Application of System Dynamic Simulation Modeling in Road Safety

Er. S. Naveen Kumar M.E. and Dr G.Umadevi[++]

ABSTRACT

Nearly 1.2 million people die worldwide as a result of road traffic collisions every year. Over 1.2 lakh of people are killed every year on Indian roads. The economic loss due to road accident is over Rs.75, 000 crores per annum in India by 2009. Road accident scenario in the State of Tamilnadu is also very grim; nearly 12000 people are killed in about 60,000 accidents annually. In Chennai City there are 35 fatalities per 10000 vehicles which are 2.5 times higher than the national average. Hence it is imperative to study the root cause of accident occurrences by developing macro level simulation model for ensuring the road safety.

In this study an attempt is made to identify the various causes for road accidents in Chennai City and to develop a System Dynamics simulation model as conventional model lacks in reducing accident severity. Systems approach is not a mere theory, but a way of thinking and practical philosophy of solving problems. System Dynamics is a methodology, whereby complex, dynamic and non linear interactions in social systems can be understood and analyzed and new structures and policies can be designed to improve the system behavior. As the road accident prediction studies involve various complex systems namely the human, road, vehicle and all other environmental factors, it is vital to develop dynamic simulation model to understand the interactions between the various complex systems. This would evolve sustainable solutions towards ensuring road safety.

In this work the System Dynamics Simulation software namely STELLA is used. Accident data pertaining to training given to the public, transport, highway and police officials are collected from Government sources. The developed model is calibrated for various scenario options ranging from best policy to worst policy. The model has also been validated with the real world accident records.

Key words

Systems Approach – System Dynamics Simulation Modeling – Application Road Accidents Analysis – Road Safety – Policy and Scenario Analysis – State Government Policy on Accident Reduction.

++M.E.Urban Engineering scholar and [++] **Associate Professor in Civil Engineering**
Transportation Engineering Division, College of Engineering (CEG), Guindy Anna University, Chennai 600 025.
E-mail: gudevi1@gmail.com [+]

From the study results the optimum scenario which would reduce the road accidents towards ensuring road safety is selected and suggested. The study inferences reveal that it is imperative to impart training not only to all the government personnel concerned but various stakeholders who are involved with road accidents. This is because the human factors contribute more than 95 percent of road accidents among the total road accidents.

1 Introduction

Millions more are injured and often remain disabled for life. In India 94968 persons were killed and 465282 were injured by motor vehicles annually. In Tamilnadu level 60,794 were injured and 13,746 were killed by motor vehicles in the year 2009. Tamil Nadu has the second place in the country in Accident Risk Index, and the number of accidents is estimated to increase three folds by 2020. The total accident in Chennai City is around 6000 per year and the fatal accident contributes one – tenth in it. The increasing population has exerted an increasing number of vehicles. The rise in number of vehicles without adequate augmentation of road infrastructure is one of the major reasons for the road accident occurrences. Hence it becomes necessary to identify the causes of accidents with respect to the various factors such as human, road, vehicle and environmental factors.

2 Need for the Study

In the above back drop of the accidents scenario 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. Hence the system dynamics (SD) methodology comes as a handy tool to reduce the accidents to ensure road safety. 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 host of factors causing accidents in any region or metropolitan cities. Most of these accidents have been caused as a result of neglecting road etiquette. Human factors are one of the major causes which contribute more than 95 percent of road accidents. Other factors namely road factors and vehicle factors contribute only a very negligible proportion. Since factors responsible for human errors are very dynamic in nature involving physical, physiological and psychological factors it is very imperative that a dynamic modeling should be developed to understand the system and its interactions.

3 Objectives of the Study

- To identify the various causes for road accidents in Chennai City;
- To develop the System Dynamics simulation model for the prevailing conditions;
- To test the developed model for various scenario options including the existing Road Safety Policy of the State Government;
- To suggest appropriate policy to reduce the road accidents and ensure road safety.

4 Dynamics of road accidents

Fig.1 depicts the system approach with its importance of thinking with creativity. The system thinking has three dimensions. Firstly its conceptual structure of connectivity between the various factors responsible for system dynamism. Secondly the feedback mechanism which is the fundamental building blocks responsible for system performance. Lastly its degree of abstraction which considers the holistic way of conceptualizing various sub systems with its dynamic elements.

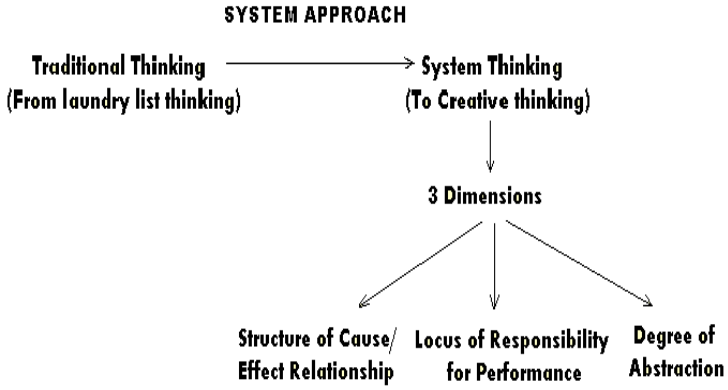

Fig. No.1 Systems Approach with Systems Thinking

Fig.2 shows the various factors responsible for accident occurrences in floundering or laundry way thinking. This should be modified and systems principles should be applied before conceptualizing the system interaction. Figure.3 shows Dynamic Frame Work of accident occurrences with Precision by establishing cause and effect relationship between the various elements involved within the systems with vital variables. This leads to evolve sustainable solution for a given complex and dynamic system.

