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## THE SYSTEM DYNAMIC AND COMPRAM METHODOLOGIES FOR MODELLING, SIMULATION AND FORECASTING OF ROAD SAFETY OF UZBEKISTAN

**Abstract:** *In Uzbekistan, about 2,000 people die every year as a result of a traffic accident. At the same time, according to the Pulitzer Centre on Crisis Reporting, the Republic has the lowest rate in road mortality among the countries in the Central Asian region - for every 100,000 people, it is 11.32 people. Losses from road accidents in Uzbekistan equivalent up to 2.8% of GDP that is also one of the lowest indicators. But according to traffic safety experts, the losses from accidents are greater than reported data. Nowadays there are a lot of methods to analyse and ensure road safety and traffic management on the roads. The authors believe that road safety is a complex societal problem not only in Uzbekistan but all over the world. One of these methods is System Dynamic (SD) and COMplex PRoblem hAndling Methodology (COMPRAM). In this work, the Vensim PLE SD software tool (it is one SD tool amongst many others) has been used to perform the SD modelling of the case study at hand. In the methods of system dynamics, a computer model is created using a graphical technique for constructing flow diagrams and causal relationships of the system under study and then simulated on a computer. COMPRAM allows us to figure out the way to handle complex societal problems while involving a System Dynamics (SD) simulation option. There are similarities between COMPRAM and the traditional way of analysing road safety. In traditional ways, each element or factor is studied as a separate phenomenon. These indicators are studied in the stages of COMPRAM. This article has been studied a different aspect of how road accidents happen. The developed a comparison (according to six criteria) of the different modelling paradigms which have been historically used to assess road safety. Also, the authors made a comparison of the COMPRAM methodology with the traditional road safety assessment approach to highlight similarities and differences.*

**Keywords:** Uzbekistan, system dynamic, COMPRAM, road safety

## **1. Introduction**

The number of road traffic deaths continues to climb, reaching 1.35 million all over the world. However, the rates of death relative to the size of the world's population has stabilized in recent years. But anyway 93% of the world's fatalities on the roads occur in low- and middle-income countries, even though these countries have approximately 60% of the world's vehicles. Road traffic crashes cost most countries 3% of their gross domestic product. More than half of all road traffic deaths are among vulnerable road users: pedestrians, cyclists, and motorcyclists. The data presented in "The Global status report on road safety 2018" of the world health organization show that progress has been achieved in important areas such as legislation, vehicle standards and improving access to post-crash care [57].

The above statistics show that the reduction of traffic accidents is one of the initial problems for all countries. Especially, those countries which economies are developing progressively and called "developing country" like Uzbekistan. Population of this country is more than 33 mln. [41]. The length of the road network of Uzbekistan is 183,783 km, of which public roads are 42,530 km, internal local roads are 71,324 km, city streets and roads are 69,229 km. Public roads are the main highways of the country [3, 29-31].

In Uzbekistan, about 2 thousand people die every year as a result of a traffic accident. At the same time, according to the Pulitzer Center on Crisis Reporting, the republic has the lowest rates in road mortality among the countries of the region - for every 100,000 people, they are 11.32 people. Losses from road accidents in Uzbekistan equivalent to GDP make up 2.8%, although this is also one of the lowest indicators. According to experts, the losses from accidents are huge amounts [2, 37, 45].

Nowadays there are a lot of methods to analyze ensure road safety and organization traffic management on the roads [44, 37, 45]. The authors believe that road safety is a complex societal problem [7] not only in Uzbekistan but all over the world. Complex societal problems are real-life problems [34, 52-55]. Real life problems are almost always without exception complex [43]. There are many sub-categories of complex societal problems, such as complex social problems, complex technical policy problems and complex organization problems. Social problems are closely related to the well-being of people [40, 47], such as welfare problems, unemployment problems and healthcare problems. Complex technical policy problems involve less direct human suffering, but can cause also much trouble. Environmental problems, possible climate change, and transport and infrastructure problems can be considered as complex technical policy problems [5, 8, 10].

