSLR results in an increase in the quality of vehicle inspection.

Road Accident Data Handling Processes

Figure 5 presents that causal loop diagram showing the road accident data handling processes with three reinforcing loops (R3-R5) and one balancing loop (B8):

- Loop R3 demonstrates a virtuous cycle that exists between quality of data analysis and understanding of systemic failures in accident causation, whereby more of one variable increases the other and vice versa;
- Loop R4 shows that understanding of systemic failures in accident causation increases the quality of data analysis which in turn increases the quality of policy analysis. As the quality of policy analysis increases, the effectiveness of the policies will increase leading to a deeper understanding of system failures;
- Loop R5 shows that the more effective policies are devised, the more complete data will be collected by competent data handling personnel. An increase in complete data results in improved quality of data stored which is supported by quality of data storage materials which may include databases that store data about the entire RTS. As the quality of data stored increases, the quality of policy analysis increases which enhances the effectiveness of the policies thus leading to a deeper understanding of system failures;
- Loop B8 illustrates that as effective policies are implemented, the risk of accident occurrence is lowered and this in turn reduces the need for an increase in policy analysis.

Figure 4. Causal loop diagram for vehicle safety aspects



BEHAVIOR OF ROAD USERS

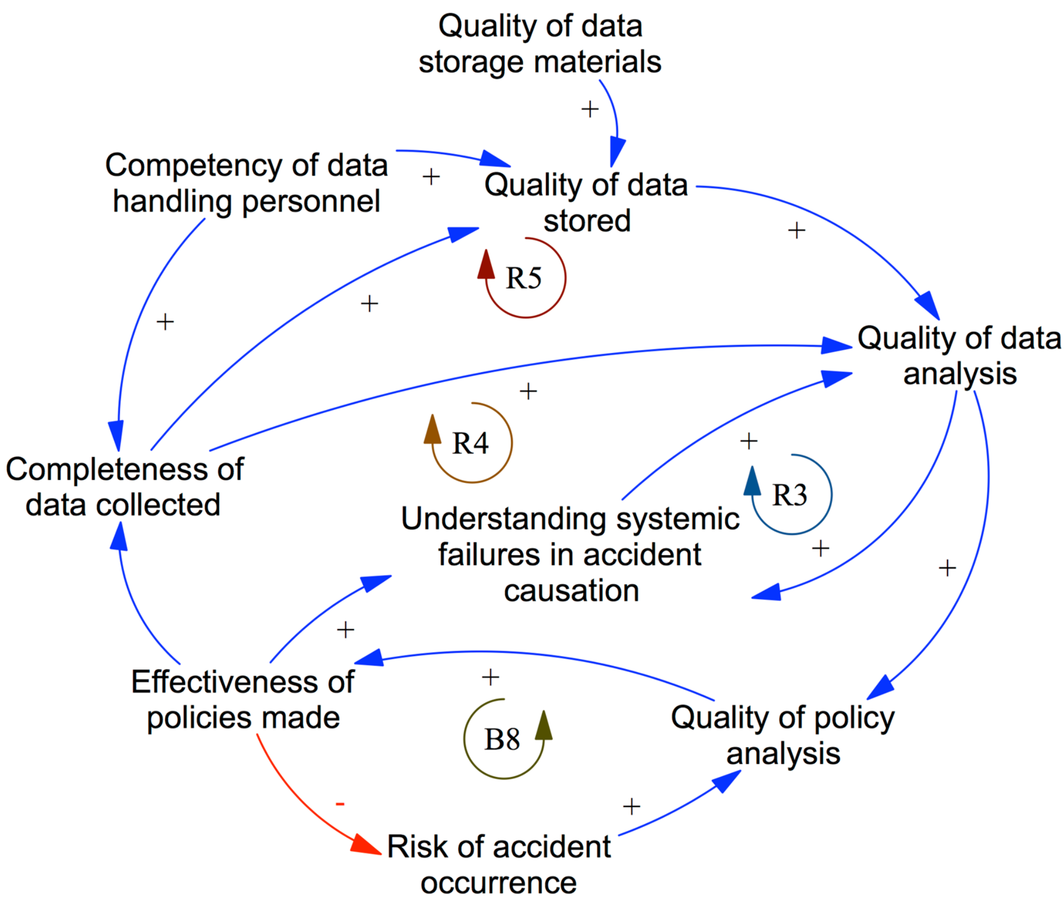
The CLD for issues related to the behaviors of road users consists of five balancing loops (B9 – B13) as shown in Figure 6. B10 itself would lead to a reduction in accident propensity. It shows how intensifying public sensitization and awareness about road safety practices positively affects their understanding of the TRSLR and safety practices prompting them to desist from engaging in unsafe behaviors while on the road. Increasing the level of enforcement of the TRSLR also has an effect of increasing the understanding of the TRSLR of the road users as depicted by B12. This will also make drivers understand the effects of fatigued driving making them to do it less often which consequently reduces the risk of accident occurrence. B9 shows that intensifying public sensitization and awareness about road safety practices can reduce the probability of driver distraction by making them ignore all activities that would reduce their concentration on the driving activity.

