Systematic Literature Review of Vehicular Traffic Flow Simulators

Mian Muhammad Mubasher
Punjab University College of Information Technology
University of the Punjab
Lahore, Pakistan
mubasher@pucit.edu.pk

Syed Waqar ul Qounain Jaffry
Punjab University College of Information Technology
University of the Punjab
Lahore, Pakistan
swjaffry@pucit.edu.pk

Abstract—**In modern world means of communication and commutation plays a significant role in collective social growth. It is a well observed phenomenon that due to concentration of educational, career, and business opportunities along with easy access to services, population is increasing in urban centers. Increasing population in urban centers is posing many challenges to urban managers and engineers. Ensuring smooth vehicular traffic flow is very important among them. It includes maintenance of current traffic infrastructure, optimal deployment of traffic regulators and cost effective extension of existing infrastructure which requires experimentation of different what-if scenarios. Urban traffic is among those systems which cannot be interrupted in order to experiment hence simulation is most suitable option for policy makers to perform different what-if scenarios. Choice of vehicular traffic flow simulator play a vital role in experimenting these what-if scenarios. This paper presents a systematic review of existing vehicular traffic flow simulators presented and used in research literature. This review includes type of license i.e. the simulator is closed or open source and freeware or proprietary, usage of the simulator i.e. what type of modeling and simulation tasks can be performed using the simulator, developer of the simulator, and citations of the simulator in research literature.**

Keywords—vehicular traffic flow; what-if scenarios; simulator; opensource

I. INTRODUCTION

Computational modeling is a branch of computer science which has several applications in diverse areas of study. It assists other disciplines to explore dynamics of complex phenomena under observation by providing theories, tools and technologies for modeling and simulation of those phenomena. Transportation engineering and urban traffic management is among one of the most important areas of study for computational modelers which has a direct impact on sustainable development of a society. Hence techniques of computational modeling have widely been studied and applied in this area [1]. Various aspects of the urban traffic management has been benefited through such studies. Urban traffic management is a very interesting and challenging phenomena. Due to huge population growth and of an increasing trend in migration towards cities its complexity is ever growing. In large metropolitans, population is growing because of employment opportunities, better living standard, improved educational and health facilities.

An increase in urban population has direct correlation with increase in number of vehicles on road which is evident through Transportation Energy Data Book (TEDB). TEDB is being published since 1976. Thirty third edition of this book has been published in 2014 [2]. The book provides a data set in chapter three about the automobile registration over the years [3]. The dataset from this edition is presented in Fig. 1. This data is collected from more than fifteen countries including Argentina, Brazil, Canada, China, France, India, Indonesia, Germany, Japan, Malaysia, Pakistan, Russia, South Korea, United Kingdom and United States which spans over 1950 to 2012. This data set shows aggregated number of registration of cars in millions in the mentioned countries per year. In this graph, years are presented on horizontal-axis and number of automobile registrations in millions are on vertical-axis. This graph is an indicator of an ever increasing pressure on traffic flow which is resulting into various new emerging phenomena.
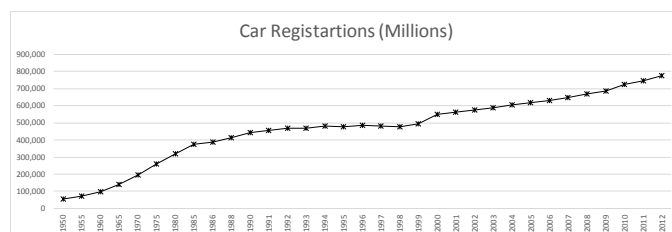

Fig. 1. Car registration (in millions) per year

Traffic management in big cities with growing number of vehicles is and has been a great challenge. For a better understanding of this phenomenon computational modeling techniques have been applied. This challenge spans over several areas including but not limited to the optimal resource allocation, new infrastructure planning, effective use of existing infrastructure, avoidance of traffic jams and accidents etc. Computational modeling and simulation techniques applied to date have tried to address these and related problems through design, evaluation and experimentation of urban traffic flow. Through simulating experiments on computational model of urban traffic several valuable insights and improvements have been made in cities. Besides overall urban traffic flow, simulation techniques have also assisted in better understanding of the driver's behavior in different scenarios and helped in designing interventions to facilitate the drivers [4].

