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Vehicular Traffic Simulation Software: A Systematic Comparative Analysis

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Abstract- **With increasing urbanization, the importance of intelligent transportation system (ITS) has become paramount for devising future smart cities. ITSs encompassing policy, planning, designing, management and traffic engineering plays an oversized role in making urban mobility efficient. In this regard, various traffic simulation software (TSS) have been developed for efficient road network planning, designing and management. In this work, a comprehensive comparative analysis has been undertaken to assess different TSS. For this purpose, twenty-nine simulation software have been explored, analyzed and compared to assess their suitability for different real world traffic flow scenarios. For this assessment, considered parameters ranged from traffic behavior (homogeneous or heterogeneous), traffic flow models (microscopic, macroscopic or mesoscopic), traffic models (such as car following, lane changing), system (discrete or continuous) and availability (open source or commercial). Furthermore, viability of each TSS for different road infrastructure (such as intersections, urban roads, freeways, land use to name a few) is reported. Though no single simulation software can cover every aspect of road network simulation. However, this work can facilitate researchers in selecting the most appropriate TSS according to local traffic conditions and project under investigation.**

Index Terms-- **Intelligent Transportation System, traffic flow, traffic modeling, Traffic Simulation Software.**

I. INTRODUCTION

With rapid urbanization, the proportion of urbanites in the total world population will increase to 68% by 2050 from the current estimate of 55% [1]. Urban mobility has thus become a major challenge in achieving smart city, where too many people have to be moved at the same time each day. Inefficient urban mobility not only results in greenhouse gas (GHG) emissions but overall degradation in urbanite's quality of life. Especially so when the share of the transportation sector in overall worldwide energy consumption and greenhouse gas (GHG) emissions stands at 25% and 29% respectively [15]. According to World Health Organization's report, 4.2 million premature deaths were attributed to ambient air pollution in 2016 [2]. Traffic related pollutants are a major contributing factor in an increase of cancer, cardiovascular, pulmonary and respiratory diseases [2], [16]. Hence, it has become imperative to adopt intelligent transportation system (ITS) methodologies to make urban mobility more efficient.

A. RESEARCH CONTEXT

Intelligent Transportation system (ITS) is an agglomeration of a range of applications to gather and process information to plan, design and efficient management of existing road infrastructure. The objective is to improve safety, productivity and mobility by reducing road network congestion and associated environmental costs. For example, according to WHO's report, reducing particulate matter from current levels of 35 ug/m^3 in urban settings to 10 ug/m^3 will reduce premature deaths by 15% (of 4.2 million worldwide deaths reported in 2016) [2]. Traffic congestion's main source being road bottlenecks, are caused mainly due to flawed road planning and design [15]. Traffic congestion in addition to time and productivity losses, increase aggressive driver behavior. This aggressive driver behavior in turn results in 15-20% increase in fuel and GHG emissions [15]. In the United States, traffic congestion costs were estimated at $87 billion with each driver losing 97 hours and $1,346 per year in 2018 [10].

In this context, an important application to provide ITS solutions are Traffic Simulation Software (TSS) for planning, designing and management of road infrastructure. With accuracy of these TSS highly dependent on traffic flow mathematical models, researchers have been proposing incrementally accurate mathematical models [71], [72], [78], [79]. Traffic flow mathematical models are simplified representations of real time systems with level of details depending upon the system being simulated [4]. These models help to explore complexities of the system being simulated and different variable's impact on overall results. Urban infrastructure planning and transport engineering are amongst utmost crucial fields of research for the mathematical modeler which impacts directly on development of a community in terms of sustainability. Prominent examples of TSS are Vissim, Aimsun, and Paramics for transportation planning, policy and traffic engineering.

B. SCOPE AND OBJECTIVES

In existing literature, little effort has gone into comparative analysis of different available TSS. To the best of the author's knowledge, only five review papers of different depth have been published [3], [4], [5], [6], [7]. In [6], a systematic review of five TSS Vissim, paramics, Aimsun, corsim and SUMO have been presented. Talevska et al. presented a comparative review of SFStree, FreeSim, Aimsun, PTV Optima and corsim, highlighting each TSS strengths and weaknesses for specific applications [3]. Ejercito et al. compared SUMO, Vissim and Aimsun for Manila traffic, reporting that though all provided reasonable results but each have limitations which should be understood before selecting any TSS [7]. In [4], a comparative analysis was done on 14 different simulators with emphasis on selecting an appropriate TSS for local conditions of Saudi Arabia. Saidallah et al. reported comparative analysis on 11 different traffic simulation software [5]. The comparison was done based on nine different capabilities such as visualization, infrastructure and supported vehicle types to name a few.

This work was undertaken with the following objectives,

1. To fill the gap by giving a comprehensive systematic comparative analysis of twenty-nine most commonly used TSS,
2. Parameters on which these TSS were analyzed ranged from license type, traffic flow models, mathematical models, traffic behavior and scenarios that can be simulated and the road infrastructure type on which they can be simulate,
3. Comparative analysis based on reported results in existing literature between different TSS undertaken under same local traffic conditions,
4. To report best choice of TSS by analyzing limitation and strengths of each TSS according to local conditions.

Reminder of this work has been organized as; section II categorizes traffic simulation, while in section III twenty-nine TSS have been detailed. In section IV, systematic comparative analysis has been reported under different scenarios. Discussion and conclusion have been presented in section V and VI respectively.

II. TRAFFIC SIMULATION CATEGORIES

Simulations in general and traffic simulation in particular are an approximate imitation of traffic flow behavior on any road network. Traffic flow simulations are inherently complex systems because of human-machine and machine-machine interactions. Furthermore examination, calibration and validation of a simulated system is imperative before its physical execution [4]. With advancement in computing and communication technologies, simulating such complex systems have become possible. Though a lot of effort has gone into development of TSS, there are many possible pitfalls in modelling traffic flow behavior. One such pitfall is variation in driver behavior depending upon the driver's origin or country. Underlying models of TSS should consequently provide an option to calibrate varying parameters settings according to local conditions. Even with the aforementioned calibration option, variation in driver's behavior between two countries can be so great that the same car-following model won't be able to simulate traffic flow correctly. Similarly, different underlying mathematical models with different calibration settings might be mandatory for contrasting traffic conditions such as congested and non-congested traffic conditions.

A. TRAFFIC BEHAVIOR

Traffic flow behavior can be categorized into two different types. Micro-simulation for traffic flow varies greatly depending upon traffic flow behavior.