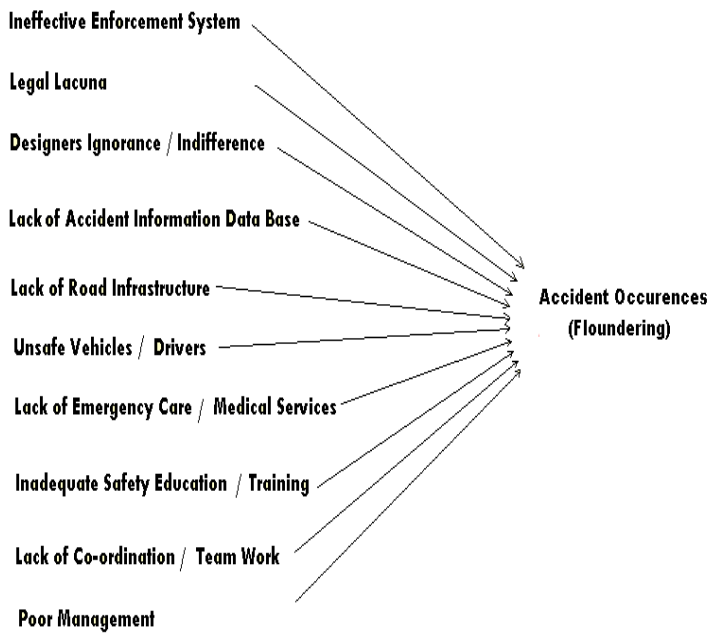

Fig. No.2 Static Frame Work of Accident Occurrences

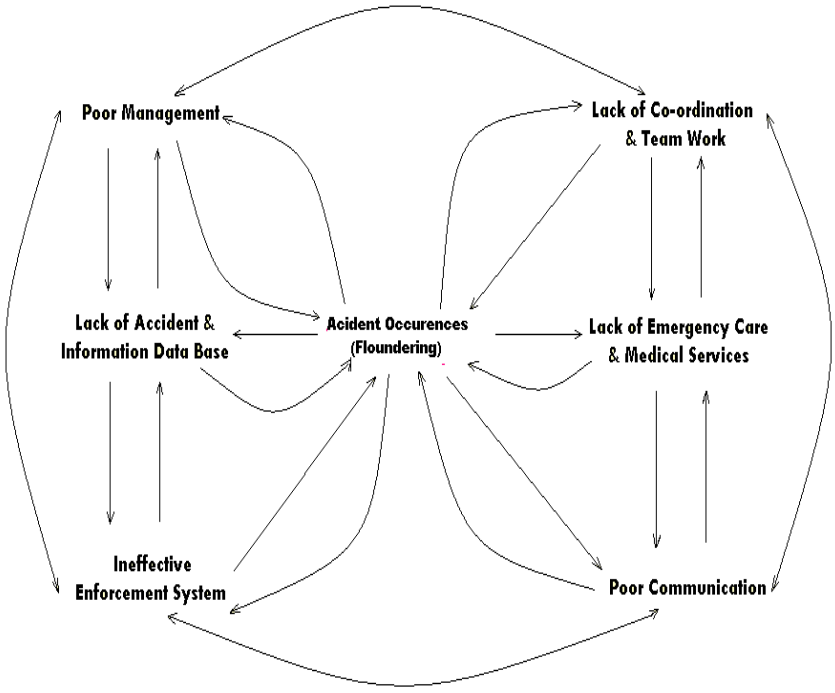

Fig. No.3 Dynamic Frame Work with Precision

4.1 Dynamic feed back in SD

It could be seen from fig.4 that the various feedback loops exist with its interdependency between the action, condition and the target to be achieved to ensure road safety in a temporal manner. Like this there may be any number of target conditions and discrepancies which could be accounted. Conditions and actions might be evolved for horizon years based on the complexity of the problem in system dynamics modeling. This would justify the applicability of SD modeling in addressing very complex problems.

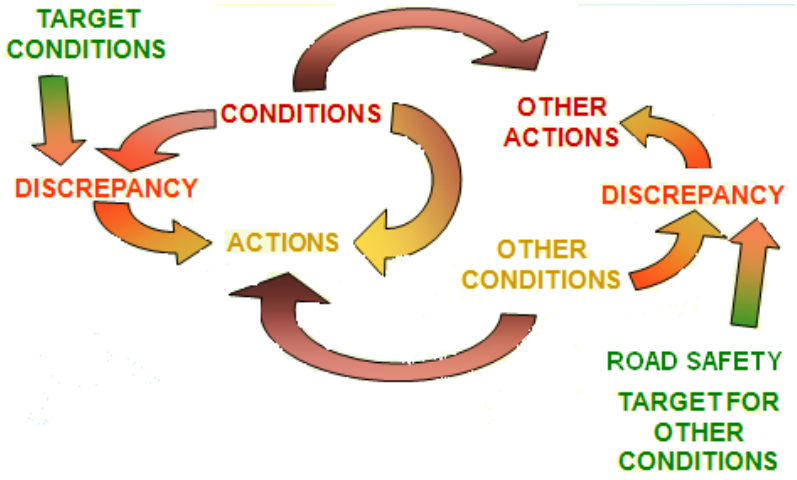

Fig. No.4 Feedback with Simple Inter dependency

4.2 Phases in Model Building Process

The phases in the model building process are given in Fig. 5. The first phase of model building process is the problem definition which involves how to infer causal relationships and how to interpret graphs. Second phase is system conceptualization by evolving causal-loop diagram to account cause and effect relationship between the variables within the system. Model representation is the third phase in which models are represented in the form of flow diagrams. In model behavior phase, Computer Simulation is done to observe the system behavior over a period of time. Under model evaluation phase, checking for logical consistency, matching model output against observed data collected over time. At this stage

formal statistical significance of the parameters are carried out. The last phase of policy analysis and model use would test alternative policies that can be implemented in the system. Designing and testing policies using computer simulation model is major part of this phase. Implementing the results of computer based analysis is often even more challenging.

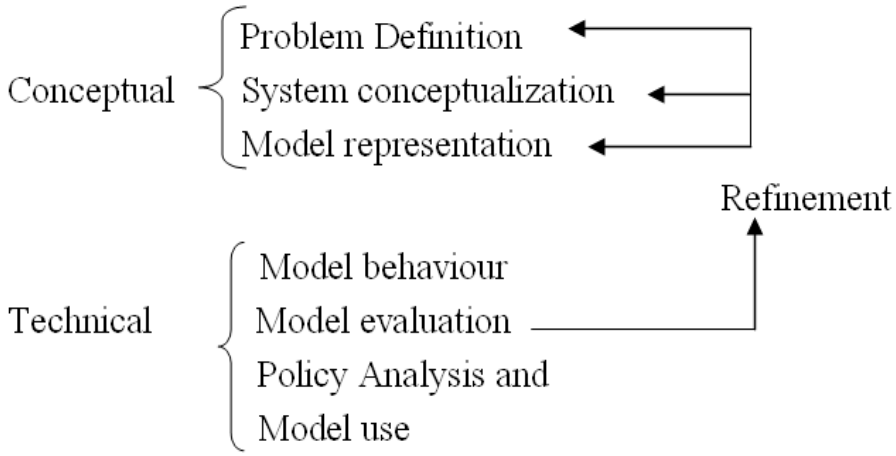

Fig. No. 5 Phases in Model Building Process

5 Description of Study Area

Chennai is the one of the vital metropolitan cities of India, which is located in the state of Tamilnadu at the southern region of the country. The System Dynamics model has been developed for the whole Chennai city at macro level in the present work. Though in this research work SD model is built for various hierarchies of urban roads it is not presented in this paper by considering the length of the paper.

5.1 Data Collection

The data collected includes primary as well as secondary data. The accident data collected has been analyzed for observing the current trend of accidents in various roads. From the secondary data collected from the concerned authorities the prioritization of the spots is made. The secondary data collected includes details like year of accident, time of accident, type of accident, locality of accident, fault and victim vehicle involved in the accident, type of injury, etc. the secondary data collected for five years from 2005-2009 from the Chennai City Traffic Police (CCTP). Fig. 6 depicts the key map of study area.