In literature several computational models of urban traffic flow are designed, verified and validated based on different theories including centralized and decentralized control [5]. In decentralized controlled urban traffic simulations individuals (vehicles/agents) can take personal decisions and their decisions eventually effects overall traffic dynamics. The decentralized approach includes modeling and simulation techniques of cellular automata, and multi agent systems. These techniques are usually thought of as of more faithful and realistic then centralized techniques because of individual's autonomy and freewill for taking decisions which is natural to many social phenomena. For curious readers an extensive coverage of data, models and simulations related to driver and vehicular traffic modeling is presented in [1].

A. Research Questions

To carry research in a domain it is very important to enquire about state of the art of that domain. In this research aim is to come up with comprehensive list of already performed literature reviews and comparative studies on vehicular traffic simulators. Another aim of this study is to develop a comprehensive list of simulators which may help researchers to choose best suitable simulator according to their requirements. To address these two enquires a systematic literature review has been performed. While reviewing literature following pieces of information are gathered related to each simulator.

- License type of simulator

- Developer of simulator

- Usage of simulator

- Number of research articles in which simulator is cited

It is also worth noting that most recent comprehensive study to enquire state of the art simulators and their calibration is performed in 2008 [6]. Hence this study aims to perform a systematic literature review to evaluate recent progress in the domain.

Remaining paper is organized as follows, section II presents state of the art of research effort to address research questions of this paper, section III explains systematic literature review process adopted for current research, section IV states outcome of the literature review, section V and VI present conclusion and future direction of this research respectively.

II. BACKGROUND

Modeling and simulation of vehicular traffic is in practice since 1955 [7]. Being a very rich domain it demands comprehensive review of state of the art work and recent efforts. In order to establish significance of this work a systematic literature review has been performed to find out if there are any already existing literature reviews which covers traffic simulators.

Three queries are formulated and given to Google search engine in order to explore web for existing literature reviews. Those queries are presented in TABLE I. along with total relevant results. It is worth noting that there is significant overlapping in relevant results of all queries. It is also worth noting that there is significant literature which is not related to vehicular traffic but selected by search engine. These irrelevant results are primarily due to literature on computer network traffic simulators.

TABLE I.   QUERIES TO EXPLORE WEB

Query	Total Results	Relevant Results
traffic simulation comparison	359	27
traffic simulation review	360	19
traffic simulator evaluation	299	8

The articles explored using this systematic exploration were reviewed to identify which simulators have been covered in these articles and is there any systematic evaluation or calibration mechanism used. TABLE II. presents explored literature reviews in chronological order. The table presents year of publication, reference of the research article, number of simulators covered in review and type of publication of literature review. Type of publication refers to whether it is a conference proceeding, journal article, thesis, case study or a book.

TABLE II.   EXPLORED LITEARATURE REVIEWS

Year	Reference	Simulator Count	Type
1996	[8]	3	Journal Article
1997	[9]	31	Book
2000	[10]	2	Journal Article
2000	[11]	3	Conference Proceeding
2003	[12]	9	Journal Article
2003	[13]	4	Journal Article
2003	[14]	2	Conference Proceeding
2005	[15]	2	MS Thesis
2006	[16]	3	Conference Proceeding
2006	[17]	2	Book
2007	[18]	3	Conference Proceeding
2008	[19]	5	MS Thesis
2008	[6]	6	Book
2009	[20]	6	Journal Article
2009	[21]	2	Conference Proceeding
2010	[22]	3	Journal Article
2010	[23]	2	MS Thesis
2010	[24]	4	Journal Article
2010	[25]	2	MS Thesis
2011	[26]	7	Research Article
2011	[27]	10	Book
2011	[28]	2	Conference Proceeding
2012	[29]	2	Book

Year	Reference	Simulator Count	Type
2013	[30]	2	Case Study
2013	[31]	2	MS Thesis
N.A	[32]	2	Case Study

For more curious readers complete breakdown of this report along with names of reviewed simulators have been hosted at http://goo.gl/nSV1gy.

