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Decongestion of Nairobi-Thika Highway-Outer Ring Road “Gsu” Intersection Using Microsimulation and Geometric Modeling

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Abstract A lot of studies have been done to decongest urban road networks especially at major intersections mainly to improve flow efficiency and capacity. Both simulation and computer aided geometric modeling techniques have facilitated these investigations, but little has been done to document the steps leading to the selection of the most optimized architectural configuration of the interchange for implementation. This paper presents the explanation of the steps followed during the decongestion design process of the “GSU” interchange located at the intersection of Nairobi-Thika Super Highway and the newly improved Outer Ring Road (ORR); two key arterial road corridors in Nairobi city, Kenya. The new “GSU” interchange design deployed both micro-simulation modeling using Parallel Microscopic Simulation Software (PARAMICS) and AutoCAD Civil 3D geometric modeling techniques. Using excerpts from the traffic engineering expert’s micro-simulation work together with the design report prepared by the ORR improvement supervision consultant’s team, this paper outlines the workflow steps that led to the final choice of the interchange configuration’s shape and form. The finding of this paper demonstrates the efficacy of the use of micro-simulation models in supporting CAD geometric remodeling of existing intersections for enhanced capacity and flow. The process involving the integration of simulation and geometric modeling is rather complex in nature as it requires team members to exercise patience with each other. This paper recommends that urban road authorities should have a dedicated traffic flow simulation team to work closely with road design engineers in city road network decongestion plans.

Keywords: *decongestion, geometric, modeling*

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1. Background

The capacity of road transport system is a major issue of concern in all cities of the world [1]. The key matter that continues to dominate the debate in this area is often how to sustain an efficient traffic flow continuum [2]. There is paucity of knowledge on steps of integrating simulation results in geometric modeling in resolving congestions in most developing nations. A traffic flow in an urban road is the “level-of-service” (LOS) that it provides to travelers. Ideally, all major and arterial urban roads are expected to provide uninterrupted flow in which the density of traffic (number of vehicles per linear length) remains as per the posted design speed. In addition, the efficiency of the traffic flow depends largely on the state of the road and the driving habits; factors which may contribute to congestion.

Traffic congestion refers to a slowed traffic flow phenomenon which is the manifestation of the imbalance between traffic demand and the capacity of the road [3]. Frequent congestion and delays on most urban roads especially the expressways are caused by crashes [4]. The crash menace elimination is one of the targets of the new sustainable development goals which aim to cut the number of deaths and injuries from road traffic accidents globally by half by 2030.A lot of research works have shown that congestion does interfere with a city’s economic efficiency since it imposes extra costs on the local inhabitants, more specifically on the travelers who suffer the loss of wellbeing or satisfaction from the trips made [5].

The costs and losses are primarily in terms of the lost time in terms of man-hours [6]. For example; congestion is a problem in all the America’s 439 urban areas. In the 2009 America’s urban mobility report stated that in 2007, congestion forced travelers to stay on the roads for an extra 4.2 billion hours and a 2.8 billion more gallons of fuel purchase thereby occasioning a huge economic loss of about $87.2 billion [7]; counts which increased by an average of 50% in the 2014’s reporting [8]. Actually, congestion is a pervasive problem affecting both developed and the developing nations.

For instance, it has been reported that China witnessed a 20% annual motorization growth rate in the period 1978-2014 which triggered the yet to be fixed traffic congestion on most of the Chinese cities' roads [3]. In the same fashion, in Kenya, it was one time noted that, the 2014 traffic congestion in Nairobi had a daily aggregated economic loss of about $570,000 per day [8,9,10]. Scholars like [11] attributed the congestion in Nairobi to the fact that, out of the approximately 2 million registered motor vehicles in Kenya as per the 2013 records, about 60% were located in the Nairobi Metro region. This problem of congestion in Nairobi is affecting public service delivery including access to emergency healthcare, where sick people waste significant minutes on the city roads daily as they navigate city roads to get to treatment centers [12].