Exogenous variables like re-enforcement (promoting more of the desired behaviors instead punishing and discouraging bad ones) can promote more of the safe road user behaviors than the bad ones. Corruption has the negative effect of reducing the level of enforcement of the TRSLR in two perspectives; 1. by reducing the amount of funds available for the acquisition of the required enforcement facilities, and 2. by luring the enforcement personnel to enter into binding contracts with traffic offenders not to arrest them after receiving bribes from them. Raising the level of formal education of the drivers increases their ability to read and understand road signs. Poor health condition of the driver (including driving after taking certain drugs and/or medications) and driving for very long distances without getting enough rest increase the probability of fatigued driving which increases the risk of an accident occurrence. Increase in body alcohol content beyond certain limits culminates into drunkard driving which also increases the risk of an accident to occur.

Insights From the Causal Loop Diagrams

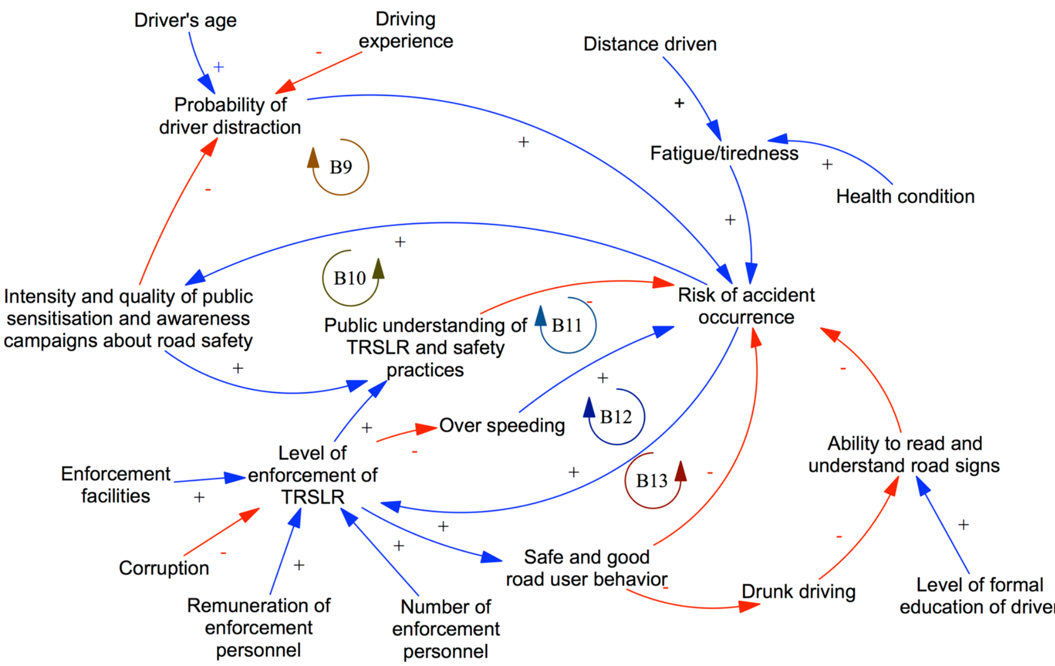
The following insights were generated from the CLDs for the various sub components shown in figures 3-6 above:

Figure 5. Causal loop diagram showing road accident data handling processes



1. While intensifying sensitization of road users about road traffic laws and safety practices leads into an increase in their knowledge and understanding of these laws and practices, it does not necessarily guarantee safer road user behaviors from them. However, effective enforcement of the traffic laws does;
2. Intensifying enforcement of traffic laws in response to an increasing rate of accident occurrence gives positive results but only for a short time after which the benefits soon fade away and the situation deteriorates back to the original level or even worse. Therefore, enforcement efforts should never be relaxed once the initial intended benefits are realized, and it should form part of the continuous ongoing efforts to reduce the occurrence of Ras;
3. An accident can occur depending on whether a road safety feature is present or absent. Therefore, roads should be designed, constructed and maintained with safety of their users given the consideration it deserves. Features like medians, speed humps and bumps, road width, traffic lights should always be prioritized when constructing roads. Traffic guidance should also be intensified by use of road signs for roads to "talk" more to their users in order to create roads that by themselves have the ability to reduce the chances of occurrence of accidents;
4. Short-term interventions like giving heavy fines to traffic law offenders, promoting desirable road user behaviors (reinforcement); target the immediate causes of RAs and can have a positive effect in the short term, but they are not substitutes for long term interventions. Therefore, as

Figure 6. Causal loop diagram showing issues related to the behavior of users



short-term measures are implemented to alleviate the occurrence of RAs when it is at its peak, more emphasis should be paid on implementing the long-term intervention measures that target the root causes, like constructing roads which are safe for the users.

CONCLUSION

The research achieves its objectives by providing a holistic approach to understanding the factors associated with road accident causation in developing countries and builds qualitative models from which insights for reducing the occurrence of RAs on highways are obtained. This research makes a significant contribution to the available scientific literature and to the body of knowledge by proposing a more holistic model developed using SDM; a methodology which is underpinned by the systems theory and is rooted and grounded from systems thinking. The dynamic and non-linear analysis of the occurrence of RAs in Developing Countries is presented and the usefulness and potential of SD for modeling and analysis of the road transport system over other systems-based modeling approaches (like The 'Swiss cheese' modeling, Rasmussen's Socio-Technical modeling Framework, STAMP analysis and the Haddon matrix) forms the basis for novelty in this research. The research demonstrates how the complexity theory can be applied in the promotion of road traffic safety on highways in developing countries. Future work will focus on building a quantitative model (Stock and Flow) which can be used to run simulations and use sensitivity analysis to identify the variables that can cause a substantial change in road accident management.

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