Software calibration is a systematic process in which software under study is reviewed confirming a standard. In this study, it was explored that if there are any reviews which involves calibration. Comprehensive software calibration has been performed in [11], [13], [17], [6], [24] and [28].

In background exploration fifty four simulators have been identified. TABLE III. presents top five simulators with respect to frequency of their occurrence in literature. For curious readers that break down is also available in above mentioned hosted report.

TABLE III.　　IDENTIFEID SIMULATORS

Simulator Name	Number of Occurrences in Literature	License Type
VISSIM	15	Commercial Software
PARAMICS	12	Commercial Software
CORSIM	10	FOSS
AIMSUN	9	Commercial Software
SUMO	5	FOSS

In background exploration it has been identified that the commercial simulator VISSIM and the FOSS simulator CORSIM have been compared in six studies presented as following chronologically [11], [12], [15], [17], [18] and [19].

This literature review shows that the most comprehensive comparative study of traffic simulators which covers six simulators which was published in 2008 [6].

III. RESEARCH METHODOLOGY

Science demands to be reproducible. In this literature review a systematic approach is employed in order to enquire state of the art progress in relevant area of research. Systematic literature review allows reducing subjectivity of researcher by minimizing random walk through selective research literature. Systematic literature review also makes it possible to reason and improve process of literature review.

In this study a systematic literature acquisition activity has been performed. This section describes details of the methodology using which literature has been acquired so that comparative study can be done.

In this activity metadata about research publications has been acquired. The metadata includes title, authors and year of the publication. To acquire this metadata multiple research repositories has been used as the data source. List of these research repositories is presented in TABLE IV.

TABLE IV.　　RESEARCH REPOSITORIES

Repository	Host
ACM Digital Library	Association of Computing Machinery (ACM)
IEEEXplore	Institute of Electrical and Electronics Engineers (IEEE)
DBLP	University of Freiburg
IET Digital Library	The Institution of Engineering and Technology
arXiv	Cornel University Library
ArnetMiner	ArnetMiner
ePrints (soton)	University of Southampton
CiteULike	CiteULike
SiteSeerX (IST)	College of Information Science and Technology, Pennsylvania State University
The Collection of Computer Science Bibliographies	University of Karlsruhe

The main objective to use multiple research repositories was to have a comparative and broad overview of state of the art and current research trends. Using a single research repository poses some challenges such as a single research repository does not covers complete research literature.

To acquire the literature a set of queries has been used which is presented in TABLE V.

TABLE V.　　QURIES

survey urban traffic model	state of the art urban traffic model
survey city traffic model	state of the art city traffic model
survey urban vehicle model	state of the art urban vehicle model
survey city vehicle model	state of the art city vehicle model
survey urban traffic simulation	state of the art urban traffic simulation
survey city traffic simulation	state of the art city traffic simulation
survey urban vehicle simulation	state of the art urban vehicle simulation
survey city vehicle simulation	state of the art city vehicle simulation

Metadata of literature is fetched from all research repositories against each query. Each metadata record is stored in database ensuring that none of the publication has multiple entries in database. Title of publication is used to avoid duplication. Same publication can have variation in title due to punctuations, to handle it text processing techniques are used to preprocess publication titles. Afterwards MD5 [33] hash has been computed for every title before storing it in database, that hash digest is used as primary key of a publication record to guaranty uniqueness. After employing the literature acquisition process total twenty thousand eight hundred and fifty seven metadata records for unique publications have been downloaded.

Rapid Automatic Keyword Extraction (RAKE) [34] is a heuristic to extract keywords from a piece of text. It assign all keywords a score according to their occurrence in a text. A

variation of this algorithm is used on all titles to extract keywords. All titles are combined in a document and that document is used as input to RAKE. The heuristic generated forty one thousand nine hundred and twenty two keywords. According to the score of keywords top ten thousand keywords are read manually and two sets of keywords are made from it. One set of keywords is used for rejection criteria and other is used for selection criteria to select relevant publications. The selection criteria key words are such keywords which were very much relevant to the domain under study whereas keywords in rejection criteria are such keywords which shows that the article is an anomaly in query result and belong to some other research domain. Using selection and rejection criteria the publication count reduced to eight thousand four hundred and six.