There are varieties of approaches to solving social problems [13-17, 39]. One of these methods are System Dynamic (SD) and COMplex PRoblem hAndling Methodology (COMPRAM) [25-27, 33, 35].

The main objective of this work is to analyze road safety as a complex societal problem and to propose a sustainable solution for avoiding this reality. Secondly, we focus on

Systems Dynamics based modeling to assess the effect of for modeling, simulation, and forecasting of road safety of Uzbekistan.

In this work, the Vensim PLE SD software tool (it is one SD tool amongst many others) has been used to perform the SD modelling of the case study at hand. This software is user-friendly simulation software which allows the development of any complex, dynamic and nonlinear systems with significantly less effort, more interaction, and conventional tools than using other traditional programming languages.

## **2. Objectives**

System Dynamic method was developed by Jay Forrester Professor of the Massachusetts Institute of Technology [12]. System dynamics is a methodology and mathematical modeling technique to frame, understand and discuss complex issues and problems. Also, it is an approach to understanding the nonlinear behavior of complex systems over time [56] using stocks, flows, internal feedback loops, table functions, and time delays [1]. It can be used in variety sphere to show relationship multiple factors in a huge mechanism. The elements of system dynamics diagrams are causal loop diagram (feedback), accumulation of flows into stocks and time delays.

Dorien DeTombe is the founder of the field Methodology for Societal Complexity. She developed the Compram Methodology for political decision making on complex societal issues like sustainable development, terrorism, credit crisis and water affairs [9]. The conceptual model has been divided (in COMPRAM) in a seven-layer model. That seven layer model begins by describing the problem in text form as the first layer. Retrieved concepts and phenomena from the text constitute the second layer. A reflection is made on the knowledge status based on hypotheses, theories, experience, intuition or assumption through verbal description; it constitutes the third layer. A further step does explain the influence of the concepts and the phenomena or vice versa, and a graphical representation of the knowledge; this is performed in the fourth layer. In layer five, a semantic model does represent graphically the relations between the concepts and the phenomena. And in layer six a causal model is provided, which is the graphical representation of the causal relations from layer five. In the last layer seven, the system dynamical simulation of the problem related developed system-model is performed through some SD computer software tool such as Vensim/ Stella/Ithink/PowerSim [22].

Compram methodology consist of six steps. Each step is a group process of differently composed groups each separately guided by a facilitator. This process can take a long time depending on the urgency and the complexity of the problem. These six steps are not 'the seven steps to heaven'. Handling complex societal problems will always be difficult, never simple, and the outcome uncertain [9,10].

It is imperative to reduce the level of road accidents through some sort of advanced methodology since the conventional methods lack to prevent the accident occurrences and reduce the severity [36]. Hence the system dynamics (SD) methodology comes as a handy

tool to reduce the accidents to ensure road safety [32, 46]. The SD technique under the systems approach methodology presents the Planners and the Engineers a cohesive set of steps to be followed systematically by accounting the basic root cause of any problem under considerations. There are the host of factors causing accidents in any region or metropolitan cities [24]. There have been many different efforts to model the road safety problem [6, 21, 28, 48]. For instance, Kelly investigated and discussed five common modeling approaches in road safety. Among their studied models, system dynamics (SD) was said to have several advantages, including providing useful learning tools to increase the general understanding of the system and system thinking, knowledge integration for modelers and end users, a distinction between true and perceived system conditions, a platform for policymakers, and more. The SD simulation approach provides a means to collectively analyze all of the factors involved in any given accident as well as the interactions between these factors [50].

A.K. Kazadi et al. [22] in their studies used these two methods in a complex were able to very well describe the simulation of the model of following the car for degraded roads. However, the discussion of whether these approaches have advantages over traditional one-by-one parameter models has been neglected. Traditional approaches do not have the ability to model interactions among parameters of the system, but in the SD approach this problem has been overcome [50].

COMPRAM is used to analyses globally this phenomenon. COMPRAM allows us to figure out the way to handle complex societal problems while involving a System Dynamics (SD) simulation option.