Homogenous traffic (HOM): Traffic follows strict lane discipline with variation between on-road vehicles not varying by much. Traffic in developed countries such as the USA, Europe are of homogenous nature.

Heterogeneous traffic (HET): This type represents traffic flow with no lane discipline and great variation in on-road vehicles. These on-road vehicles range from passenger cars, bikes, bicycles, three-wheelers, human/animal driven carts, light trucks, buses. Traffic behavior in developing countries such as Pakistan, India is of heterogeneous nature.

B. TRAFFIC FLOW MODELS

Proposed traffic flow models and hence TSS can be categorized into three distinct models. These models have different sets of rules which they must follow.

Microscopic Models (Mic) simulate traffic flow considering the characteristics and behavior of individual agents (vehicle and driver). Model's dynamic variables represent microscopic properties of an individual vehicle's position and velocity. These models can be subcategorized into; (1) discrete in time and space known as cell automata and, (2) Continuous models, which are continuous in time and required for detailed studies in car-following behavior and traffic instabilities.

Macroscopic Models (Mac) simulate the overall flow of vehicles on a road instead of individual vehicles. The three important variables for macroscopic models are flow (number of vehicles passing through a point per unit time), speed (distance covered per unit time) and density (number of vehicles in given length).

Mesoscopic Models (Mes) are developed to fill the gaps between microscopic and macroscopic models. Mesoscopic models simulate vehicle flow in aggregate terms with behavioral rules defined for each individual vehicle. More recently, hybrid mesoscopic models have been proposed combining microscopic and macroscopic models.

C. MATHEMATICAL MODELS

Depending upon traffic flow behavior and traffic simulation model that needs to be simulated, different traffic flow mathematical models are employed. The underlying capabilities of these mathematical models can define the success of different TSS in simulating real life traffic behavior. Twenty-nine TSS have been reported in this work as can be observed in Table 1. These TSS have been categorized based on traffic flow behavior and traffic model simulation. The most important type of traffic flow mathematical models are as following;

Car Following Models are used to simulate a vehicle following another vehicle in an uninterrupted flow [24]. In existing literature, a lot of effort has gone into development of car following models such as Pipes, Forbes, Gipps, Weidmann to name a few [24], [25]. Car following model greatly affects TSS performance. They have different parameters such as reaction time, acceleration which affect departure headway [44], [64]. Each car-following model has its own unique characteristics and properties which make them suitable for different traffic flow conditions.

TABLE I
LIST OF COMMONLY USED TSS AND THEIR CHARACTERISTICS

TSS	TFB	Characteristic	System	Availability
Aimsun [9]	HOM	Mic/Mac/Mes	Discrete	Commercial
AnyLogic [20]	HOM	Multimodal	Discrete	Commercial
ArchiSim [5]	HOM	Mic	Discrete	Free
CityTrafficSimulator [59]	HOM	Mic	--	Free
CorSim [69]	HOM	Mic/Mac	Discrete	Commercial
Cube/Sugar/ Urban-Engines [60]	--	Mic/Mac/Mes	Discrete	Free
Dracula [77]	HOM	Mic/Mes	Discrete	Commercial
DynaMIT [29]	HOM	Mes	Discrete	Free
DYNASMART-P [74]	HOM	Mes	Discrete	Commercial
DynusT [76]	--	Mes	--	Commercial
HeteroSim [11]	HET	Mic	Discrete	Free
INTEGRATION [52]	HOM	Mic/Mes	Continuous	Free
Kronos [55]	--	Mac	Continuous	Free
MATSim [18]	HOM	Mic	Continuous	Free
Mezzo [57]	HOM	Mic/Mes	Discrete	Free
MITSimLab [17]	HOM	Mic	--	Free
MovSim [12]	HOM	Mic	Discrete	Free
NeXTA [73]	--	Mes	--	Free
OmniTRANS [75]	HOM	Mac	--	Commercial
Paramics [8]	HOM	Mic	Discrete	Commercial
Polaris [61]	--	Mes	Discrete	Free
PTV Toolkit [19]	HOM	Mic/Mac/Mes	Continuous	Commercial
SATURN [30], [31]	HOM	Mic	Discrete	Commercial
Sidra [70]	--	Mic	Continuous	Commercial
SUMO [51]	HET	Mic	Continuous	Free
Synchro [22]	HOM	Mic/Mac	--	Commercial
TransModeler [21]	HOM	Mic/Mac/Mes	--	Commercial
Transims [58]	--	Mic	Continuous	Free
Urbansim [26, 27]	HOM	Mic	Discrete	Free

TABLE I. TFB = Traffic Flow Behavior

Lane Changing Models play a very important role in microscopic and macroscopic traffic flow for simulating effect of surrounding vehicles. Each TSS use different lane changing models. These models can be subcategorized as either driving assistance models or driving decision models. Driving decision models can be further subcategorized as either (1) collision prevention/automation models or (2) tactical decision/operational decision models [25].

III. TRAFFIC SIMULATION SOFTWARE

In this section, twenty-nine TSS have been analyzed to help in selecting the most suitable traffic simulation software for different local conditions. Depending upon the underlying mathematical models, the performance of TSS can vary depending on the scenarios and sections of road being simulated. It has been concluded that no single TSS is better than other. However, depending upon traffic behavior, road network and configuration some TSS simulate better. Some TSS were developed for urban planning by employing their forecasting capabilities such as traveler demand, transport network and land use. While some TSS have the capabilities for optimizing traffic at road junctions and intersections by simulating and analyzing traffic behavior at such points through traffic light timing synchronization and shock wave phenomena analysis to name a few.

A. AIMSUN

Aimsun (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) can be employed to study exigency management by traffic engineers and planners [9]. Different tools are provided from simulating dedicated bus lanes to whole regions using microscopic, mesoscopic and hybrid simulation models. In addition, it is less restrictive in response to calibration than the microscopic simulation. Aimsun comes with two high-performance software applications Aimsun Next and Aimsun Live [9]. For simulating and assessing future traffic patterns of any scale and complexity, Aimsun Next, a fully integrated modeling platform, can be used. Aimsun Live is a tool for decision making which is used for predicting traffic outcomes with the help of simulating projected scenarios dependent on chronicled and real-time feed. It has the ability of real-time decision-making for traffic predictions and provides a traffic management system for critical traffic congestions and unexpected conditions [9], [50].