To further reduce the time complexity of literature review another heuristic is employed to sort and prune remaining research articles. That heuristic gives 0.5 points to publication year, 0.35 points to number of research repositories in which a particular publication is indexed and 0.15 points to number of authors. Scores of metadata entries are sorted and first fourteen hundred records are manually read. Along with these research papers all those papers were manually picked which have "agent" or "driver" word in title. While evaluating a research article it has been logged that if there is any simulation carried out to verify the proposed model, if so than name of simulation tool has been logged. After this process sixty nine papers have been identified in which the model is verified using a traffic simulator.

A. Time Complexity of the Methodology and Pruning Huristic

I this study a systematic literature review methodology is employed. The methodology to conduct systematic literature review is involves manual effort. Each publication is read manually and according to selection and rejection criteria the publication is pruned for detailed study. Amount of acquired literature is huge, it would have been extremely time consuming to cover whole literature dataset. In order to reduce time complexity; according to availability of time, human resource and required literature coverage a heuristic has been used.

The heuristic uses three parameters to prune the literature data set. The parameters are as follows.

- Year of publication

- Number of research repositories in which the publication is indexed

- Number of authors of publication

Other attributes could also be used in order to improve heuristic. A significant improvement could be assign a score to research venues in which publication is published i.e. impact factor and in case of conference, number of time the conference has been organized; using this information research literature could be priorities more effectively.

In current study, heuristic uses above mentioned three properties of a publication. The assigned weights to filter literature is subjective to the author and can be adjusted. The more important a property is, more weight should be assigned to the property.

IV. REPORTING ON REVIEW

In this study it has been identified that research community is using a wide range of vehicular traffic simulators. In sixty nine identified research articles forty five different simulators have been used. In this study details about top fifteen simulators according to their citation frequency has been presented. For more curious readers complete list has been hosted at http://goo.gl/MCiqPv.

Information about top fifteen simulators has been presented in TABLE VI. This information includes license type, usage of tool which is stated as type and its presence in research articles or citations are presented.

TABLE VI.   IDENTIFIEF SIMULATORS

Simulator	License	Type	Citations
VISSIM	Comercial	Traffic	7
SUMO	FOSS	Traffic	5
ATLAS	FOSS	Traffic	3
CORSIM	FOSS	Traffic	3
Netlogo	FOSS	General	3
PARAMICS	Comercial	Traffic	3
JADE	FOSS	General	2
MATLAB	Comercial	General	2
OMNet++	FOSS	General	2
SCATS	Comercial	Traffic	2
UrbanSim	FOSS	Traffic	2
x10	FOSS	General	2
3DS-MAX	Comercial	3D Modeling	1
ARCHISIM	N.A	Traffic	1
AIMSUN	Commercial	Traffic	1

In TABLE VI. values of column titled "type" is explained as follows. The keyword Traffic in this column depicts that the tool is specifically made for vehicular traffic modeling and simulation. General depicts that the tools may be used for general purpose agent based modeling and simulation. 3D Modeling depicts the tool can be used for 3D modeling only and other tool may be required for simulation.

In TABLE VII. information about simulator developer is presented.

TABLE VII.   SIMULATOR DEVELOPER IFROMATION

Simulator	Developer Website
VISSIM	http://vissim.com
SUMO	http://sumo-sim.org
ATLAS	http://corfu.pucrs.br/redmine/projects/atlas
CORSIM	http://mctrans.ce.ufl.edu/featured/tsis/version5/corsim.htm
Netlogo	https://ccl.northwestern.edu/netlogo/

Simulator	Developer Website
PARAMICS	http://www.sias.com/2013/sp/sparamicshome.htm
JADE	http://jade.tilab.com/
MATLAB	http://www.mathworks.com/products/matlab/
OMNet++	http://www.omnetpp.org/
SCATS	http://www.scats.com.au/
UrbanSim	http://www.urbansim.org/
x10	http://x10-lang.org/
3DS-MAX	http://www.autodesk.com/products/3ds-max/overview
ARCHISIM	N.A
AIMSUN	http://aimsun.com

V. CONCLUSION

This study has huge significance as developers who develop, practitioners who use and policy makers who get assistance from simulators would need to know recent developments in simulators. In a recent comprehensive and systematic study six simulators have been reviewed [6]. It was published in 2008 so it is required to consolidate state of the art in simulation tools.