As can be seen in the following example (fig. 1) shown simple causal loop diagram of road safety to represent dependents between each other.

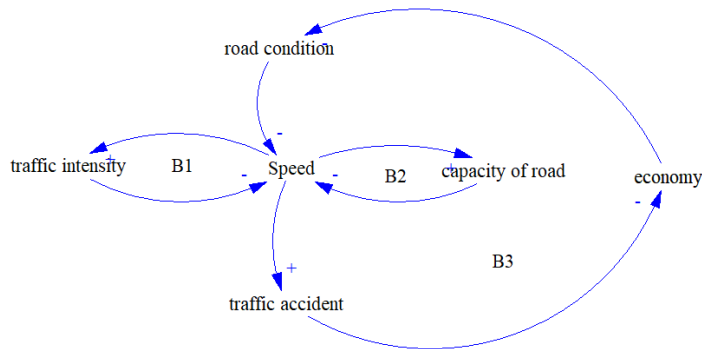


Fig. 1. Causal loop diagram

The constructed causal loop diagram consists of several balancing loop. These loops are indicated in the figure. B denotes the balancing loops. It is noteworthy to mention that all of the relationships between different parameters in this causal loop diagram are fundamental for road safety and the available literature in this field. In this figure, the authors have proven the relationship between specific parameters by logically discuss the existence of the available relation.

**B1: Traffic intensity-Speed-traffic intensity:**

The intensity of the movement of vehicles is the number of vehicles passing through the cross section of the road in a certain direction or directions per unit time (per day or per hour). The speed of the traffic flow is an indicator of the speed of the whole or a particular type of vehicle on a certain section of the road, measured in m/s or km/h. On the subject of the organization of road traffic, we know that with an increase in the intensity of the traffic flow, the flow speed decreases as the density increases.

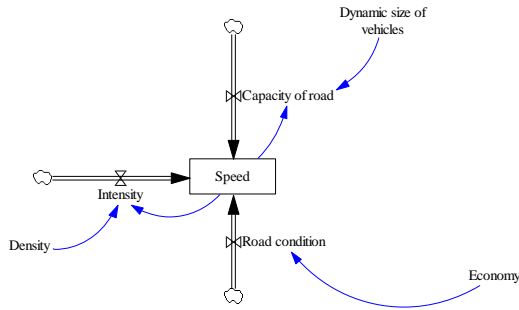
**B2: Speed-capacity of road:**

Capacity of road is the maximum traffic flow obtainable on a given roadway using all available lanes; usually expressed in vehicles per hour or vehicles per day. There are two types of capacity of road, theoretical and practical. With an increase in the flow rate, the capacity of the road increases. But this trend does not continue indefinitely. When the flow rate reaches the H number, the throughput decreases. This is explained by the fact that the gap between the cars increases.

**B3: Speed-traffic accident-economy-road condition:**

One of the main factors of traffic accident is an increasing speed. According this we can claim that speed help to increase the volume of accident. Traffic accident always impact economy of country in bad side as the economy is losing money on the restoration of the victims and the dead. as the economy is losing money on the restoration of the victims and the dead. And then lead to a decrease in the country's budget. The consequence of this may be to reduce funding to support road infrastructure. And if the road does not respond with transport and operational qualities, then the traffic speed decreases.

Usually, the developed causal loop diagram will help to construct stock and flow diagram for different systems in the next step of the SD modeling process. The model of speed is developed in this paper, using the System Dynamics Simulation Software Vensim PLE. The Vensim is object oriented simulation software which allows the development of any complex, dynamic and nonlinear systems with significantly less effort than using traditional programming languages. It has a user-friendly graphical interface and supports modular program development.