A. ANYLOGIC

Any Logic [20] has the capability to deliver efficient road traffic engineering and design through traffic flow simulation using “Road Traffic Library”. It can be used for traffic planning and optimization by throughput analysis and generating statistics for congestion, traffic jams and traffic light timings. Development in Any Logic is further made easy by providing clear visualization and animation with density maps. Congestions, bottlenecks and traffic flow are highlighted in different colors for better visualization. It provides the freedom to experiment with the ability to optimize accurate models. It helps in designing by adding changes, additions, or subtractions to existing road networks of public objects and buildings. Detailed assessment of these changes on traffic flow are provided.

B. ARCHISIM

ARCHISIM [5] is a behavioral simulation software, implemented through multi-agent concepts. There are two simulated components: agents (vehicle's drivers and pedestrians) and objects (road signals, intersections). Each simulated agent perceives, interprets the simulated virtual environment and makes a decision according to his skills. ARCHISIM's strength lies in its ability to let driver simulators be part of traffic simulation by creating realistic environments for drivers.

C. CITYTRAFFICSIMULATOR

CityTrafficSimulator [59] is a microscopic TSS using "Intelligent Driver Model" car following model. It is intended for simulating small to middle sized road networks such as small urban areas and intersections. It is designed to be universal and flexible to forecast and manage almost any real-world scenario. Road network can be implemented by connecting multiple nodes and using "Signal Light Editor". Traffic flow can be evaluated under variable signal light timings. Furthermore, lane changes (both forced and voluntary) and vehicle's velocity can be controlled to make the simulation more realistic to the local conditions.

D. CORSIM

CORSIM (CORridor Simulation) [69] though commercial, is available at nominal fee to academics. CORSIM was publicly released in 1998 after combining NETSIM (NETwork SIMulation) for traffic simulation on urban roads and FRESIM (FREway SIMulation) for highway traffic simulation. Using two different microscopic models, CORSIM can simulate any traffic situation. In addition, it comes with three packages for different road network conditions. HCS 2010 (highway traffic simulation under varying conditions), TRANSYT-7F and TSISCORSIM for traffic signal synchronization [53], [54].

E. CUBE/SUGAR/URBAN ENGINES

Cube/Sugar/Urban Engines [60] as a TSS package can be used to monitor, predict and plan traffic systems. Combining mobility and demographics data with predictive models, it can be used for urban planning and design (transport network and land-use). Various modules are provided for planning and designing road transport networks [50], [60]. These modules range from: (1) Sugar Network Editor for creating any type of road network, (2) Sugar Access for understanding accessibility to different location using public transport, (3) Cube Voyager for large scale travel demand, (4) Cube Avenue for dynamic congestion modeling, (5) Cube Dynasim for microscopic traffic simulation, (6) Cube land for land use forecasting, (7) Cube Cargo for freight movement simulation, (8) Cube Analyst for travel pattern estimation, and (9) Cube Cloud for sharing data and results with different stakeholders [60].

F. DRACULA

DRACULA (Dynamic Route Assignment Combining User Learning and Micro-simulation) is commercially available (with trial version) TSS [50], [77]. It provides a range of details and options for traffic simulations such as route choice, modelled through both microscopically or macroscopically. Moreover, it can model driver response to diversion, storing each diver's experience in their personal history. On the traffic flow side (using gap acceptance and lane changing models), it can model queue spillbacks and its effect on driver behavior and dynamic propagation of congestion backward (i.e., shockwave phenomena) [72], [77].

G. DYNAMIT

DynaMIT (Dynamic Network Assignment for the Management of Information to Travelers) is a multimodal, real-time traffic prediction simulator. Providing effective support to the Traffic Management Center (TMC) for Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS) [29]. Effectiveness of DynaMIT is its integration of detailed network representation and traveler behavior models with databases containing both historical information as well as real-time inputs from field equipment.

H. DYNASMART-P

DYNASMART-P (Dynamic Network Assignment-Simulation Model for Advanced Roadway Telematics –P) is a commercially available TSS. Initially it was developed at University of Maryland (UMD) but is currently maintained and further developed by Federal highway Administration (FHWA) [50]. DYNASMART-P has the capability to provide support for transportation network planning and traffic operations decisions. Using new state-of-the-art transportation planning procedures, it can readily interface with existing four step methods. It provides an extensive type and range of traffic flow scenarios for evaluation purposes [74].

I. DynusT

DynusT, a commercially available TSS provides support to address emergent transportation issues through its dynamic traffic simulation (DTA) and assignment software [76]. It has two different modules for traffic simulation and traffic assignment. Road network system creation is both easy and simple in DynusT. Vehicles can then be created and loaded on the road network with their respective origins, destinations and a specific route to follow. Anisotropic properties of traffic flow are taken into account using DynusT's Anisotropic Mesoscopic Simulation (AMS) model. Furthermore, its gap function vehicle-based (GFV) model is computationally efficient. It is unique because of its simulation-based DTA model which is capable of simulating large-scale, real-world road networks for long time periods using mesoscopic simulations [76].

J. HeteroSim

HeteroSim was developed by Arasan and Koshy [11] as a microscopic traffic simulator for heterogeneous traffic. It can be applied to mixed traffic flow including vehicles types such as cars, motorcycles, bicycles, buses and trucks. Because it was an academic initiative, HeteroSim can be used to simulate only a segment of road but with close enough results to real time heterogeneous road traffic.

K. INTEGRATION

Initially developed by Michel Van Aerde in 1983 as a mesoscopic model, it is currently being developed under the guidance of Dr. Hesham A. Rakha since 1999. Since then, INTEGRATION has evolved into a trip-based microscopic TSS. Additional models have been incorporated to provide simulation support for multi-modal dynamic traffic assignment, adaptive signal control, transit vehicle's priority, emissions, fuel consumption and crash risk models. It has capability to trace each vehicle's movement and performance from its origin to destination at one deci-second resolution. Vehicle's performance parameters that are traced range from vehicle delay, stops, fuel consumption, emissions (carbon monoxide, carbon dioxide, nitrous oxides) and crash risk of 14 different types [52].

L. KRONOS

KRONOS is a personal computer-based macroscopic dynamic freeway/highway TSS. Its simple continuum macroscopic model is based on Lighthill-Whitham-Richards (LWR) traffic flow model [55]. Unlike other macroscopic simulation TSS, it has the capability to model interrupted flow behavior such as weaving, merging and diverging. It can also take into consideration drivers accelerating, decelerating and lane changing behavior [56].