Rapid growth in vehicular traffic simulation scientific knowledge body demands development of systematic processes for literature review. It is important to increase reusability and decrease redundancy of research. It is also worth highlighting that literature review itself must be reproducible so that coverage of literature could be validated. Similar issue is identified in this study that number of simulators being used in research community is fairly high which may be due to lack of reusability of existing work on simulators. Optimistically due to diversified nature of vehicular traffic flow phenomena number is very high or from pessimistic point of view the simulators are redundant. Consolidation of such multiple simulation tools which are presented in research into a unified development environment is required. Consolidation demands a systematic review of literature as most recent comprehensive study in this area is performed in 2008 [6].

VI. FUTURE WORK

This section states potential future extensions in this study. These extensions are as follows. Systematic literature review may be performed using multiple research repositories to identify existing comparative studies on simulation software. As in this study commercial search engine Google has been used to identify state of the art in literature reviews. A consolidated classification of feature set of simulators may be identified which could be used in calibration of simulators. That classification of feature set may assist in comparative study of simulators. Usage of currently identified simulators in research articles could be expanded which may assist in identifying research community trend towards simulators.

REFERENCES

[1] M. Treiber, A. Kesting, and C. Thiemann, Traffic Flow Dynamics: Data, Models and Simulation. Springer, 2012.

[2] S. C. Davis, S. W. Diegel, and R. G. Boundy, Transportation Energy Data Book: Edition 33. Oak Ridge National Laboratory, 2014.

[3] S. C. Davis, S. W. Diegel, and R. G. Boundy, "Chapter 3 All Highway Vehicles and Characteristics," in Transportation Energy Data Book, 33 vols., 2014.

[4] H. Dia, "An Agent-Based Approach to Modelling Driver Route Choice Behaviour Under the Influence of Real-Time Information," Transp. Res. Part C Emerg. Technol., vol. 10, no. 5–6, pp. 331–349, Oct. 2002.

[5] A. Doniec, R. Mandiau, S. Piechowiak, and S. Espié, "A Behavioral Multi-Agent Model for Road Traffic Simulation," Eng. Appl. Artif. Intell., vol. 21, no. 8, pp. 1443–1454, Dec. 2008.

[6] J.-B. Lee, Calibration of Traffic Simulation Models Using Simultaneous Perturbation Stochastic Approximation (SPSA) Method Extended Through Bayesian Sampling Methodology. ProQuest, 2008.

[7] D. L. Gerlough, Simulation of Freeway Traffic on a General-purpose Discrete Variable Computer. University of California, Los Angeles, 1955.

[8] S. Taori and A. Rathi, "Comparison of NETSIM, NETFLO I, and NETFLO II Traffic Simulation Models for Fixed-Time Signal Control," Transp. Res. Rec. J. Transp. Res. Board, vol. 1566, pp. 20–30, Jan. 1996.

[9] S. Algers and S.-S. M. A. to R. T. E. S. Tests, Review of Micro-simulation Models. Institute for Transport Studies, 1997.

[10] L. Bloomberg and J. Dale, "Comparison of VISSIM and CORSIM Traffic Simulation Models on a Congested Network," Transp. Res. Rec. J. Transp. Res. Board, vol. 1727, no. -1, pp. 52–60, Jan. 2000.

[11] B. Moen, J. Fitts, D. Carter, and Y. Ouyang, "A Comparison of the Vissim Model to Other Widely Used Traffic Simulation and Analysis Programs," in Institute of Transportation Engineers, 2000.

[12] D. Gettman and L. Head, "Surrogate Safety Measures from Traffic Simulation Models," Transp. Res. Rec., vol. 1840, no. 1, pp. 104–115, Jan. 2003.

[13] J. Hourdakis, P. Michalopoulos, and J. Kottommannil, "Practical Procedure for Calibrating Microscopic Traffic Simulation Models," Transp. Res. Rec., vol. 1852, no. 1, pp. 130–139, Jan. 2003.