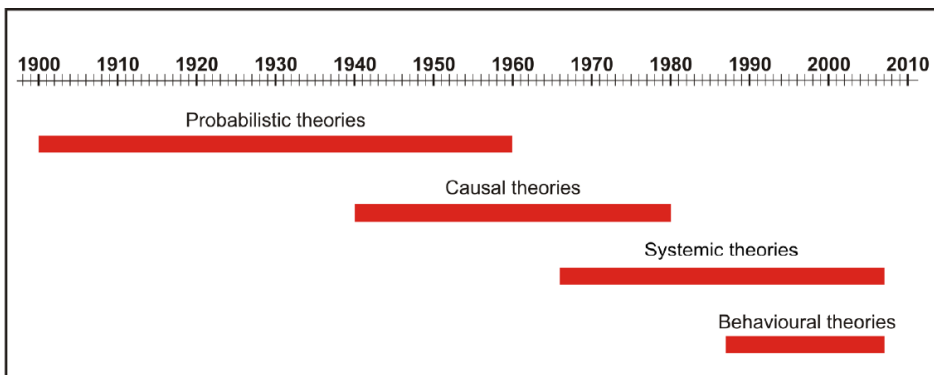


**Fig. 2.** Model of system dynamics

As seen in fig. 2 speed is one of the main factors to enhance road safety on roads and streets. There are several impacts as an intensity, road condition, and capacity of road which were taken as the inflow in the model. Inflow in the model influences an increase to the existing level value while the outflow contributes a decrease to the present level.

### 3. Results

It has been a hundred years since the first attempts at explaining the different aspects of how road accidents happen. Within this time there have been many theories explaining why accidents happen. There are four periods of the history of road accident research. These are given in fig. 3. Each of these periods was dominated by one of four groups of road accident theories: stochastic, causal, systemic and behavioral [20].



**Fig. 3.** The chronological sequence of groups of road safety theories [9]

**Stochastic theories** dominated road accident analyses in the first half of the previous century. Within this period road accidents are analyzed as random events and from the point of statistical accident theories. The main reason for this idea was in this time they have not so many vehicles and traffic accident, as a result, they could not define the relationship between accidents.

**Causal theories** of accidents claimed that only an exact knowledge of the real factors causing accidents can help to prevent them. We can distinguish two main trends in causal accident theories: deterministic (sequence of events) and probabilistic (set of factors) [18]. Heinrich is considered the precursor of the theory based on the sequence of events. He developed the “domino theory” which is based on the assumption that an accident consists of a single event with a cause. Consequently, better safety, according to this theory, requires that the cause of the accident is established and eliminated. The most developed theories are those of multi-linear event sequences, which assume that accidents are an element of a series of events and suggest a process approach to accidents [20].

**Systemic theories.** The theory of systems applied to road transport is designed primarily to eliminate accidents by modifying the technical elements of the transport system. The systemic theory is so far the best. The improvements in the roads system, traffic enforcement, and vehicle design have significantly reduced accident rates and casualties in western motorized countries [11]. Systemic theories and models are used to identify the relations and dependencies that have an effect on accidents (so called factors transferred in time and space) and factors that occur at the time and place of the road accident to build a system of road safety measures, monitoring and control of the dependencies and relations.

**Behavioural theories.** The last 15-20 years have shown that not even the systems theory can explain accidents. Could it be that accidents are an unsolvable problem? A new approach was put forward by in 1980 by Gerald Wilde giving the basis for behavioral theories. The basic assumption of all behavioral theories is how people assess risk and accept it as a very important determining factor of accidents [19]. Similarly to the previous theories, there are several groups of theories here as well: homeostasis of risk, behavioral adjustment, and change of health behavior. Wilde formulated a simple thesis which is that the only factor that causes sustainable changes in accident numbers long-term is when the public as a whole wants safety. He found that every community only has as many accidents as it wants to have and the only way to change this is by changing the desired risk level (desired level of safety) [20]. According to it the number of casualties or the likelihood of becoming a casualty in an accident depends on the following elements: health promotion (education, motorization, communication with the public, programs, policy, legal regulations, and organizational changes), human factors (local level, social level) and behaviors and the environment. The theory helps to explain which behaviors and environmental factors are responsible for increasing the number of casualties and suggest safety measures.