M. MATSim

MATSim (Multi-Agent Transport Simulation) was designed to simulate large-scale, agent-based transportation systems. The framework is developed using a modular approach with multiple modules, which can be used as standalone or in combination. Individual or multiple modules can be replaced with custom implementations to analyze various aspects of developer's work [18]. Being a fast and dynamic simulator, it can simulate 24 hours traffic flow data in just a few minutes and provide the option to compare it with real world data for analysis purposes [18], [50].

N. MEZZO

Mezzo [56] is managed by Center for Traffic Research (CTR) at Royal Institute of Technology (KTH) Stockholm. It is a discrete-event TSS, which can simulate large networks with a hybrid model. This hybrid model consists of a microscopic model for simulating vehicle's movement and driver decisions, while employing a mesoscopic model for simulating the surrounding network.

O. MITSIMLab

MITSIMLab (MIcroscopic Traffic SIMulation Laboratory) [17] is a microscopic TSS, which can be used for advanced traffic management systems (ATMS) and route guidance systems. It comes with two distinct modules namely;

- ***MITSIM*** which simulates road networks by assigning driver behavior and vehicle characteristics. This driver/vehicle combination is then used to capture traffic flow sensitivity to control and routing strategies on the road network.
- ***Traffic Management Simulator*** (TMS) for traffic control systems evaluations.

a. MOVSIM

MovSim (Multi-Model Open-Source Vehicular-Traffic Simulator) is a microscopic lane-based TSS, incorporating different car-following coupled map models and cell automata [12]. It can simulate all basic traffic scenarios and discrete decisions such as lane change, overtaking, yielding on roads and reaction to traffic lights through both command-line as well as graphical user interface (GUI). The simulated output results can be saved for further in-depth analysis. For fuel consumption estimation on both individual and collective level, a physics-based fuel consumption model has been employed.

P. NeXTA

NeXTA (Network Explorer for Traffic Analysis) is an open-source TSS with graphical user interface that can be used for traffic analysis, simulation and datasets scheduling, and post-processing. NeXTA employs DTALite (Light-weight Dynamic Traffic Assignment Engine) for transportation network analysis [50]. DTALite uses a mesoscopic simulation approach with an extremely thorough queuing model. Because of parallel computing, the analysis process is very fast. It takes at most 1 hour to compute an agent-based dynamic traffic equilibrium with 1 million vehicles for 20 iterations [73].

Q. Omni TRANS

OmniTRANS is developed by DAT.mobility in collaboration with Goudappel Coffeng mobility consultants, providing both local and web-based access [50], [75]. OmniTRANS can be used for computing time periods and trip purposes, with easy-to-use comparative analysis of different outcome scenarios. OmniTRANS uses both aggregated and disaggregated traffic estimates. It can support both static and dynamic traffic assignment of cars including junctions and ramps.

R. PARAMICS (QuadStone)

PARAMICS (Parallel Microsimulation), a microscopic TSS is developed for wide ranging application where predominant feature is traffic congestion. Its various modules when combined together can give added value to users by improving integration, productivity and usability [8]. It is fully scalable from handling simple scenarios such as single intersection to congested freeway and ultimately to simulating the entire city's traffic system. The toolkit for developers provides access to data from infrastructure, control, communication and other applications to create and improve behavioral models, independent of its complexity.

S. POLARIS

Polaris (Planning and Operations Language for Agent-based Regional Integrated Simulation) was initially developed at Argonne National laboratory with FHA, Department of Transportation USA sponsorship [61]. It is open source, high performance agent-based framework for simulating large scale traffic networks. Its key feature is integrated network-demand model, thus enabling it to consider all aspects of travel decisions such as destination and route choice, departure time, planning and rescheduling can be modelled simultaneously [61].

T. PTV ToolKit

PTV is the most comprehensive commercial toolkit providing services from traffic engineering, public transport, urban planning over fire protection to 3D visualization [19]. These tools are PTV Visum (for transport modelling), PTV Visum Safety (crash data analysis), PTV Vissim (for traffic simulation), PTV Viswalk (pedestrian and crowd simulation), PTV Vistro (for traffic engineering), PTV Optima (traffic management software), PTV Epics (adaptive signal control), PTV Balance (Network-wide adaptive signal control), PTV Vistad (traffic accidents analysis software) and PTV Visum Data Analytics [19]. These tools provide the ability to simulate road mobility from any element position and level under any traffic condition.

U. SATURN

SATURN (Simulation and Assignment of Traffic in Urban Road Networks) is a congested highway assignment software, capable of generating highly converged highway assignments [30]. Saturn provides four basic functionalities such as [31]

1. Combined traffic assignment and simulation model for analyzing traffic management plans,
2. Conventional assignment model for large road network analysis,
3. Simulation model for individual intersections, and
4. Network database and analysis system

SATURN comes with SatCoder, a user-friendly graphical user interface for developing road networks for simulation. According to a rough estimate, Saturn can cope with a network size of 5 to 100 intersections. Making it an ideal TSS for freestanding towns of less than 100,000 population [32].

V. SIDRA

SIDRA (Signalized Intersection Design and Research Aid) [70] is a micro-analytical traffic evaluation software. It employs lane-by-land and vehicle path (drive-cycle) models with an iterative approximation method. Sidra has the capability to provide statistical estimates of capacity and performance (such as delay, stop rate, queue length). It can determine queue length as a backward spread of congestions. It can estimate queue length and backward congestion propagation (i.e. shockwave propagation).

W. SUMO

SUMO (Simulation of Urban Mobility) is an open source, highly portable, microscopic vehicular traffic simulation package, designed to handle large road networks [51]. It can simulate both time-discrete and space-continuous vehicle movement across multi-lane streets with lane changing capabilities. Rules for right-of-way and traffic lights timing can be incorporated [51]. Using intermodal simulation, it can create any traffic scenario with networks having 10,000 streets and 100,000 vehicles updates/sec on a 1GHz machine [51]. It can import road networks from VISUM, Vissim, OSM, MATsim, Shapefiles, ToboCup, OpenDRIVE and XML-Descriptions.

X. Synchro/SimTraffic

Synchro/SimTraffic [22] is a suite of products for traffic analysis, optimization and simulation applications. Synchro is a macroscopic analysis and optimization tool working in conjunction with SimTraffic. SimTraffic is a microsimulation tool with 3D animation capabilities to animate vehicular and pedestrian traffic. It can be complemented by other modules such as [22],

1. Warrant for traffic signal need evaluation at an intersection,
2. TripGen for trip generation calculations, and
3. SimTraffic CID which is an interface between SimTraffic and Traffic signal controllers.