Because the traffic jam problem is on a steady growth mode, worker in [13] opined that, the-do-nothing traffic improvement scenario in Nairobi city would by 2030 increase the traffic congestion by about 198.76% from the 2010 base year volume over capacity ratio (v/c). This assertion, in a sense, sort of amplified the earlier warning by [14] whose finding heaped the blame of city's traffic congestion on the lack of a reliable public transport system that can assure the travelers of their personal safety, comfort and or convenience, hence the preference for personal cars over public transport vehicle. This congestion in Nairobi is exerting considerable pressure on the government of Kenya. In response, it is worthy to note that, over the last decade, the government of Kenya together with its development partners have been investing heavily on strategies to increase road network capacity within Nairobi city that includes the introduction of intelligent transport system [15]

For example, a lot of energy has been expended on improving city's traffic flow and connectivity with the hinterland. On connectivity, the construction of Nairobi-Thika Super Highway [16], several city road bypasses and missing links have contributed immensely in trying to ease traffic grid-locks. As these developments were being undertaken, major roads remained in poor conditions due to deferred maintenance [17]. Further, most of the city roads are narrow and rarely allow for multimodal configurations. The gravest concern however is the fact that most of the arterial roads have feeder roads joining them in many places which ends up causing disruptions in the main-line traffic flows.

With more than 4.5 million people, traffic congestion in the Kenyan capital can be maddening, especially if the peak hours get you on some of its major roads [18]. One such road is the Outer Ring road (ORR) which intersects with the Nairobi-Thika Super Highway at the General Service Unit headquarter gate, a location which is colloquially known as "GSU".In 2013, the government of Kenya through the funding from the African Development Bank planned for the improvement of ORR which is one of the major arterial roads within the city. The improvement was designed as a congestion relief highway [19].

The improved road was opened to traffic towards the end of 2018.But there arose another challenge. The traffic flow at GSU intersection did not improve, subsequently occasioning a need to undertake a geometric remodeling which was hailed by the public as a timely intervention with a potential to ease the jam [20]. Accordingly, this paper aims to highlight the engineering processes that were undertaken to facilitate the geometric remodeling precedent to the implementation of the design. The rest of the paper is as follows; section 1.2 presents the traffic congestion problem contextualization. Section 1.3 highlights related work, while section 2 sketches the methodology. Section 3 presents the results and the discussion. Section 4 is the conclusion.

1.1. Problem Contextualization

Urban road transportation system's traffic flow efficiency has been a subject of investigation for many decades. The research interest in this area continues to increase since the global urban population is soaring past the 50% mark rendering the capacity of most roads ineffective [21]. This is perhaps the reason behind the shift to smart systems in an effort to make urban life comfortable and enjoyable [22]. European cities such as Bristol, Helsinki, and Stockholm are already being counted as the trail blazers in the implementation of the green mobility patterns in which flow efficiency is monitored through online platforms **[23]**.

Despite these efforts, dependency on cars is growing and millions of people sit in gridlock because of disruption in flow as road capacity get overwhelmed with burgeoning traffic volumes during rush-hours particularly at weaving sections [24]. The most critical flow efficiency factor is the cost of the travel time, which is often used as the predictor of congestion [25]. Traffic flow theorists initially were concerned with the controlling of the traffic demand and road network capacity [2]. Stemming from the seminal work by [26] on the analysis of delays at an uncontrolled intersections, increasingly, the concern has been on how to make flow efficiency improvements [1]. Both demand and supply side approaches have been used, notably the deployment of traffic signal timing optimization (an elaborate computer based routines or simple manual heuristics) to control the former.

For the supply side, structural adjustment methods like; use of roundabouts ,minor physical changes such as adding lanes, grade separations, and addition of short traffic lanes at junctions are the most popular methods [27]. But some modern scholars strongly oppose these supply side solutions. Instead they prefer the use of alternative travel modes in cities. For example, [28] recently observed that the urban motor-traffic is more comparable to a gas which expands to fill any available space. Regardless of the size of the road network, congestion is a problem. Often, the larger the network, the worse the congestion. "Build it and they will come" is true of car traffic. A now common adage, commonly quoted which states that "adding lanes to deal with urban road congestion is like loosening your belt to cure obesity. It does little to address the cause while providing space for the problem to grow".

Historically, traffic engineers have always used simulation methods to aid decongestion efforts. The simulation models do support transportation planning and traffic management decisions because of their presentation of a "virtual reality "environment [29]. By definition, traffic simulation is a dynamic representation of a part of the real world through the building of a computer model and moving it through time [2]. The big question that arises is how to configure the intersection geometry that meets the congestion-free condition for a reasonable time. Through this, negative traffic externalities are eliminated from a given link to the larger network level.

While doing this, the focus is always at the intersection levels which are the bottlenecks of all urban road traffic loadings. For unsignalized intersection for example, the flow efficiency is dependent on entry capacity that takes care of the safety and priority vehicles. In high density traffic situations especially at the intersections, the scenario often witnessed is of drivers who violate the Highway Code rule which avoids collision and promotes continuous flow of traffic. Specifically, the Highway Code rule says that drivers must not enter an intersection if they are not sure they will be able to exit the intersection in a single movement [30].