The authors argue that the time has come to introduce a new period of history explaining how to occur traffic accidents using system dynamics. Last 10 years scientist from all of the world started to use System Dynamics to understand verity factors to assess

road safety and find the relationship between each other. Such scientists as N. Kumar [24], O.Tatari [50], J. Rasmussen [42], M. Alirezaei [4], D. Topolshek [51], M. Dolores Soto Torres [49], A.K. Kazadi [22], N. Minamy [38] and others used this method to study road safety. As the road safety studies involve various complex systems D-V-R-P-E that is driver, vehicle, road, pedestrian, environment, it is initial to develop a dynamic simulation model to understand the interactions between the various complex systems. This would evolve sustainable solutions towards ensuring road safety.

Grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering, system dynamics models are built to solve complex problems and to understand the nonlinear behavior of complex systems over time. Thus, in system dynamics models, human behavior, physical and technical systems are (can be) simultaneously considered as displaying an interdisciplinary characteristic. Components such as stocks, flows, converters, internal feedback loops, and time delays are used for system modeling and simulation. In system dynamics, a stock represents a part of a system whose value at any given instant in time depends on the systems past behavior. The value of the stocks at a particular instant in time cannot simply be determined by measuring the value of the other parts of the system at that instant in time – the only way you can calculate it is by measuring how it changes at every instant and adding up all these changes. Thus flows represent the rate at which the stock is changing at any given instant, they either flow into a stock or flow out of a stock. Converters either represent parts at the boundary of the system or parts of a system, whose value can be derived from other parts of the system at any time through some computational procedure [22].

Further, the comparison criteria for all the above methods for assessing road safety are determined:

Criteria 1: Does the paradigm allow a causality analysis, i.e. relationship between causes and accidents or road safety related occurrences?

Criteria 2: Does the paradigm allow a simulation of various scenarios and some form of sensitivity analysis?

Criteria 3: Does the paradigm allow a forecasting of road safety related parameters or values?

Criteria 4: Does the paradigm allow a comprehensive consideration and integration of statistical data collected from the field?

Criteria 5: Does the paradigm allows the consideration, in the model, of all relevant elements such as people, drivers, road infrastructure (+related parameters), environment, training (levels), enforcement, and policy measures/aspects?

Criteria 6: Does the paradigm allow the integration of expert knowledge in the model?



**Table 1**

**A comparison (according to six criteria) of the different modelling paradigms which have been historically used to assess road safety**

Road safety analysis approach	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Criteria 6
Stochastic theories	No. In this method, it is impossible to causality analysis. Since this theory, it is believed that all road accidents are random.	No. For a simulation of various scenarios, it should have data.	No. if the theory considers that accidents are random, then there is no point in predicting parameters or values related to road safety	No. The paradigm does not fully satisfies the requirements	No. The paradigm does not fully satisfies the requirements	No. The paradigm does not fully satisfies the requirements
Causal theories	Yes. This theory allows find a relationship between causes and accidents or road safety. The real causes of accidents can only be identified by detailed studies of each accident.	No. Each case is studied separately and the reason is determined. With this in mind, complex simulation of different scenarios is impossible.	Yes. If a systematic relationship between causes and effects is established, then it can be predicted.	No. In this paradigm, it is believed that drivers are always guilty and does not allow comprehensive consideration and integration of statistical data.	No. Causal theories only consider drivers.	No. To create a model you need to study in a complex. And not from one view.
Systemic theories	Yes. The paradigm allow a causality analysis complex into account not only people but roads and vehicles too.	No. For a simulation of various scenarios you should have all impacts of road safety.	Yes. It is possible to more or less predict road traffic safety taking into account influencing it.	No. Not enough comprehensive consideration as there is a lack of statistical data.	No. This paradigm is not studied so deeply.	No. There is a lack of statistical data
Behavioral theories	Yes. Behavioral theories allow a causality analysis	Yes. This theories allow a simulation of various scenarios and some form of sensitivity analysis	Yes. The paradigm fully satisfies the requirements	Yes. It can allow a comprehensive consideration	Yes. The paradigm fully satisfies the requirements	No. This paradigm doesn't allow to create a model
System Dynamics	Yes. The paradigm fully satisfies the requirements	Yes. The paradigm fully satisfies the requirements	Yes. The paradigm fully satisfies the requirements	Yes. The paradigm fully satisfies the requirements	Yes. The paradigm fully satisfies the requirements	Yes. The paradigm fully satisfies the requirements

## 4. Conclusion

COMPRAM allows us to figure out the way to handle complex societal problems while involving a System Dynamics (SD) simulation option. There are similarities between COMPRAM and the traditional way of analyzing road safety. In traditional ways, each element or factor is studied as a separate phenomenon. These indicators are studied in the stages of COMPRAM.