4. TransModeler

TransModeler [21] is a powerful TSS for traffic planning and modeling for all kinds of road networks with in-detail analysis. These road networks can range from urban downtown areas to freeways. It can evaluate traffic flow dynamics, traffic signals and overall network performance. Using TansCAD for travel demand and forecasting, it can evaluate traffic demand for future planning scenarios.

Y. TRANSIMS

TRANSIMS (Transportation Analysis and Simulation System) [58] is a set of tools for regional transportation system analysis based on cellular automata microsimulation. It consists of four submodules after creating road and transit network and transit schedules [58],

1. Population synthesizer helps to mimic population to real world demographics,
2. Activity Generator helps to input each household activities according to priority, location, time, mode and travel preference of population,
3. Route planner helps in selecting fastest path at that time of the day based on population activity data, and
4. Micro-simulator executes all travel plans created by Router using cellular automata principles on a second-by-second basis throughout the network.

Z. UrbanSim

UrbanSim (Urban Simulation) is free to use traffic simulation package developed by Paul Waddell and diverse collaborators to support use of metropolitan land, transportation and environmental analysis [26], [27]. Initially UrbanSim was developed in java however from 2005 it was re-written in python. Different packages have been introduced for models like dynamic traffic assignment, activity-based travel, emissions, and land sprawl modification [27]. UrbanSim provides a web-based platform known as UrbanCanvas modeler. This platform is cloud-based, ascendible and provides on-demand computing power. The rationale of developing UrbanCanvas was to supply flexibility to designers and planners from completely different regions of the globe [28].

TABLE 2
LIST TSS BY LATEST VERSION, LAST UPDATED

Simulator/ Developed by (Year)	Main Features/Operational Conditions

Aimsun [9] / Transport Simulation Systems, Inc. (2019)	Surface streets, freeways, actuated signals, dynamic traffic assignment, variable message signs, telematics, online travel information systems, dynamic emergency vehicle routing, emissions management, accident response strategy assessments, urban and interurban congestion management, security threat mitigation and large-scale evacuation management, Transit Signal Priority (TSP), Bus Rapid Transit (BRT) schemes, Feasibility studies for High Occupancy Vehicle (HOV) and High Occupancy Toll (HOT) lanes, Impact analysis of designed infrastructure which includes highway corridor enhancement/construction, Safety analysis.
AnyLogic, The Anylogic [20] / Company (2019)	Pedestrian, Rail and Road Traffic Libraries provide detailed physical-level simulation of objects' movement and interaction
Archisim [5] / INRETS	Adaptive driver behavior simulation, Integration with driver simulators for realistic environments.
CityTrafficSimulator [59]/ Christian Schulte zu Berge (2015)	Forced and Voluntary Lane changes, IDM, Various vehicle types (Truck, Bus, Tram, Car), Layered grade separation, arbitrary signal times, Real-Time destination routing, evaluation of statistics such as number of stops, number of lane changes, average velocity etc.
CORSIM [69] / McTrans Center (2012)	Surface streets, freeways, actuated signals, weaving sections, incidents, changeable message signs.
Cube/Sugar/Urban Engines [60] / CITILABS (2019)	Create and monitor networks from ArcGIS Desktop, can make macroscopic regional models, mesoscopic simulation for knowing congestion, microscopic simulation for parking and other traffic operations, freight movement and its impacts, accessibility to cloud.
Dracula [50], [77] / Institute of Transport Studies, University of Leeds	Route choice calibration, congestion and time-based road pricing, transportation demand management (TDM), analysis of environmental impact on TDM, real time traffic signal control, segregated busway design, emergency evacuation procedures, strategic (inter-urban) modelling.
DynaMIT [29] / Oak Ridge National Laboratories (ORNL) (2011)	ATIS, ATMS, dynamic estimation of network state, a variety of real time scenarios, Per trip simulations.
DYNASMART-P [50], [74] / University of Maryland (UMD) and FHWA	traffic network planning and forecasting, traffic system design, operation and management, analysis of traffic flow using time-varying simulations with respect to speed of vehicles, queue lengths and delays, ability to model large networks
HeteroSim [11] / V. Thamizh Arasan (2016)	heterogeneous traffic simulation with different types of vehicles, bus lane
INTEGRATION [52] / Michel Van Aerde	Coordinated traffic signals, Adaptive traffic signals, Ramp metering, Motorway flow control, incident control, static and dynamic route guidance, toll plaza pricing, congestion pricing, roundabouts, emission analysis
Kronos [55], [56] / University of Minnesota	Freeway operation evaluation such as lane changing, merging, diverging, and weaving, development of queues and propagation of congestion on freeways and ramps connected to those freeways, ramp metering
MATSim [18] / Open Source (2018)	Demand modeling, both private and transit traffic, Traffic system timing optimization.
Mezzo [57] / Open Source	Simulate large road networks with hybrid models. Incident management
MITSimLab [17] / Intelligent Transportation Systems (ITS), MIT (2010)	Advanced Traveler Information Systems, Advanced Traffic Management Systems, ramp control, Freeway mainline control, lane control signs, variable speed limit signs, portal signals at tunnel entrances, Intersection control, Variable Message Signs, In-vehicle route guidance
MovSim [12] / (2017)	onramps, off-ramps, "flow-conserving bottlenecks" and traffic-lights
NeXTA [73] / (2014)	Parallel computing, trip generation, trip distribution, model split, traffic assignment, unlimited number of link types, vehicle emissions, safety prediction models and movement specific parameters
OmniTRANS [75] / DAT.mobility (2018)	Junction modelling, ramp metering, different vehicles, pedestrians, output comparisons, aggregated and disaggregated estimates, static and dynamic assignment and matrix calibration.
Paramics [8] / SIAS Ltd and Quadstone Ltd, Scotland	Surface streets, freeways, transit operations, roundabouts, congested networks, public transport, pedestrians, traffic engineering, infrastructure. Ramp metering, incident management, static and dynamic route guidance, congestion pricing
Polaris [61] / Argonne National Laboratory (2018)	Traffic flow simulation, activity-based demand simulation, model building and analysis geographic information system (GIS) tools, and tools for result analysis.
PTV Toolkit [19] / PTV, Germany (2018)	Surface streets, freeways, ramp metering, pedestrians, transit operations.
SATURN [30], [32] / University of Leeds and Atkins (2015)	Individual junctions, traffic measurement, highway design and assignment, demand forecasting, economic appraisal, environment assessment, road user charging
Sidra [70] / Sidra Solutions Inc. (2019)	signalized and unsignalized roundabouts, freeways, pedestrian crossing and (both diamond and diverging diamond) interchanges, emission analysis
SUMO [51] / Institute of Transportation Systems at the German Aerospace (2019)	Traffic lights evaluation, route choice and re-routing, evaluation of traffic surveillance methods, simulation of vehicular communications, traffic forecast.
Synchro/ SimTraffic [23] / Trafficware, A Cubic Company (2017)	signalized, unsignalized intersections, roundabouts, freeways
TransModeler [21] / Caliper Corporation (2018)	Electronic toll collection, route guidance, traffic detection and surveillance, intersections, junctions, overpass, underpass, transit access, walkways, travel demand forecasting.
TRANSIMS [58] / Los Alamos National Laboratory, USA	Regional transportation System analysis
UrbanSim [26] / Paul Waddell of University of California, Berkeley (2017)	Planning and analysis of urban development considering economy, land use, transportation and environment.