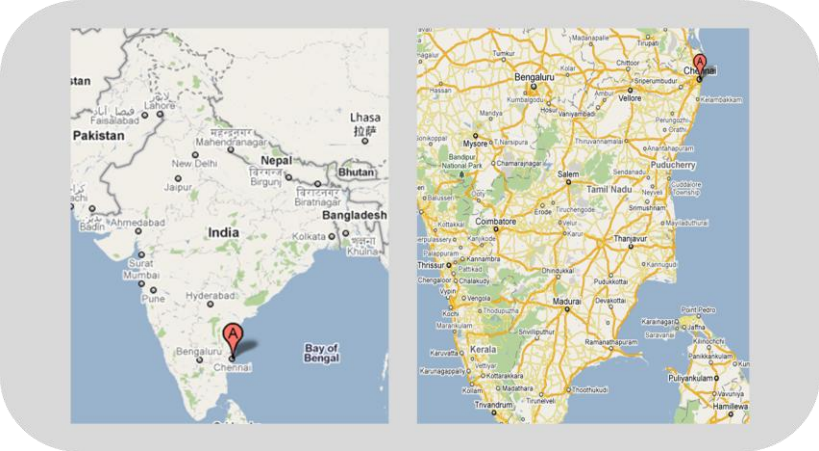

Fig. No.6 Key map of Chennai city

Data regarding the amount spent for training to prevent accidents are collected from the Government Departments. Information on public awareness programs are collected from TNRSP (Tamil Nadu Road Sector Project). The accident data collected has been statistically analyzed to identify the pattern of occurrence of accidents. From the yearly distribution of accidents from 2005 to 2009 it is found that during the year 2008 there is a drastic increase in the total number of accidents. The accident analysis part is presented in the succeeding sections.

5.2 Analysis of Accidents

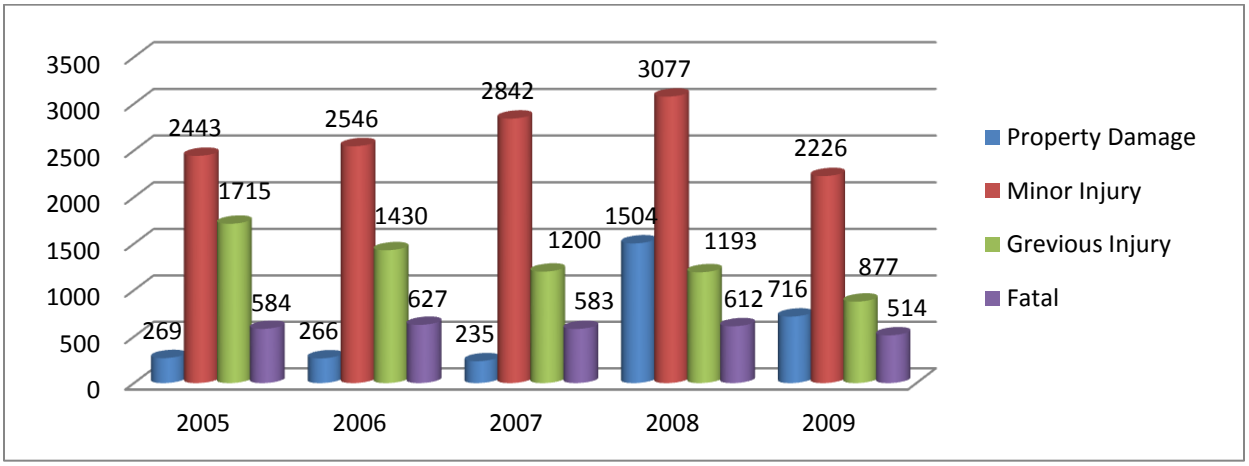

Fig. No.7 Distribution of Accidents by Type of Injuries

The above fig.7 shows the yearly distributions of accidents according to the type of injuries namely major, minor, fatal and property damage. It is observed from the figure that the minor injury is mainly on the increasing trend yearly.

5.2.3 Nature of Injuries

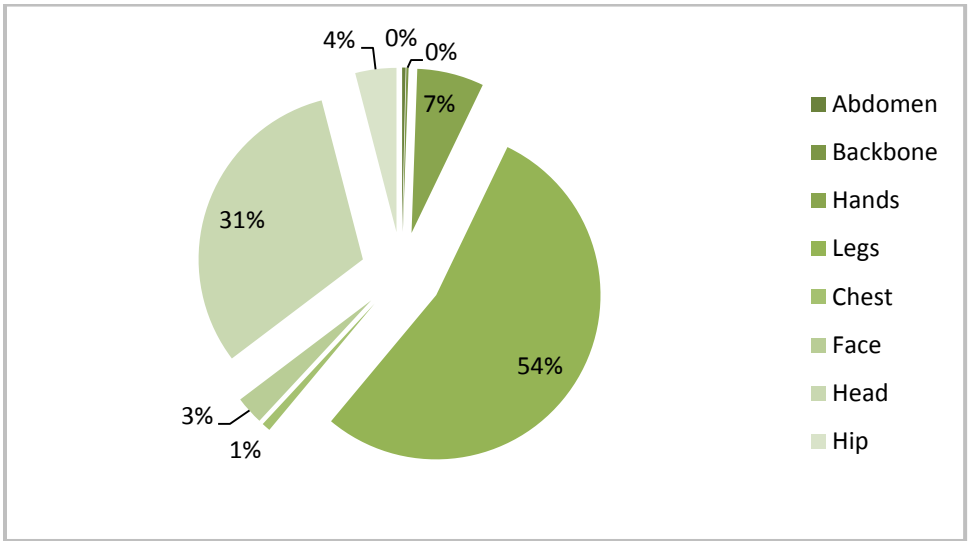

Fig No. 11 Accident Distribution by Nature of Injuries

The fig 11 gives the nature of injuries for the year 2009 and in which abdomen injury is more contributing nearly 54percent of the nature of injury when compared to all other injuries.

5.2.4 Agewise and Timewise Accident Occurrences

Fig. 12 shows the age wise distribution of the accidents. It is observed that the age slab between 21 – 30 years is met with more accidents which is in the order of 1225 in numbers when compared to all the other groups. The next group is 31 – 40 which is in order of 969 in numbers.

The fig.13 illustrates the accidents with respect to time wise. In which the evening hour's accidents are more when compared to the morning hours. The order of accident occurrences are around 1170 for morning hours and 1384 in evening hours. Surprisingly the lunch hour occurrences are around 1300 as well.