1.2. Related Work

Decongestion of urban roads has been done in many places using different methods. Using traffic flow data collected from Cao'an Highway in Shangai China, worker in [3] deployed Traffic Software Integration System (TSIS) to simulate the flow behavior which resulted in lane widening and intersection remodeling. In trying to work with demand approach, workers in [31] analyzed the urban traffic demand distribution alongside the correlation between traffic flow and the built environment in which they suggested that city authorities should promote flexible work time and places. The traffic simulation methods have been used for a long time to aid decongestions according to [32] .For example, workers in [33] used it to estimate lane flows for intersection analysis.

In 2001, workers in [34] deployed micro-simulation and analytical methods for modeling urban traffic. In road network flow analysis, scholars in [35] used calibration and validation of a micro-simulation model.Recently, workers in [36] deployed the method of analysis of traffic operations at two diamond interchange types. Building on the work by [37] on grade-separated junctions and interchanges, scholars like [38] developed guidelines for selecting single point urban and diamond interchanges which act as the single locations for road entrances and exits. The intersection locations; often the bottleneck points, require an accurate traffic density estimation. The traffic flow volume estimation work was pioneered by cell transmission model designed by [39] for a microscopic traffic flow condition. And for macroscopic traffic flow condition, the switching-mode model was developed particularly for the unmonitored locations along busy highways [40].

Since the advent of computer aided designs (CAD), collaborative work between road traffic engineers and highway geometric engineers has birthed marveling innovative designs of interchanges [41]. The geometric design of highways using AutoCAD Civil 3D as explained by [42] is a trend setter. Even designs of rural roads follow the same approach in most places as affirmed by [43]. But the most illuminating use of technology in the design of roads is the development of 3D model for a highway alignment as explained by [44]. Because of the malleability of the design processes in computer-based designs, the process of optimization of highway geometric designs has been made flexible and more efficient [45]. Due to this reason, and to mainstream the ensuing benefits of technology in education and training of road engineers, interactive geometric design tools for transportation like; ROAD, MXROAD et cetera, are today highly recommended [46,47].

But to aid faster highway capacity and level-of-service analyses, forecasting through simulation is a precedent requirement [48]. This requirement has been demonstrated elaborately by [49] in their work titled “a traffic capacity improvement example of urban road intersection”. This can lead to the increasing of the capacity of intersections by short traffic lanes [50], saturation flow changes [51] and / or automation of road transport in urban areas [52]. The values for highway capacity and level-of-service from simulations are very important design variables particularly at the intersections [53]. They help in shaping and forming of the intersection model geometry from the simulation results, but surprisingly there seems to be a gap regarding the presentation of the steps for the geometric modeling process. The objective of this paper therefore is to explain the steps that were followed towards the geometric remodeling of GSU interchange from the micro-simulation results.

2. Methodology

The methodology is divided into two sections. The first section is the micro-simulation phase whose processed information is credited to the team from Timcon Associates whose principal is the undisputed expert in modeling of heterogenous urban road traffic flows [54]. The traffic flow data for this study was collected over a period of four days from 5th to 8th of November,2018.The second section is credited to the author who was the highway geometric design engineer for the improvement of the Outer Ring Road as a freelance sub-consultant of the joint venture between LEA International and LEA Associates South Asia PVT.The geometric modeling was undertaken in two stages. Stage one was an initial configuration to aid micro-simulation process.

Stage two was the optimization of the initial configuration to accommodate the most efficient flow with the least delay on set time as was first discussed by [55]. In the micro-simulation, Timcon Associates was in joint venture with CIMA International and in association with ITEC Engineering Ltd .The Timcon/CIMA/ITEC team developed a four stage study process, beginning with; the baseline study followed by field data collection which subsequently led to micro-simulation modeling and ending with the stakeholder engagement. In the scoping of the traffic flow data catchment area, the team delineated the main-line traffic corridor; along the Nairob-Thika Super Highway from Pangani Interchange to Garden Estate Interchange as shown in dashed lines in the Figure 1 below.