IV. TSS COMPARATIVE ANALYSIS

As can be seen in the above section, a wide range of TSS are available for traffic flow simulation both commercially as well as open source. However performance of these varying TSS are dependent on different variables which makes it imperative to choose appropriate TSS from a local conditions perspective. For example, a particular TSS can simulate traffic flow identically to real world scenarios for homogenous traffic. However, it will be severely handicapped in simulating heterogeneous traffic conditions. These variables range from [63],

1) Local traffic behavior such as homogeneous or heterogeneous,
2) Granularity of simulation such as at microscopic, macroscopic or mesoscopic level,
3) Employed mathematical traffic flow models by each TSS,
4) Real world scenarios being simulated such as intersections, local roads or freeways, travel demand forecasting, emissions and crash analysis to name a few.

Hence an effort was undertaken in this section to present a comparative analysis of different TSS to establish strengths according to different scenarios as can be seen in Table 3. In this context, this section is subdivided into (1) General features, (2) intersections, (3) roundabouts, and (4) freeways.

A. GENERAL FEATURES

Other features that can make a particular TSS apart are its graphical user interface, ease of calibration and validation, available documentation to name a few. In this regard, in [68] a comparison was done between 12 different TSS such as FRESIM, AIMSUN 7, Quadtone PARAMICS, Trans modeler, S-PARAMICS, PELOPS, PTV Optima, SUMO, DRACULA, CORSIM, CUBE and GEVAS Drivers. This comparison was based on existing studies, product reviews, available documentation and an online survey of product developers. It was concluded, as the authors of this work have concluded that very few TSS have the capability to simulate heterogeneous traffic.

In [63], FRESIM (submodule of CORSIM) and INTEGRATION were compared in terms of steady-state car following models. INTERATION’s steady-state car following model with additional degree-of-freedom, overcomes the imperfections of currently available state-of-practice car following models. It achieves this by incorporating microscopic and macroscopic steady state behavior over different roadway facilities. Despite calibrating FREESIM’s Driver Sensitivity Factor using macroscopic loop detector data, shortcomings remained in its steady-state car following model.

B. INTERSECTION

Tan el al. [43] compared VISSIM and Trans Modeler in terms of departure headway at signalized intersections. For this study, different reference observing points and queue positions were assumed. Simulated results of both TSS were compared and found to be nearly identical to empirical data. However, in-depth analysis showed differences between the two TSS because of different car following models used. The primary differences noted were, (1) vehicles had faster acceleration rate in VISSIM, and (2) significant difference in reaction time to speed up. For example, the headway between the first and sixth vehicle was 2~3 seconds in the TransModeler, while in VISSIM it was about 5 seconds. It was concluded that parameters affecting departure headway are inter vehicle's interaction while in queue, especially car-following model's parameters such as reaction time and acceleration.

In [45], PARAMICS and VISSIM were compared in terms of simulated and field-measured conflicts at an urban signalized intersection. The simulation considered only rear end conflict type and one conflict indicator i.e. time to-collision. The comparison had three aspects; (1) car-following models and parameters corresponding to safety, (2) correlation between field and simulated conflicts and, (3) conflict-spatial distribution. It was concluded that without calibration both PARAMICS and VISSIM gave poor performance with respect to field measured data. After calibration the performance of both simulation software improved markedly. The performance difference between PARAMICS and VISSIM was (1) at 1.5sec time to-conflict threshold PARAMICS overestimated and VISSIM underestimated number of conflicts, (2) at 3 sec time to-conflict threshold both PARAMICS and VISSIM overestimate the number of conflicts. Though near identical correlation between simulated and field measured conflicts was reported, both simulation software failed to capture conflict occurrence mechanism.

Chen et al. [64] evaluated VISSIM and SIDRA from operation’s simplicity and output-error perspective on a signalized road intersection. Both were properly calibrated and adjusted based on average vehicle delay. SIDRA was found superior in regards of road network construction, phase setting and output speed. However, simulated results of VISSIM were closer to realistic road behavior in terms of output-error results.

In [65], Synchro and TRANSYT-7F (variant of CORSIM) were compared for an urban arterial road with three intersections in terms of signal timing plans. The comparison was done on the basis of average delay and queue length size on each traffic signal. It was concluded that TRANSYT-7F provided superior results as compared to Synchro for queue length size and average delay estimation.

C. ROUNDABOUTS

Shaaban et al. compared VISSIM and SimTraffic in terms of dual and triple lane roundabouts. Simulations were undertaken under different traffic scenarios by changing traffic volume, percentage of truck numbers in overall traffic and number of left turning vehicles. It was concluded that both TSS didn’t show significant difference in simulation results. The only tangible difference was, VISSIM exhibiting higher average delays under high traffic volumes.

In [47], MATSim and VISSUM were compared in terms of traffic modeling and forecasting based on three indicators namely link volumes, distance and average travel time. A virtual city with a 60,000 population with a road network and OD matrix describing travel demands was created. It was concluded that though overall results of both systems had correlation, difference was noted in detailed distribution of traffic. This difference is because of the difference in algorithms used by the two simulation software. Shorter travel times, despite increase in distance were observed in MATSim as compared to VISUM. This is because agents who got stuck in traffic jams in one iteration took alternate routes in the next iteration. It was concluded that MATSim and VISUM dynamic assignment procedure gave similar results [47].