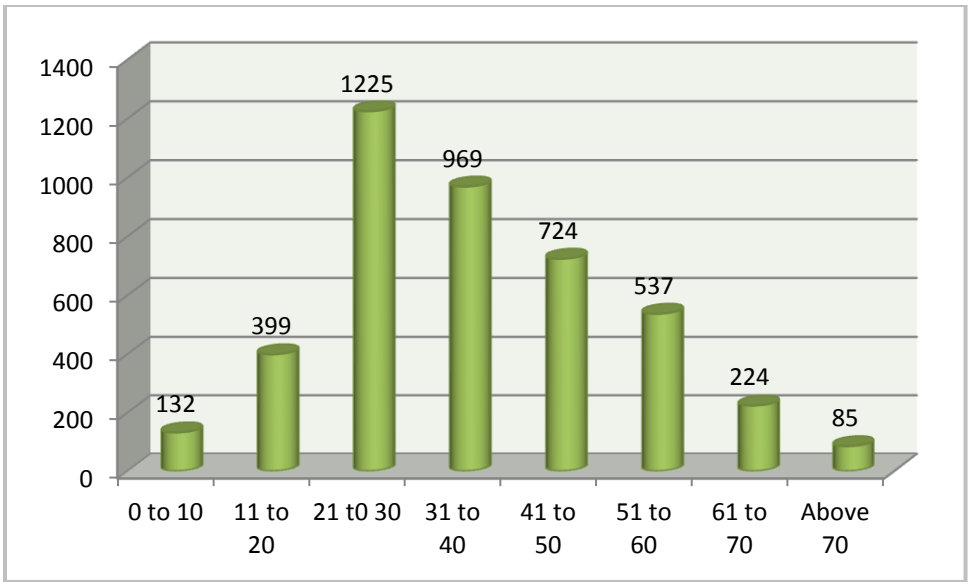

Fig No.12 Agewise Accident Occurrence

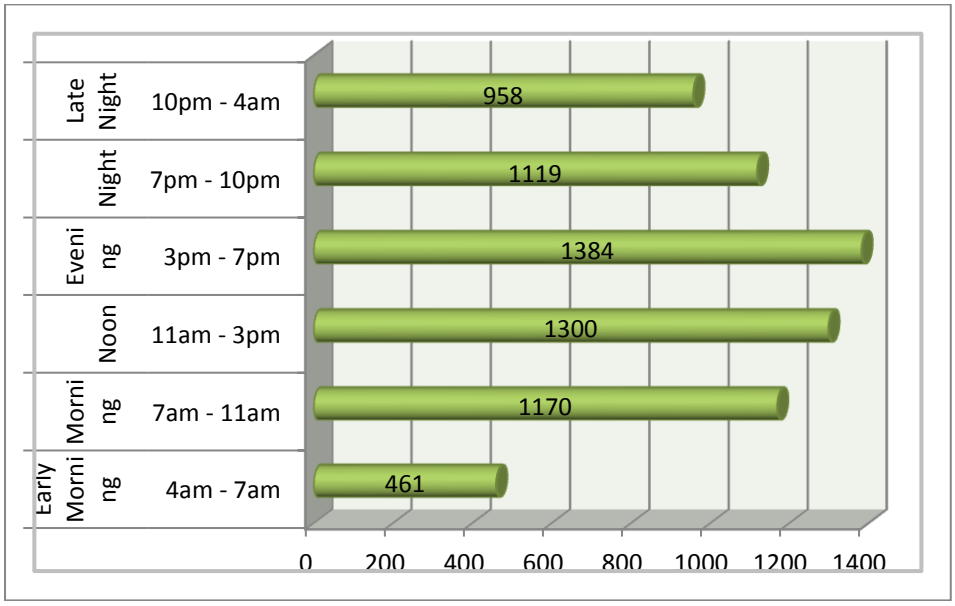

Fig No. 13 Timewise Accident Occurrence

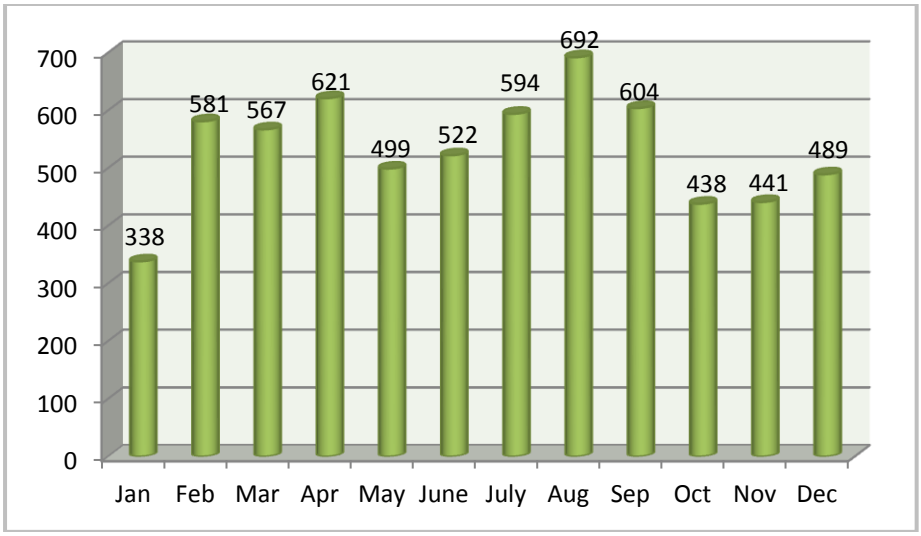

Fig No.14 Monthwise Accident Occurrences

The fig.14 shows the accidents occurred in month wise for the year 2008. In the month of august 692 accidents occurred which is followed by 621 in the month of apirl.

6 System Dynamics

System dynamics has a long history as a modeling paradigm with its origin in the work of Forrester (1961) from Massachusetts University in United States, who developed the subject to provide an understanding of strategic problems in complex and dynamic systems. System dynamics models, by giving insight into feedback processes, provide system users with a better understanding of the dynamic behaviour of systems.

It is a methodology whereby complex, dynamic and non linear interactions in social systems can be understood and analyzed and new structures and policies can be designed to improve the system behaviour. It is the result of 'Cross Fertilization' among elements of traditional management, feedback control theory and computer simulation.

7 Building Blocks of Model

The system dynamics modeling tool has four basic building blocks. Stocks or levels are used to represent anything that accumulates. An example of stock would be population level at one point of time. Flows or rates represent activities that increase and decrease stocks. An example of flow includes birth rate or death rate. Connectors are used to establish the relationship among variables in the model, which is represented as arrows graphically in the model. They carry information, which can be a quantity, constants, an algebraic relationship or a graphical relationship. Converters transform input into output. Converters can accept input in the form of algebraic relationships, graphs and Tables. For ease of presentation, the symbols used for flow diagramming of System Dynamics are depicted in the Fig.15 Flow Diagramming symbols. Through the flow diagram symbols only the system dynamics simulation modeling is represented in the computer.

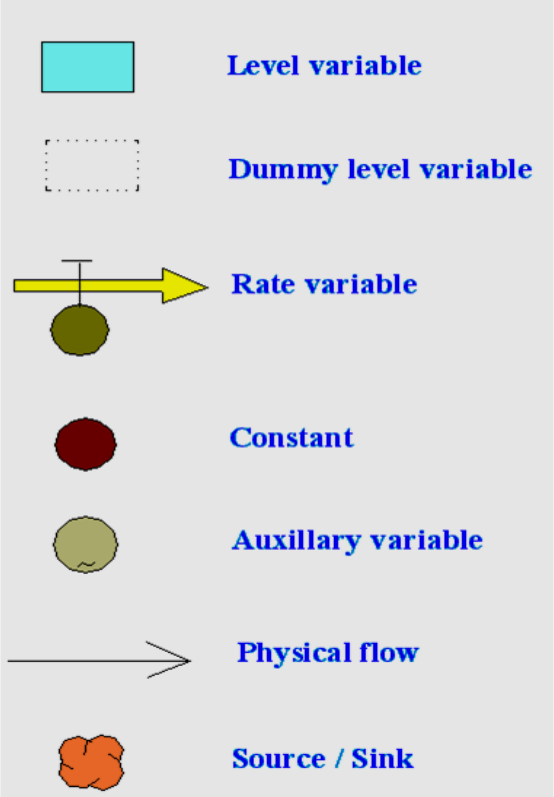

Fig.15 Flow Diagramming Symbols

8 Model conceptualization

In system dynamics modeling after defining the problem the next vital stage is model conceptualization. In this stage the complete concept based on which the model is built is derived. A causal loop diagram is a visual representation of cause and effect of variables in a system. Usually a positive effect is indicated using the '+' sign and negative effect with '-'sign. The causal loop diagrams are represented separately for the individual sectors and as a whole.