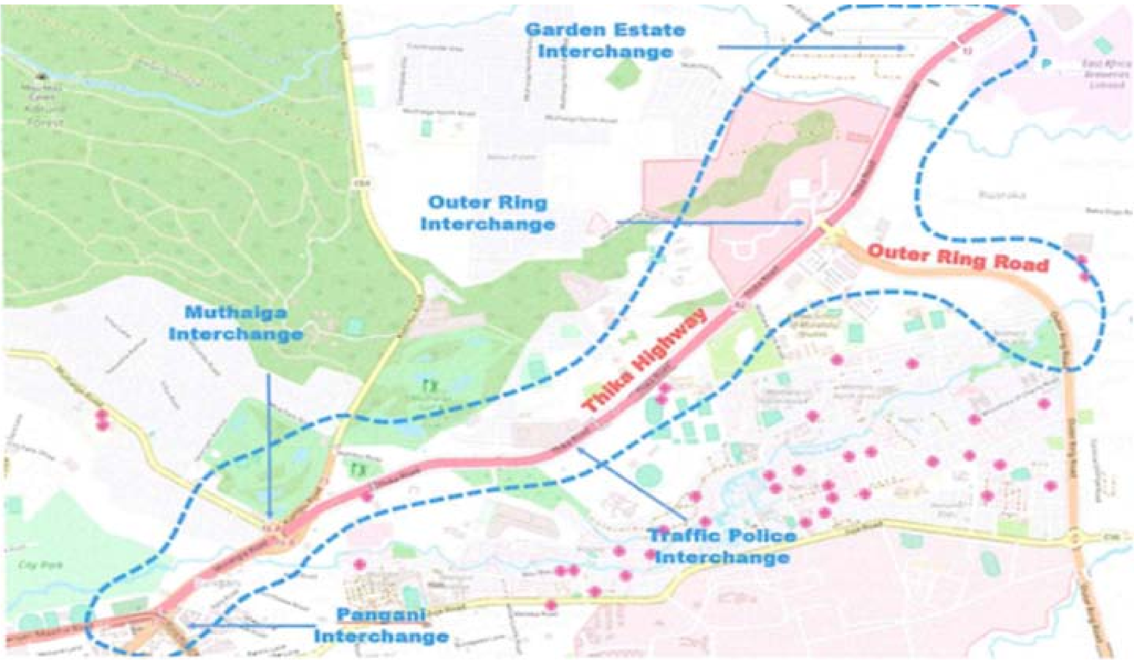

Figure 1. main-line traffic flow data catchment area

Because this paper is all about Outer Ring Road GSU interchange geometric remodeling, the descriptions presented herein are limited to its location features. The simulation team assessed the area from aerial view, CAD drawings shared by the LEA team and site visits that preceded traffic data collection. The data that were finally collected included; posted speeds, lane numbers, intersection configuration and magnitude of the conflict at the intersection especially at peak hour periods. Since the flow analysis depends heavily on traffic volume, traffic survey was organized on two points at the ORR -Thika road intersection. It should be clarified that the main-line of Thika road traffic is vertically below the grade level (free flowing), so that it is the service road traffic (LHS) coming from the Nairobi Central Business District located to the far left in Figure 1 above after Pangani Interchange which mainly conflicts with the Thika town bound traffic turning to the right at the ORR intersection with the Thika road service road at the GSU headquarter gate.

Figure 2 illustrates the existing junction of ORR with the Left Hand Side (LHS) Thika road service road .This LHS service road conveys a mix of Thika town bound traffic from CBD and the right turning traffic onto ORR which conflicts with the Thika town bound right turning traffic from ORR along the weaving section hence the spillback delays on both legs during peak hours.

The traffic survey entailed actual counts and observations using video camera. Flow characteristic towards the GSU intersection from both legs; CBD outbound and ORR feed was captured using speed and travel time speedometer records. For flow distribution from the intersection point, origin-destination survey was done from a sampled population which gave indications on OD movements. Sample size was decided to be 5% of the sample frame, the 12-hour traffic volumes observed at the site. From CBD to ORR, the 12-hour count was 12,535 while the ORR to CBD 12-hour count was 14,982.The O-D movement analysis indicated that 78% of the CBD outbound traffic on the LHS service road join ORR at GSU junction while on 28% of the ORR traffic make a right turn to the LHS service road proceeding towards Thika town as shown in Figure 3 below.

