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A Developed Approach for Modelling Overtaking Process on Egyptian Rural Roads

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Abstract

Overtaking is one of the complicated manoeuvres on two-lane two-way (TLTW) roads where the follower vehicles use the opposing lane to overtake the leader slower vehicles with the presence of oncoming vehicles on the opposite direction. The main objectives of the present study are (1) to modify Ghods' overtaking gap-acceptance model for TLTW roads to be representative for Egyptian conditions, (2) to calibrate and validate both of new modified overtaking gap acceptance model and Ghods' model, then the results have been compared, (3) to check whether new modified model to be representative to real-world collected overtakes for TLTW Egyptian roads or not. Three class II rural TLTW sites located in Dakahila Governorate are studied. Eight-hour videotaped data for sites were collected for both directions. About 82 vehicles overtook successfully but 119 failed to overtake. Modified criteria for overtaking model are derived. The 82 successful observed overtakes are used for calibration, the others 119 failed overtakes are used for validation based on the modified criteria. The modified overtaking gap-acceptance criteria are matching with successful observed overtakes on these three sites by 100% while the Ghods' criteria are matching to them by 79.12 %. These criteria are also successfully validated on all sites. Then, the modified overtaking gap-acceptance criteria are representative for TLTW Egyptian conditions. Furthermore, the modified overtaking model was more representative to reliable collected measures (i.e. overtaking duration and overtaking distance) rather than Ghods' and Tang's models for TLTW Egyptian roads while they are checked using hypothesis t- test.

Key words: Overtaking, two-lane two-way (TLTW), modified, Time-To-Collision, Egypt.

1- LITERATURE REVIEW

Overtaking is one of the riskiest manoeuvres on the two-lane two-way (TLTW) undivided highways, where the follower vehicles use the opposing lane to bypass the leader slower vehicles, especially with the presence of opposing vehicles from the opposite direction. (Asaithambi and Shravani 2017) mentioned that overtaking manoeuvres occur when traffic moves slower than the design speed. Therefore, these processes become necessary when some follower vehicles in the traffic stream move fast while other leader vehicles move slowly. (TRB 2010) mentioned that overtaking plays a vital role on road safety and its capacity as the rejection of overtaking leads to formation of large queues.

1.1 Factors affecting Overtaking Maneuvers

Cirianni et al.(Cirianni, Leonardi, and Palamara 2016) summarized the parameters for achieving successful overtaking are the type of the overtaking vehicle, volume of traffic flow in the opposite direction and characteristics of the overtaken vehicle. LIorca and Garcia (Llorca and García 2011) proposed a methodology framework to observe passing maneuvers on four passing zones on two-lane highways in Spain. Six video cameras were installed at a fixed point next to studied sections. They collected a sample of 234 manoeuvres; trajectories of 58 maneuvers were completely analyzed with specific restitution software. At high design speeds, higher differences (≥100 m) were found between observed data and previous existing models of PSD. Furthermore, the observed average speed difference between passing and overtaken vehicles was higher than those other models. Vlahogianni(Vlahogianni 2013) studied factors affect overtaking duration on two-lane highways in Greece. He concluded that speed difference (SD) from the leader vehicle, the speed of opposing traffic, the spacing from the lead and opposing traffic were influenced overtaking duration. Hassan et al.(Hassan et al. 2014) discussed factors affecting speed of overtaking vehicle for a single carriageway road in Johor, Malaysia. They concluded that the overtaking speed was influenced by the speed of leader vehicle, drivers' decision times, safety margin, overtaking durations and acceleration of follower vehicles during overtaking process. Durbin (Durbin 2006) mentioned that overtaking maneuver on TLTW highways is fully depended on three parameters that are proportion of slower leader vehicles in the traffic stream, traffic flow in each direction and the average SD between slower vehicles and the rest of the driver population.