The various causes for road accidents are classified under five categories namely human factors, vehicle factors, road and traffic factors, environmental factors and other factors which are clearly depicted in fig.16. From the analysed data it is observed that human factors contribute more than 95 percent but the vehicle factors and road factors together contribute only less than 5 percent.

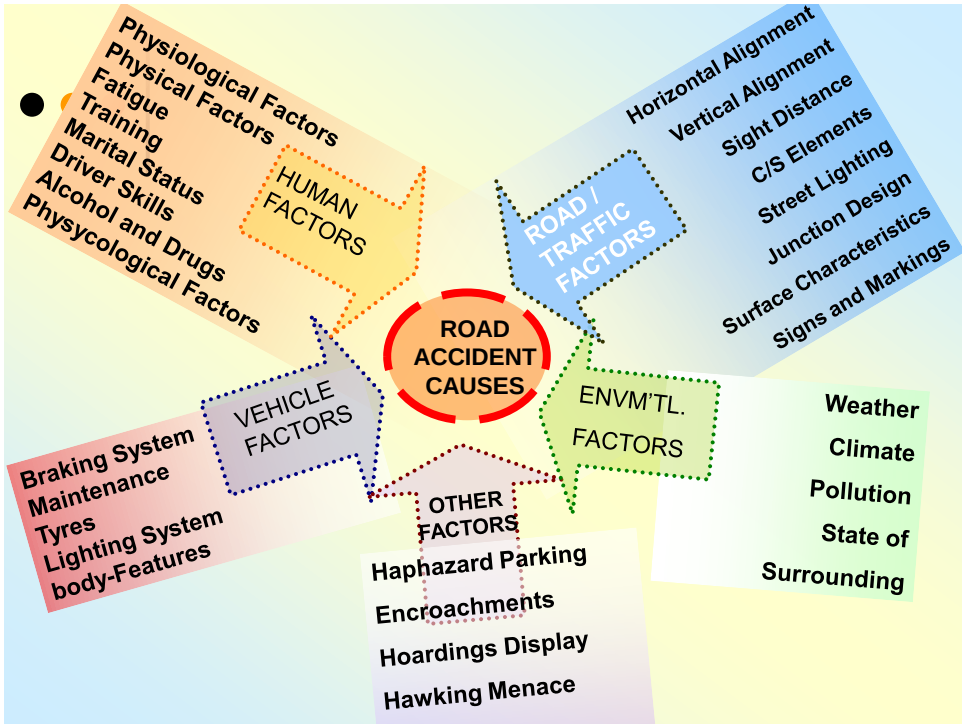

Fig. No. 16 Causes of Road Accidents

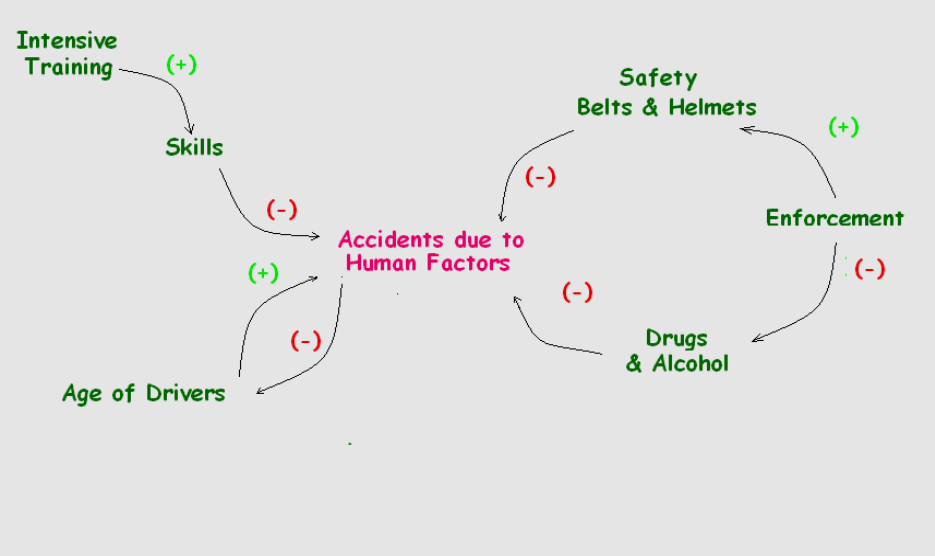

Fig. No. 17 Human Factors influencing road accidents

The various factors which are responsible under human category with its influence between the variables are shown in fig.17. From the figure, the influence of enforcement and age of drivers on the accident occurrences, either positively with a reinforcing effect or negatively with an inhibiting effects, is observed.