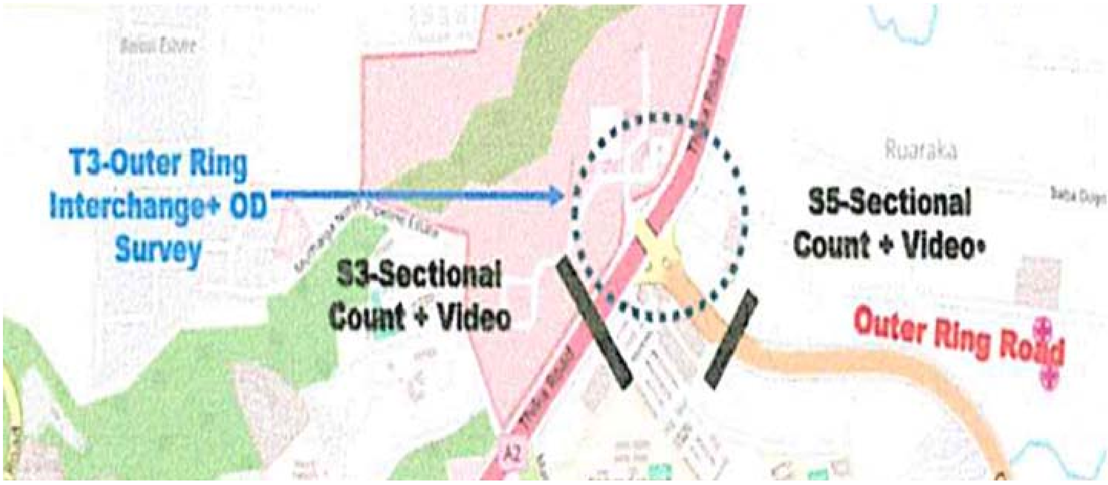

Figure 2. GSU intersection

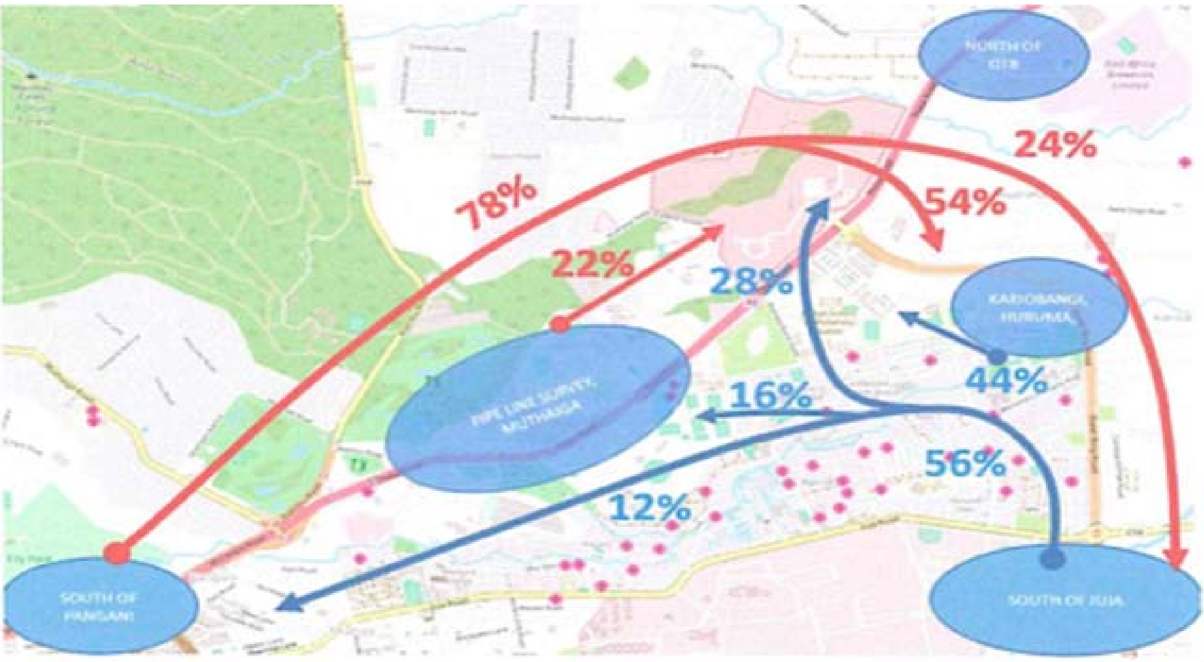

Figure 3. O-D movement direction analysis

The simulation team modeled using Parallel Microscopic Simulation software. This is normally known as PARAMICS and is a microscopic traffic tool developed by SIAS Ltd and Quadstone Ltd of Scotland and is designed for a wide range of applications where traffic congestion is a predominant feature [56]. Its modules combine together to improve usability, integration and productivity allowing users and clients to get added value from the modeling process. PARAMICS basically models the movement and behavior of individual vehicles on road networks. Following the advice by [57], the team installed the software. They subsequently followed the guide by [58] titled “application of paramics simulation” from which they executed the steps thus; coding, input of the demand matrix, assigned traffic, ran the simulation using visualization, calibrated base model by comparing with observed data and validated the model against independent data from GEH statistics.