There are similarities between COMPRAM and the traditional way of analyzing road safety. In traditional ways, each element or factor is studied as a separate phenomenon. These indicators are studied in the stages of COMPROM.

The core difference from the traditional ways of analyzing road safety is that using this technique it is possible to comprehensively and completely study the problem of road traffic.

Table 2 below shows the differences between COMPRAM Methodology with the traditional road safety assessment approach where explained each stage.

Since this is a preliminary study, the authors set themselves the task of creating a model for assessing road safety in cities using COMRAD and System Dynamics.

**Table 2**

### Comparison of the COMPRAM Methodology with the traditional road safety assessment approach – Similarities and differences

COMPRAM general methodology to assess a complex societal problem	The traditional general way to assess road safety	Comments – describe similarities and differences, if any, between COMPRAM and the traditional Road Safety Analysis Procedures
Description of the problem. <i>Description in words (natural language) of the problem</i>	Clarification, systematization and critical analysis of factors affecting road safety	COMPRAM uses a 7-step layer for problem finding and analysis. For clarification it can be use 2-layer (Definition, concept and phenomena), for systematization 5- layer (semantic model) and for critical analysis 7-layer (system dynamic simulation model)/
Definition concepts and phenomena. <i>Definition of the concepts, phenomena and actors of the problem</i>	Selection of factors that may contribute to the deterioration of road safety	COMPRAM has similarities in choosing the right factors like traditional methods. But the best side is that it systematizes these factors and can determine how much they influence each other.
Theories hypotheses assumptions. <i>Verbal description of the basis of the knowledge: theories, hypotheses, experiences, intuition or assumptions, which explains the influence of the concepts, phenomena and actors on each other</i>	Establishment of technical reasons for a single incident and the possibility of its prevention by individual participants	COMPRAM has similarities in this issue
Knowledge island. <i>Graphic representation of the knowledge in the knowledge islands</i>	Justification of measures aimed at ensuring traffic safety (improving road conditions, improving the design of vehicles, preventing children's road traffic injuries, training drivers, etc.).	The use of system dynamics in the COMPRAM method makes it possible to simulate different case scenarios and justify each resolution.

**tab. 2 cont.**

Semantic model. <i>A semantic model which is a graphic representation of the relations between the concepts, phenomena and actors</i>	Forecasting changes in accidents.	The difference with traditional methods is that COMPRAM can build and evaluate scenarios in the forecast.
Causal model. <i>A causal model which is a graphic representation of the causal relations between the concepts, phenomena and actors</i>	Development of methods for analyzing traffic safety information	The difference is that with traditional methods they study information in a narrow section than in comparison with COMPROM where all data are analyzed in a complex and influence on each other.
System dynamic simulation model. <i>A system dynamic simulation model which is a graphic representation of the causal relations between the concepts, phenomena and actors based on differential equations.</i>	Development of universal software for the analysis of accidents with the use of computers	This is a strong side of COMPRAM compared to traditional methods, where it is possible to systematize and create a specific algorithm action where absent in traditional methods.

### **Acknowledgements**

*This work was supported by the Project INTRAS - Intelligent Transport Systems: New ICT – based Master’s Curricula for Uzbekistan, co-funded by the ERASMUS+ scheme under grant agreement n. 2017-3516/001-001.*

*The article has been presented on 13th International BRD GAMBIT 2020 Conference. Article was co-funded by the Science Excellence programme of the Ministry of Science and Higher Education.*

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