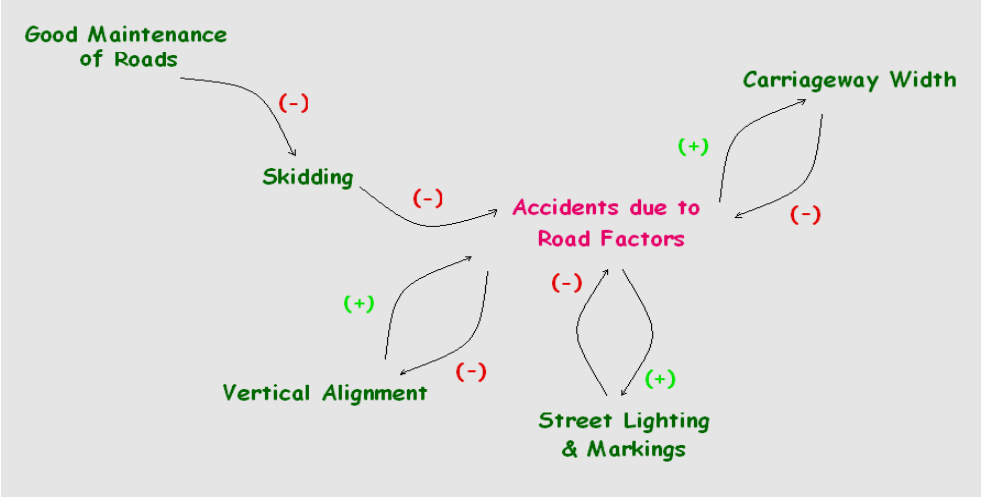

Fig. No. 18 Road Factors influencing road accidents

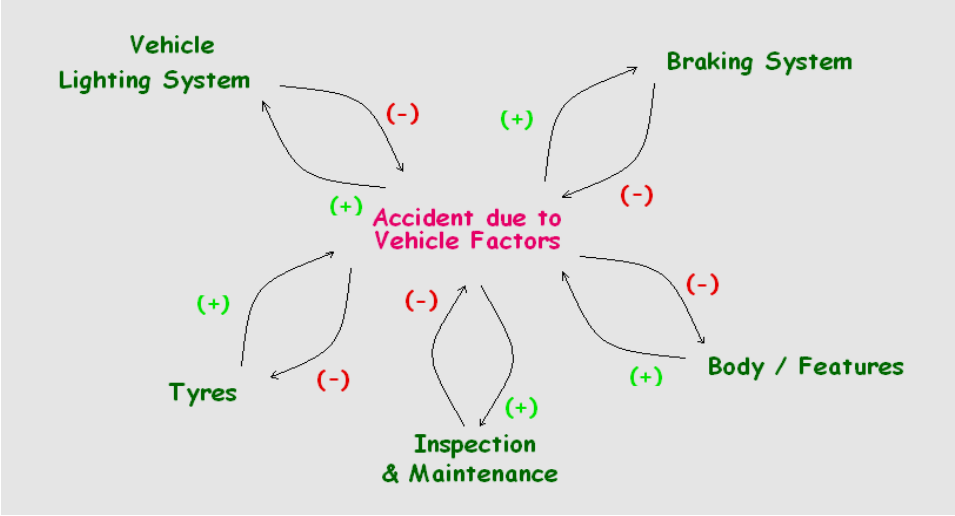

Fig. No. 19 Vehicle Factors influencing road accidents

The influence of road factors and vehicle factors on accident occurrences are evolved and shown in fig.18 and fig.19 respectively. The figures show that the influence of carriage way width and maintenance of roads in road factors and inspection, maintenance of vehicles in vehicle factors influence positively the reduction of accidents.

9 Model Development

The model of Road Accident is developed in this study, using the System Dynamics Simulation Software 'STELLA'. The STELLA is object oriented simulation software which allows the development of any complex, dynamic and non linear systems with significantly less effort than using traditional programming languages. It has a user-friendly graphical interface and supports modular program development.

In the Human factors, speed violation, overtaking, and drunken driving 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. The model for human factors is shown in the fig.20. The value of accidents occurrences for the year 2005 is taken as base year level for the human factor model.

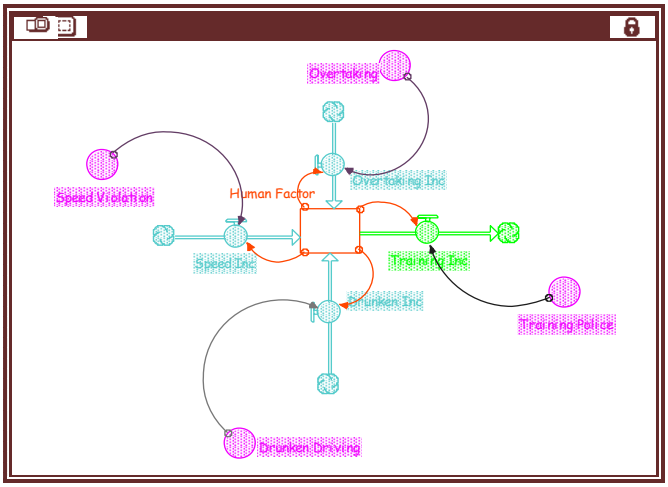

Fig. No. 20 Model Sector for Human Factors

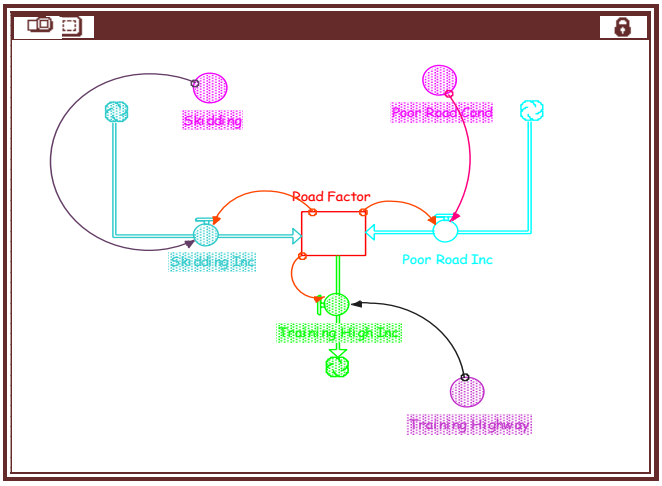

Fig. No. 21 Model Sector for Road Factors

In the road factor model poor road conditions and skidding due to the road surface is taken as main parameters and the model for road factors is shown in fig. 21 In the road factors skidding and poor road condition are taken as inputs which contribute 12percent and 52percent respectively. The base year value is given as 26 for the road factor which is the total number of accidents occurred due to the road factors for the year 2005.

In the vehicle factors tyre burst and brake failure are taken as major causes and it contributes 26percent and 53percent respectively. It is shown in the fig. 22. Here the base year value is considered as 16 which is the value for the year 2005 in vehicle factors model.

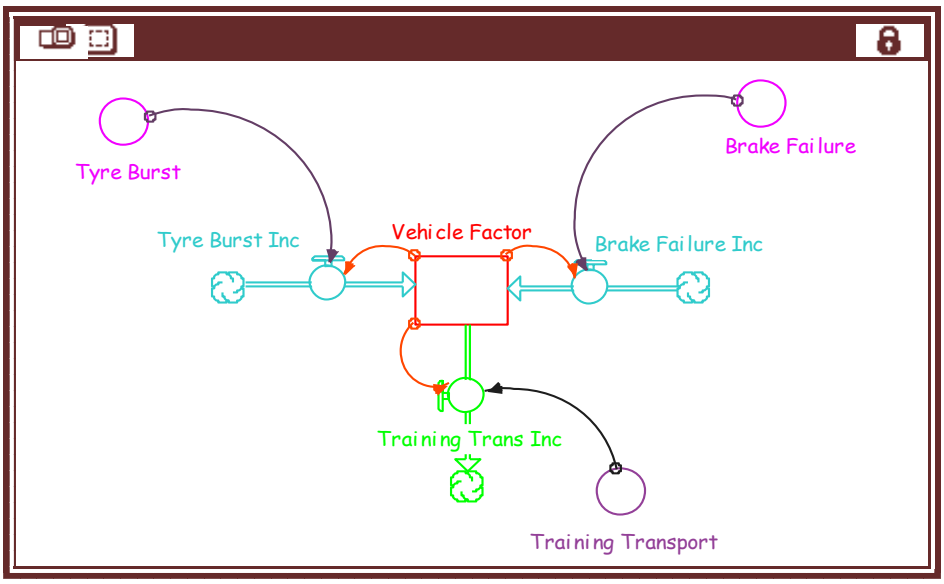

Fig No. 22 Model Sector for Vehicle Factors

Table No. 1 Model results for do minimum Scenario

Year	Human Factors
2005	4,543
2006	5,043
2007	5,598
2008	6,214
2009	6,899
2010	7,658
2011	8,501
2012	9,437
2013	10,476
2014	11,629
2015	12,909
2016	14,330
2017	15,908
2018	17,659
2019	19,603
Final	21,761

If the existing trend continues in the year 2020 the accidents with respect to human factor would increase to 21761 in number. In the case of road and vehicle factors it would reach around 142 and 83 respectively.