D. FREEWAY

In [62] three different TSS, FRESIM (a submodule of CORSIM), INTEGRATION and WATSim were compared on a 20 Kilometer freeway/arterial road. The road included three on-ramps, three off-ramps, an on/off ramp weaving section and eleven signalized intersections. For realistic results all three were calibrated, with calibration of INTEGRATION the most problematic in calibration of signal timing and line alignment. It was reported that each of the TSS has its own pros and cons. FRESIM has a problem with vehicles missing their destination, thus requiring extensive car following parameter's calibration to produce good results. INTEGRATION's simplified procedure of signalization resulted in higher street link speeds. WATSim as compared to the other two, underwent fewest calibration modification and was primarily sensitive to merging/acceleration lengths. WATSim and FRESIM speeds were nearly identical. It was reported that after reliable O-D flow estimation, INTEGRATION is both more efficient and suitable for traffic planning analysis that involve significant vehicle route changes (such as directional changes, lane closures, turn prohibitions).

Aji et al. [66] compared AIMSUN and SUMO in terms of highway traffic modeling in southern Stockholm. The traffic modeling was done by considering real world scenarios such as traveler's behavior, vehicle type and infrastructure. In this study, the calibration process was limited to only two variables; 1) speed acceptance and 2) highest desired speed. It was observed that speed data generated by SUMO was in m/s (AIMSUN was in Km/h). This affected Root Mean Square value, thus affecting SUMO results. In conclusion, Aimsum with its ease-of-use and visualization had an edge, however SUMO being free and open source provides more flexibility.

In [67] three TSS, INTEGRATION, KRONOS and KWaves were compared for freeway traffic simulation. Traffic conditions considered, ranged from medium to heavy traffic, with or without an incident, sensitivity with respect to freeway main lanes, road capacity and congestion density. Simulation results generated were compared to real life traffic conditions. It was reported that though all three TSS have their own limitations, KRONOS and INTEGRATION gave better results as compared to KWaves. KRONOS required least calibration efforts to produce acceptable results, but overestimated the benefits of adding additional lanes to the freeway for congestion reduction. For all traffic conditions, INTEGRATION produced acceptable results however its limitation was unrealistic lane-changing replication for on and off ramps connected with auxiliary lanes. KWaves gave acceptable results for freeway simulation only under heavy traffic conditions. All three TSS yielded similar results for level of service, incident simulation and sensitivity to important factors such as lance capacity and lane's number.

In [48], VISSIM and Synchro/SimTraffic were compared in terms of railroad crossing. Both software were calibrated with the help of field data to simulate existing conditions. In general, both TSS estimated delays within reasonable error range to field observations. However both overestimated the number of stops, indicating importance of calibration [48].

Lu et al. [49] compared Paramics, TransModeler and VISSIM in terms of traffic flow phase transitions behaviors. It was concluded that slight differences in microscopic models, lane geometry, changing strategies and proper calibration affect simulation results considerably

TABLE 3
COMPARATIVE ANALYSIS BETWEEN DIFFERENT TSS

Compared TSS	Comparative Analysis
CORSIM & VISSIM [33]	Both were compared to document the impact of difference in vehicle and driver behavior, primarily because they employ different car following and gap acceptance models. It was concluded that both gave consistent results and were equally user friendly.
VISSIM and CORSIM [38]	In research it was found that both models executed sufficiently well in-terms of giving mean speeds as input to project-level emission evaluation, given that proper validation is done.
CORSIM, PARAMICS & VISSIM [36]	The three TSS were compared in terms of high-capacity freeway with signalized on-ramps, off-ramps and interchanges. The output of all three varied with volume levels, speed range, link length with variation increasing linearly as the traffic volume neared capacity. It was concluded that PARAMICS and VISSIM generated simulation results identical to field observed conditions.
CORSIM, VISSIM, Q- PARAMICS & SimTraffic [34]	All four were evaluated in terms of graphical presentation (animation) capabilities by simulating bus operations. Visualization and transit-related capabilities of each TSS were summarized and reported that VISSIM stands out due to its 3-D capabilities.
CORSIM, VISSIM, AIMSUN [42]	All three required model's parameters calibration to generate acceptable capacity reductions because of incidents. In the case of AIMSUN and VISSIM, there was a need to introduce incident-specific time-variant calibration parameters.
CORSIM, INTEGRATION, PARAMICS MITSIMLab, VISSIM and WATSIM [37]	All six were compared in terms of freeways and signalized intersections. It was reported that all six produced fairly consistent results with reasonably well performance.
CORSIM & SimTraffic [35]	Both were evaluated in terms of ease to use and calibration capabilities. For the simulation scenario a freeway interchange with low-to-moderate traffic conditions was chosen. Insignificant difference was noted between the two.
AIMSUN, CORSIM & SimTraffic [39]	It was concluded that AIMSUN performed well in terms of dynamic traffic assignment in large urban and regional networks as compared to CORSIM and SimTraffic. However as compared to the other two, coding was cumbersome in AIMSUN.
VISSIM and TransModeler [43]	Comparative analysis was undertaken between VISSIM 4.3 and TransModeler 2.0 in terms of departure headway at signalized intersections from different reference points and queue sizes. The results of both simulation software were similar to empirical data, with differences emerging in detailed characteristics. The reason for these differences was because of different car-following models used by VISSIM and TransModeler.