[14] R. V. Lindgren and S. Tantiyanugulchai, "Microscopic Simulation of Traffic at A Suburban Interchange," presented at the Institute of Transportation Engineers 2003 Annual Meeting and Exhibit (held in conjunction with ITE District 6 Annual Meeting), 2003.

[15] A. P. Tagliaferri, "Use and comparison of traffic simulation models in the analysis of emergency evacuation conditions," 2005.

[16] A. Doniec, S. Espié, R. Mandiau, and S. Piechowiak, "Multi-agent Coordination and Anticipation Model to Design a Road Traffic Simulation Tool.," in EUMAS, 2006.

[17] B. Park and J. Won, Microscopic Simulation Model Calibration and Validation Handbook. Virginia Transportation Research Council, 2006.

[18] S. Birst P. E., J. Baker E. I.T., and K. Shouman E. I.T., "Comparison of Traffic Simulation Models with HCM 2000 Methodology Using Various Traffic Levels Under Pretimed Signal Control," presented at the Transportation Research Board 86th Annual Meeting, 2007.

[19] Y. Gao, "Calibration and Comparison of the VISSIM and INTEGRATION Microscopic Traffic Simulation Models," 24-Sep-2008. [Online]. Available: http://scholar.lib.vt.edu/theses/available/etd-09102008-135101/. [Accessed: 15-Sep-2014].

[20] G. Kotusevski and K. A. Hawick, "A Review of Traffic Simulation Software," 2009.

[21] T. Y. Zhi, C. R. Long, and L. D. Horng, Comparison of Paramics and Getram/Aimsun for Its Simulations. .

[22] M. Michał, "A Comparison of Microscopic Traffic Flow Simulation Systems for An Urban Area," Transp. Probl. Int. Sci. J., 2010.

[23] E. Gebru, "Selection of a simulation software to model a small signalized system of a multilane arterial in the southeastern US," Masters, The University of Alabama, USA, 2009.

[24] S. K. GUPTA ASHU, "A Critical Study and Comparison of Manufacturing Simulation Softwares Using Analytic Hierarchy Process," J. Eng. Sci. Technol., 2010.

[25] S. Chery, "A Comparison of Non-Traditional Intersection Designs Using Microscopic Simulation," MS, FLORIDA ATLANTIC UNIVERSITY, 2010.

[26] L. S. Passos, R. J. Rossetti, and Z. Kokkinogenis, "Towards the next-generation traffic simulation tools: a first appraisal," in Information Systems and Technologies (CISTI), 2011 6th Iberian Conference on, 2011, pp. 1–6.

[27] J. Barceló, Fundamentals of Traffic Simulation. Springer Science & Business Media, 2011.

[28] D. Yin and T. Qiu, "Comparison of Macroscopic and Microscopic Simulation Models in Modern Roundabout Analysis," Transp. Res. Rec. J. Transp. Res. Board, vol. 2265, pp. 244–252, Dec. 2011.

[29] A. Ronaldo and T. Ismail, "Comparison of the Two Micro-Simulation Software Aimsun & Sumo for Highway Traffic Modelling," 2012. [Online]. Available: https://www.academia.edu/2043012/COMPARISON_OF_THE_TWO_ MICRO-SIMULATION_SOFTWARE_AIMSUN_and_SUMO_FOR_HIGHWA Y_TRAFFIC_MODELLING. [Accessed: 15-Sep-2014].

[30] kristen, "Case Study: Comparative Evaluation of Different Traffic Simulation Platforms: PARAMICS & DYNAMEQ."

[31] S. Alexandersson, "Pedestrians in Microscopic Traffic Simulation," Chalmers University of Technology, 2013.

[32] "Paramics vs Vissim on Network Coding and Simulation Speed." [Online]. Available: http://www.clranalytics.com/resources/microsimulation-comparisons/paramics-vs-vissim. [Accessed: 15-Sep-2014].

[33] "MD5," Wikipedia, the free encyclopedia. 11-Jul-2013.

[34] M. W. Berry and J. Kogan, Text Mining: Applications and Theory. John Wiley & Sons, 2010.