1.2 Studies are related to Charactertics of Overtaking Maneuvers

Chandra and Shukla(Chandra and Shukla 2012) studied overtaking characteristics of various types of vehicles on four-lane divided highways in India. They concluded that as the speed differential increases, the overtaking vehicles require shorter time to overtake. Moreover, LIorca et al. (Llorca et al. 2013) compared the passing operations under daytime and night time conditions on a two-lane rural road section near Valencia, Spain. The road observed by six video cameras. About291 overtaking trails were observed, up to 20% of which were at night. Observations indicate that passing at night time is relatively safer. Farah (Farah 2011) studied differences in overtaking behavior between young and old and between male and female drivers on two-lane highways in Israel. Overtaking behaviors of 100 drivers (69 males, 31 females) were collected with an interactive driving simulator. It was concluded that male drivers maintain smaller following time gaps from the leader vehicle before beginning an overtaking maneuver. Moreover, younger drivers have lower critical gaps and higher desired overtaking speeds and keep smaller gaps from the front vehicle at the end of the overtaking maneuvers than older drivers. (L. and S.Hamamdeh 2005) studied overtaking maneuvers throughout field observations in Jordon. They concluded that risky and incomplete overtaking maneuvers on straight and flat roads occurred more than those on curvy roads. Logistic analysis indicated that probability of performing an overtaking manoeuvre is function of speed before overtaking while the success probability is function of speed of the opposing vehicles. Mondal and Pritam(Mondal and Saha 2020) studied overtaking process of E-rickshaws on suburban arterials in the city of Kolkata, India. About 50 test overtakes on each study section of the road were collected. Time accuracy was 0.01 seconds; speed of the test vehicle was recorded by the speedometer. Acceleration and deceleration characteristics (i.e. rate of increase, mean, maximum and minimum) for each vehicle were studied. It was concluded that smaller size, lower speed and rapid acceleration of e-rickshaws enable overtaking process.

(Kashani, Ayazi, and Ravasani 2016) examined effective variables on overtaking maneuvers on five TLTW roads located at Zanjan and East Azerbaijan provinces in Iran. Totally 514 overtaking maneuvers including "normal overtaking" and "aborted overtaking" maneuver were recorded. They concluded that drivers have low educational levels; the probability of performing risky maneuver of "cutting in" was about 5.3 times greater than "aborted overtaking" maneuver. On the other hand, for drivers with university degree, the probability of performing "normal overtaking" was about 4.6 times more than that of "cutting in" overtaking maneuver.

1.3 Modeling Decision for Overtaking on TLTW Roads

Farah (Farah 2016) developed a logistic regression model to predict the probability that a driver will abort an overtaking maneuver by collecting a trajectory data at a resolution of 0.1 seconds in two-lane roads in Netherlands. Detailed trajectory data of 670 overtaking maneuvers were collected; 554 of them were successfully completed, and 116 were aborted. . He concluded that possibilities of aborted overtaking are depended on the gap in the opposite direction, desired speed of overtaking vehicle, type and speed of the front vehicle. (Ameera and Verghese 2019) developed a logit model for overtaking opportunity in TLTW Indian roads. The model depends on type of overtaking, speed of overtaking and overtaken vehicles, traffic density for both directions, opposite gap, opposite vehicle type and speed of opposite vehicle. Budhkar and Maurya (Kishor BUDHKAR and Kumar MAURYA 2018) modelled overtaking decision under mixed traffic conditions in five cities of India. The model was based upon lateral and longitudinal positions of leading and following vehicles, their speeds and their vehicle types, using logistic regression**.** They found that overtaking chance increases significantly with increase of lateral staggering. It also decreases with increase of longitudinal distance, or decrease of relative speed.(Albert and Bekhor 2019) introduces a Hybrid choice model in order to explain the overtaking decision on two-lane highways, which is well known as a risky complex decision. This model combines measurement and structural equations of latent variable model and an overtaking choice model. They found that Thrill and Adventure Seeking and Geographic Ability provide significant explanation for overtaking decision. Both of them are positively correlated with higher risky overtaking behavior. Mounica et al. (Mounica et al. 2014) proposed work develops by mutual communication between Overtaking Possibility Check Algorithm (OPC) and the Overtaking Algorithm (OT) for reducing road accidents caused by overtaking to save human lives. The OPC is based on some factors such as speed of the front vehicle, distance between rear and front vehicle, traffic condition and vehicle grade. OT is operated by sending interrupts to the front vehicle for checking the overtaking possibilities. It also alerts the front vehicle just before overtaking to avoid collisions.(Cara et al. 2016) developed a warning system relies on car-2-car communication technologies for assisting driver to overtake safely depending on Agent Communication Language (ACL). This system consists into two stages: firstly, to obtain a confirmation from the lead vehicle that there is not another overtaking car from the opposite lane. Secondly, to notify other traffic participants of the overtaking that is about to take place so, vehicles will keep a constant speed during the maneuver and they will not try to overtake at the same time.

There are microscopic models that develop criteria for modelling driver's overtaking decision. They are such as the following;

Nile Journal of
Architecture & Civil Engineering
Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

Lovell et al.(Lovell, LAU, and May 1993) mentioned that TRAffic on Rural Roads (TRARR) model, developed by the Australian Road Research Board (ARRB), is used to design passing lanes in highway segments. In TRARR model, the decision of overtaking was depending on available overtaking time gap multiplied by a vehicle-specific safety factor.