When the design of Thika-Outer Ring road intersection was done by [59], the main-line traffic on Thika road was grade-separated in a subway flow pattern at the GSU intersection location. The Thika town bound right-turning traffic onto exiting Outer Ring road was designed to be conveyed by a flyover bridge over the mainline subway and made to intersect with the LHS service road. The Outer Ring road bound traffic from Nairobi CBD was then exposed to conflict with the Thika town bound right turning traffic on the exiting Outer Ring road. Later, after about six years, the design for the improvement of Outer Ring road was done but with the understanding that the GSU intersection at the LHS service road along Thika road will efficiently handle the estimated traffic volume. This expectation never worked and so upon the completion of the improvement of ORR, a need emerged on how to geometrically remodel the GSU intersection to ease the ensuing congestion problem.

Figure 4. Remodeled GSU interchange

The in-house survey team from LEA/LASA's supervision team collected survey data. Using this topographical information, the highway engineering section deployed the approach explained by [60] on geometric design of highway using Civil 3D which constantly relied on the manual "Mastering AutoCAD Civil 3D 2014" by [61]. In summary, the inventory of flow characteristics was compiled. The corridor's topographic model was prepared by selecting the file of the survey points saved in notepad to import the points to AutoCAD Civil 3D.Subsequently, this allowed for the creation of the surface of the existing ground. The next steps were; horizontal alignment geometry, pavement design, profile creation, horizontal/vertical curves and cross-section cut and fill. This iterative process was done for each alignment of the intersection configuration, see Figure 4.

3. Results and Discussions

The micro-simulation in PARAMICS had 8 alternatives. Each alternative was analyzed for base year (2018) traffic volume and future 20 year horizon (2038).Alternative 7 presented in Figure 4 above returned the most promising option. It has an elongated weaving section on the Thika road LHS service road. Its architectural configuration has a true definition of an interchange on different accounts. For example, traffic from Thika town side onto ORR are provided with an off ramp running from the lower level under the new connecting bridge on the eastern side to the weaving section. For the portion of the traffic which is CBD bound, there is an underpass culvert to connect with the ORR left turning to CBD.From the same weaving section, there is a chance for right turn for Thika town bound traffic over the existing bridge. The Thika town bound traffic from CBD passes under the new bridge as it splits with ORR bound traffic that climbs the ramp to cross over the new bridge and meets the from Thika town traffic at the weaving section on the RHS.

The geometric remodeling of the preferred alternative 7 took into account the pedestrian traffic from LHS of ORR which was ramped up to cross ORR, partly branching to cross the leg from Thika town before ramping to the ground on Alsop side. The remaining portion of the elevated footbridge proceeds to cross the leg from Thika town that u-turns traffic back to Thika before it descends to the ground behind the bus stage on RHS service road for PSVs from Thika. Pedestrians from the Thika road LHS service road have been provided with a facility over the new bridge. In terms of the operation, this alternative 7 gave an increased flow efficiency in terms of speed and an enhanced PM volume of about 3,114 vph.The PM peak hour had a higher observed traffic demand at this location. The modeling was undertaken for the 2018 existing condition and year 2038 for the future 20-year time horizon. The remodeled geometric configuration of the GSU interchange provided a satisfactory operation in terms of flow movement to each direction since it has a sufficient capacity.

4. Conclusion

The aim of this paper was to explain the steps of how the GSU interchange was geometrically remodeled using the results of micro-simulation. The findings have demonstrated the efficacy of the use of the micro-simulation in aiding geometric modeling of key intersections for improved capacity which confirms the earlier work by [62]. For a taste of the 3D impression, the reader is free to enjoy watching from the video's url, courtesy of Artis Design & Associates; https://youtu.be/N-d9wwXSGVE. The final 3D impressions by the same entity are presented in the appendix. The only short coming of this process is the complex nature of the simulation process which requires a lot of time and coordination of the various teams. This paper recommends that urban road authorities should have a dedicated simulation team in city road network decongestion plans.

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Appendix

GSU INTERCHANGE AREAL VIEW