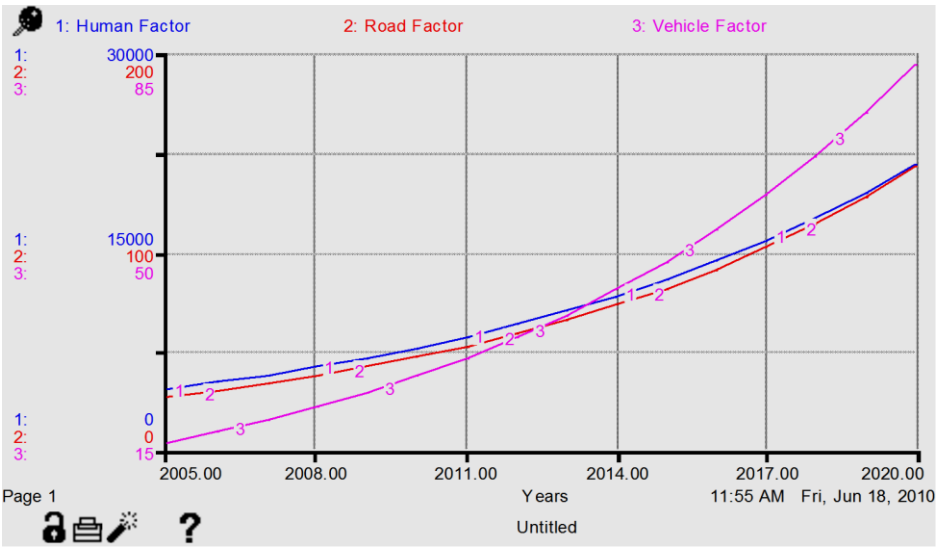

Fig. No.23 Model Results for Do Minimum Scenario

The fig.23 shows the accident trend of the years 2005 to 2020 in which the road and human factors are nearly in the same trend. In the human factors it is reaches from 4543 to 21761 in numbers. This is around four fold increase in the horizon year. The various parameter values given as model inputs are based on the actual data available with the concern authority in this scenario.

10 Partial Efforts Scenario

The table 2 shows the model results for the “Partial Efforts Scenario”. Here the values of all factors in getting reduced compared to do minimum scenario. This is done by using the amount spent for training by the authorities towards the transport peoples, police and highway officials. Amount spent for training is around Rs 43 lakhs per year. The projected parameter values given in the model are based on the actual amount spent towards training and awareness by the concern authority in this scenario.

It is observed from the table that after giving partial training the accident values are reducing substantially from 4543 to 9437. However with this values are very less when compared to do minimum scenario results. This increase in accident is, in the order of 56percent less when compared to do minimum Scenario.

Table No. 2 Model Results of Partial Efforts Scenario

Year	Human Factors	Road Factors	Vehicle Factors
2005	4,501	26	16
2006	4,726	27	17
2007	4,962	28	18
2008	5,210	28	19
2009	5,471	29	20
2010	5,745	30	22
2011	6,032	31	23
2012	6,333	32	24
2013	6,650	33	26
2014	6,983	34	27
2015	7,332	35	29
2016	7,698	36	31
2017	8,083	37	33
2018	8,487	38	35
2019	8,912	39	37
Final	9,357	41	39

Source: Model Analysis

11 State Government (SG) Policy in Accident Reduction Scenario

The state of Tamilnadu is located in the Southern part of the country where the level of accidents is in an alarming rate. On the contrary this state is one of the states in the country wherein Accident Database Management System is efficiently recorded. The Tamilnadu State Government is the first government in the country which framed the road accident target in the year 2006 to ensure Road Safety. This envisages the 20 Percent reduction of accident rate by as the State Government (SG) Policy by the year 2013 by taking 2006 as a base year.

Hence in this study the effectiveness of this policy is taken as one of the scenario while building the simulation modeling. To achieve this policy the government is very actively accelerating various schemes with huge investment to ensure Road Safety under the umbrella of Tamil Nadu Road Sector Project (TNRSP). The model also estimates the cost components to achieve this target as envisaged in the original policy.

The table 3 shows the model results of “20 percent Accident Reduction Scenario”. The model results revels that allocating a minimum of Rs. 65 lakhs per year (only on training and awareness aspects) by the state government for imparting training to public, police officials, transport department personnel’s and highway officials, the road accident target could be

achieved. The cost estimation is based on the level of training given at present by the authorities to various stake holders. The amount they spend currently for the same is collected from the authorities.

Table No. 3 Results of SG Policy in Accident Reduction Scenario

Year	Human Factors	Road Factors	Vehicle Factors
2005	4,501	26	16
2006	4,375	23	15
2007	4,252	20	14
2008	4,133	17	13
2009	4,018	15	12
2010	3,905	13	12
2011	3,796	11	11
2012	3,690	10	10
2013	3,586	9	10
2014	3,486	7	9
2015	3,388	6	9
2016	3,293	6	8
2017	3,201	5	8
2018	3,112	4	7
2019	3,024	4	7
Final	2,940	3	6

Source: Model Analysis

The value of total number of accidents in “20percent Reduction Scenario” shows that the accident reduction is observed from 4543 to 2949 in numbers vides fig.24. It clearly reveals that accident severity is reducing gradually from the base year to the horizon year.

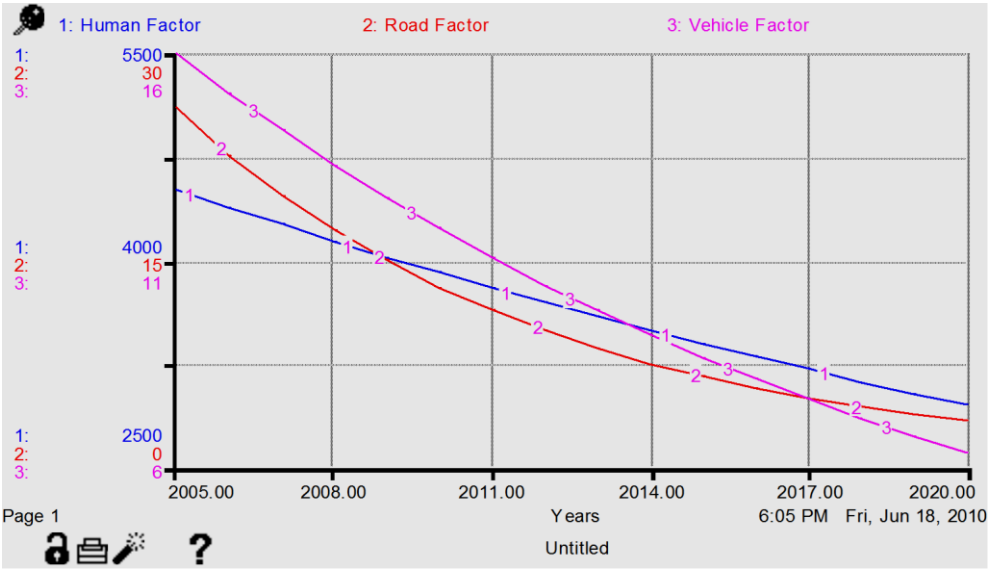

Fig. No. 24 Results of SG Policy in Accident Reduction Scenario

In the “Desirable Scenario” is done to calibrate the model to achieve nil accident trend in the future years. The amount needed for the training is Rs. 1.3 crores per year. The results of this scenario are given in the table 4.