AIMSUN, PARAMICS and VISSIM [40]	Car following model's behavior were compared. It was reported that AIMSUN's Gipps car following model resulted in lower error values. Furthermore, similar error values were recorded for psychophysical spacing models used in PARAMICS and VISSIM.
AIMSUN and VISSIM [41]	A comprehensive procedure using both quantitative and qualitative criteria was adopted for comparison in terms of simulating a medium complexity freeway. Both were reported as reasonably accurate.
AIMSUN, PARAMICS and VISSIM [44]	A comprehensive comparative review was undertaken between AIMSUN 4.2, PARAMICS 4.2 and VISSIM 3.7. It was concluded that all three have more or less the same capabilities and performance with minor differences. However, strengths and weaknesses of each simulator were identified, which makes individual simulation software more appropriate to be used for specific modeling tasks.
PARAMICS and VISSIM [45]	Both TSS were compared in terms of field-measured and simulated conflicts at an urban signalized intersection. It was reported that both TSS performed poorly without proper calibration.
SimTraffic and VISSSIM [46]	A comparison was performed in terms of dual and triple lane roundabouts with near identical results. VISSIM displayed higher average delays under heavy traffic volumes than SimTraffic.
Synchro and VISSIM [48]	Synchro and VISSIM were evaluated in terms of railroad crossings simulation and available features. Simulated results of both TSS were compared to field data recorded at peak and off peak hours. It was concluded that VISSIM generated better results than Synchro.
PARAMICS, TRANSMODELER & VISSIM [49]	PARAMICS, TransModeler and VISSIM were compared in terms of traffic flow phase transitions behavior. It was concluded no one TSS is superior. The slight differences in each TSS's microscopic models can be adjusted through changeable parameters to make simulations fit to empirical behavior.
VISSIM and SIDRA [64]	Comparison was done in terms of TSS's ease of use and output-error over a signalized intersection. It was found that SIDRA was simpler and more understandable than VISSIM, while the output-error was better in VISSIM.
VISUM and MATsim [47]	Both were compared in terms of traffic modeling and forecasting based on three indicators namely link volumes, distance and average travel time. It was concluded that MATSim and VISUM dynamic assignment procedure gave similar results.
FRESIM, INTEGRATION and WATSim [62]	Comparison was performed on a 20-kilometer Freeway with three on-ramps, three off-ramps, an on/off weaving ramp and eleven signalized intersections. It was concluded that INTEGRATION was better suited.
FRESIM and INTEGRATION [63]	Comparison was made on the basis of steady-state car following models. It was concluded that INTEGRATION's steady-state car following model performed better than FRESIM's state-of-practice car following model.
TRANSYT-7F and SYNCHRO [65]	Comparison was done on an urban arterial road with three signalized intersections. TRANSYT-7F results were better in terms of queue length and average delay.
AIMSUN & SUMO [66]	AIMSUN and SUMO were compared in terms of a freeway in southern Stockholm, Sweden. It was concluded AIMSUN had better visuals and was much easier to operate than SUMO while the results were almost the same for the both of simulators.
INTEGRATION, KRONOS & KWAVES [67]	INTEGRATION produced better results in terms of freeway traffic simulation. However, its limitation was unrealistic lane-changing replication for on and off ramps connected with auxiliary lanes.

V. DISCUSSION

For developing future smart cities, mobility has emerged as the most pressing challenge. In this respect, different aspects of ITS have come under researchers and developers scrutiny. One of the most important aspects of ITS is TSS for efficient road network planning, designing and management. The Highway Capacity Manual (HCM, 2000) defines a TSS as "a computer program that uses mathematical models to conduct experiments with traffic events on a transportation facility or system over extended periods of time". For realistic traffic simulation, multiple TSS are available both commercially and as open source. The typical process of selecting a TSS for use in a specific project varies based on the type of problem, available features, ability to replicate real-world conditions, ease of use, complexity, and cost [48], [67].

As in [63], authors of this work have concluded that no TSS has advantage over the others. Salient deciding parameters to be considered before selecting TSS for any project are detailed below for generating realistic real-life traffic simulations.

Traffic behavior: Depending upon country, traffic flow can be broadly categorized as either homogeneous or heterogeneous behavior. In general, traffic flow behavior in developing countries such as Pakistan and India have heterogeneous traffic behavior. Out of 29 TSS studied, only two TSS (HeteroSim and SUMO) have the capability to simulate heterogeneous traffic behavior.

Traffic Models: Performance of any TSS is directly dependent upon underlying mathematical traffic flow models employed [63]. Broadly these models can be sub categorized as either microscopic, macroscopic or mesoscopic models. For example, UrbanSim and TRANSIM employees' microscopic models, while OmniTRANS and Kronos are based on macroscopic models. Similarly, traffic simulators such as DynaMIT and Polaris employ mesoscopic models for traffic flow simulation. There are a few TSS that can simulate traffic flow both microscopically and macroscopically such as Aimsun and Urban Engines.

Furthermore, these models are implemented through mathematical traffic flow models such as car following, lane changing models to name a few. Results show that a minor variation in car-following models and attributes can result in noticeable variation of the dissemination. [43], [49], [62].

Project type: The process of selecting any TSS according to project type is the most important parameter. Among 29 listed TSS, the majority are developed for specialized projects. For project types such as local roads and freeways Aimsun and Paramics generate more realistic simulations. While for simulating traffic flow on intersections with traffic light optimization, Sidra and SimTraffic are far better choices. UrbanSim is specifically designed for planning and analysis of urban development considering economy, land use, transportation and environment.

Calibration: is of paramount importance in micro-simulation because of its reproduction of the local driving environment. This local driving environment is heavily influenced by locality specific factors such as the relationship between two vehicles, driver psychological and physiological responses, infrastructure, traffic operations and geometry of road network. In existing literature, various solutions have been proposed for sensing these local conditions such as traffic flow, vehicular emissions and civil structure monitoring [13], [14], [15], [16], and [80-85]. The calibration process is carried out by adjusting a combination of coefficient values of parameters in the simulation [45], [46], [48], [62], [64].

VI. CONCLUSION

In this work, a systematic comparative analysis was undertaken on most commonly used twenty-nine TSS. The comparative analysis is undertaken considering multiple parameters such as license type, traffic flow behavior, type of traffic flow models employed, type of infrastructure to be simulated and project types to name a few. Thus facilitating traffic engineers and researchers in TSS selection decision making appropriate according to their local conditions. It is concluded that no single reported TSS has an overall advantage on other TSS. The choice has less to do with the TSS itself and more with local traffic conditions and behavior. Furthermore type of road infrastructure (such as local roads or freeway, intersections, ramps) is an important parameter in the choice of TSS. Calibration and validation of TSS using real world traffic flow parameters further enhances any given TSS's simulation results.

Unique features in each TSS makes it a preferable choice for a specific kind of project to be simulated. For example for traffic flow simulation on freeways and highways, Aimsun, CORSIM, Kronos, Paramics, PTV Toolkit (VISSIM), Saturn and Sidra are the optimum choice. Whereas, INTEGRATION, Sidra and SimTraffic can give results most identical to real-world traffic behavior for roundabouts and intersections. TransModeler is the most suitable TSS for underpass and overpass traffic flow simulations. For traffic flow simulations at road bottlenecks, AnyLogic and MovSim are optimal choices. Whereas for heterogeneous traffic, the only available choice is between HeteroSim and SUMO.

As evident from this work, a lot of effort has gone into developing TSS for homogenous traffic behavior. For future work, efforts will be undertaken to extend the capabilities of available open source TSS such as HeteroSim and SUMO for heterogeneous traffic behavior.

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