Table No. 4 Results of Desirable Scenario

Year	Human Factors	Road Factors	Vehicle Factors
2005	4,501	26	16
2006	3,421	19	12
2007	2,600	14	9
2008	1,976	10	7
2009	1,502	7	6
2010	1,141	5	4
2011	867	4	3
2012	659	3	3
2013	501	2	2
2014	381	2	2
2015	289	1	1
2016	220	1	1
2017	167	1	1
2018	127	0	1
2019	97	0	0
Final	73	0	0

Source: Model Analysis

The results of all scenarios are consolidated and tabulated in table 5. Here the total accident for the horizon year is getting reduced to 20 percent in the “Desirable Scenario”. In the ‘Do Minimum Scenario’ the values are increased from 4543 to 21761 numbers and in the partial scenario it gets increased to 9437. But in the “20 percent Reduction Scenario” the values are getting reduced to 2949 from 4543 in numbers. In the “Desirable Scenario” the values are decreasing substantially which is 77percent less when compared to partial efforts scenario. In the Desirable Scenario the accident reduction more than 97 percent.

The developed model has been validated through back simulation methodology which reveals that the errors are within tolerable limits.

Table No. 5 Results of all Model Scenarios

Year	Total Accidents				
	Do Minimum	Partial Efforts	20 percent Reduction	Desirable	Desirable
2005	4,543	4,543	4,543	4,543	4,543
2006	5,043	4,770	4,413	4,311	3,452
2007	5,598	5,008	4,286	4,092	2,623
2008	6,214	5,258	4,164	3,884	1,993
2009	6,899	5,521	4,045	3,688	1,515
2010	7,658	5,796	3,930	3,501	1,151
2011	8,501	6,086	3,818	3,324	875
2012	9,437	6,390	3,710	3,157	665
2013	**10,476**	**6,709**	**3,605**	**2,998**	**505**
2014	11,629	7,044	3,502	2,847	384
2015	12,909	7,396	3,403	2,703	292
2016	14,330	7,765	3,307	2,568	222
2017	15,908	8,153	3,214	2,439	168
2018	17,659	8,560	3,123	2,316	128
2019	19,603	8,988	3,035	2,200	97
Final	**21,761**	**9,437**	**2,949**	**2,089**	**74**

Source: Model Analysis

13 Results

- In “Do Minimum Scenario”, the number of accidents is increased from 4543 to 21761 numbers.
- “Partial Efforts Scenario” shows that the accident level is 9437 which is 56.6 percent less when compared to Do Minimum Scenario. To achieve these 43 lakh rupees is needed towards training the transport, highways and police officials and public awareness.
- In 20 percent SG target in accident reduction scenario, the accidents are getting reduced to 3605 in the year 2013 from 4543 in base year. Hence in this scenario 20 percent reduction in accidents is achieved as per the policy of State Government.
- The “Desirable Scenario” achieves an accident reduction of 97 percent is achieved.

14 Conclusions

- To reduce the accidents, equal importance must be given for training the public, transport, highways and police officials. Then only appropriate reduction in accidents will be achieved.
- To achieve target of Tamil Nadu Road Safety policy to reduce 20 percent of accidents (by 2013 taking 2006 as a base year) around 65 lakhs rupees per year is needed for training (for training sector alone) the police, transport and highway officials and increase the public awareness.
- If 65 lakhs rupees is spent per year the accident trend will reduce from 4543 to 3605 by the year 2013 which is the target of the Tamilnadu road safety policy.
- Desirable scenario gives best results more than the Road Safety Policy of Tamil Nadu. Though it appears unrealistic this scenario is obviously presented here just to show the influence of extensive training and public awareness.

15 Recommendations

- Though the model reveals drastic reduction in accident is possible, it is up to the road users to obey the traffic rules and drives accordingly. Mass obedience with good mind set and change for good cause from the public is very vital to ensure road safety.

16 Scope of the research work

- All the major roads in Chennai were the accident occurrences are beyond endurance are to be taken and modeled in detail at micro level to see the variations in accident severity along each urban arterials.

17 Limitation of the study

- This research work only attempts a macro level modeling for a metro city like Chennai. However the study area may be restricted to many sectors within the metro city to see the influence of causative factors towards accident occurrences.

References

1. Ahmad Rodzi Mahmud Ehsan Zarrinbashar (2002) 'Intelligent GIS-Based Road Accident Analysis and Real-Time Monitoring Automated System using WiMAX /GPRS' Faculty of Engineering, International Journal of Engineering Volume (2), Issue (1).

2. Arul V.S. (2007) 'Cluster Analysis for improving road accident black spots', ME thesis, Anna University, Chennai.

3. Bener. A and Crundall. D (2005) 'Road traffic accidents in the United Arab Emirates compared to Western countries', Advisor WHO & Dept. of Medical Statistics Epidemiology, Doha, Qatar.

4. Bhaskar. N (2002) 'Mitigation of Bus Passenger Accidents – a case study of Accidents involving MTC in Chennai', ME thesis, Anna University, Chennai.

5. Brussels (1999), 'Intelligent transportation systems and road safety' European Transport Safety Council, Bruxelles.

6. 'Building the Road Safety Profession in the Public Sector' (2007), Transport Research Board, Washington D.C

7. Gowri. A (2004) 'Accident Analysis using GIS – A case study of Thiruchirapalli District, Tamil Nadu', ME thesis, Anna University, Chennai.

8. Hongbo Wu (2004) 'Road Safety Situation in China' Research Institute of Highway, MOT, China.
9. Mouyid Bin Islam (2008), 'Identification of factors in road accidents through in-depth accident analysis', Thailand Accident Research Center Asian Institute of Technology, Pathumthani, Thailand.

10. Padma. S (2004), 'Analysis of accidents involving MTC buses – A case study of CMA', ME thesis, Anna University, Chennai.

11. Ravishankar Rajaraman (2009), 'Analysis of Road Traffic Accidents on NH45, Kanchipuram District (Tamil Nadu, India)', JP Research, Inc, Mountain view, CA.

12. Sayer I A and Downing A J (1996) 'Pedestrian accidents and road safety education in selected developing countries', Transport Research Laboratory, Old Wokingham Road Crowthorne, Berkshire.

13. Sivagamasundari. M (2007), 'Web GIS based Accidents Analysis system', ME thesis, Anna University, Chennai.

14. Umadevi G (2010), "System Dynamics in road safety" Presented and published in the proceedings of the seminar on "chensafe - 2010 Towards road user safety" January 4-5, 2010 organized by Alumina Association College Of Engineering in association with Division Of Transportation Engineering Of Anna University and Indian Institute of Technology Madras (IIT), Chennai, at Anna University, Chennai – 25.

15. Umadevi.G. (2006), "Land Use Transport Interaction Modeling – A Systems Approach in the Highway Research Bulletin, A Journal of Indian Roads Congress (IRC) – A National Level Apex Body in Transportation Engineering.

.....