The TWOPAS model is a microscopic model of traffic on two-lane highways. It is developed by Midwest Research Institute (MRI) in 1970. This model was also applied to estimate two-lane highway capacity and level-of-service (LOS) in the Highway Capacity Manual.(St. John and Kobett 1978) mentioned that TWOPAS model was based on vehicle type, road geometry, passing and no passing zones, traffic volume, relative speed between leader/ follower vehicles, desired speed, acceleration of each vehicle, gap between leader and follower vehicles and available overtaking distance.

Moreover, (Minderhoud, Michiel, and Zuurbier 2004) mentioned that the Dutch model (SiMoNe) is developed as a motorway simulation model enabling modelling of vehicles equipped with driver assistance systems. They extended SiMoNe model to be applied on two-lane rural roads with oncoming traffic. The total time needed for overtaking is summation of time headway, passage time, and lane change time with safety margin. When the time needed for overtaking is smaller than the estimated available gap until the next opposite vehicle arrives, an overtaking is accepted.

1.4 Previous Models for Estimation of Overtaking Durations and Distances

Polus et al (Polus, Livneh, and Frischer 2000) developed models to quantify the major components of the passing process. They collected about 1500 passings by videotaping from high vantage points on two-lane highway sections in Israel. Required sight distance is summation of three components (distance travelled by FV to initiate overtaking + distance between opposite and overtaking vehicles after overtaking + (5/3) multiplying by distance travelled by FV to bypass overtaken leader vehicle). A model showing that 54% of passings were characterized as “single passing,” in which one driver passed a single, slower vehicle. Very short headway before the start of the overtaking maneuver and very short (≤1 second) driver-reaction times were observed.

Ghods (Ghods 2013) developed an overtaking gap-acceptance model to simulate traffic operations and safety performance measures on TLTW highway in Southern Italy. **Equations 1** represents the distance travelled by follower vehicle to take a decision for overtaking; **Equation 2** represents the distance travelled by leader vehicle to take a decision for overtaking. **Equation 3** represents the time needed by follower vehicle to achieve desired overtaking speed at phase 2. **Equations 4 and 5** represent the distance travelled during phase 2 by follower and leader vehicles respectively. **Equation 6** represents the time needed by follower vehicle to achieve safe separation while returning to its original lane at phase 3. **Equation 7** represents the distance travelled during phase 3 by follower vehicle. **Equations 8 and 9** represent total overtaking distance and total overtaking duration respectively. **Equation 10** represents the distance travelled by opposite vehicle during overtaking process. **Equation 11** represents the time –to – collision between overtaking and opposite vehicles that must be achieved to avoid collisions. A total of 97 vehicles trajectories of 900 m road section were extracted from the three-hour videotaping. Ghods’

Nile Journal of
Architecture & Civil Engineering
Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

(2013) model was depended on the overtaking driver's perception of time-to-collision (TTC) with an opposite vehicle. Ghods' (2013) model was validated using OverTaking SIMulation (OTSIM) microscopic software. The decision to overtake was based on perceived TTC that was compared to an established driver risk threshold (critical TTC). In Ghods' (2013) model, there are three main phases for achieving a successful overtaking. The first phase presents the distance travelled during a decision for overtaking; second phase presents the distance needed to achieve desired overtaking speed in the opposite direction during overtaking process; and the last third phase presents the distance needed to achieve safe separation during returning of FV to its original lane. The three phases are shown in **Figure 1**.

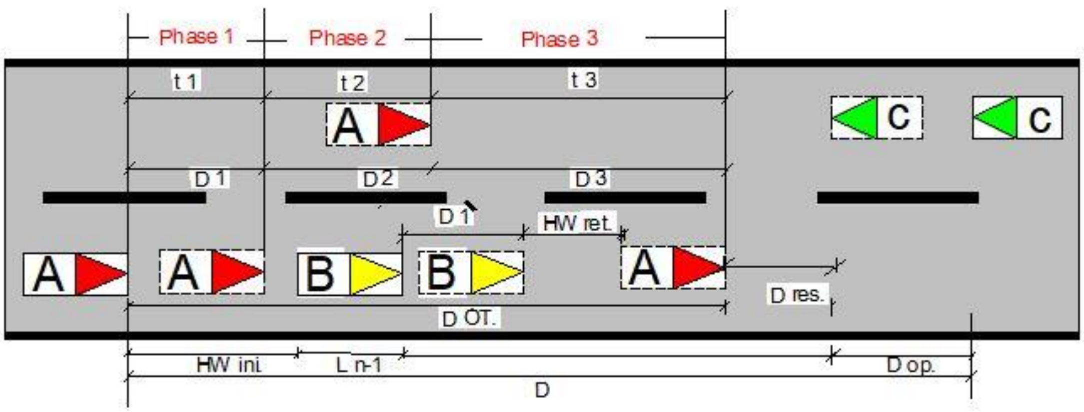


Figure 1: Phases of Overtaking process according to overtaking model used in the OTSIM software

$$D_1 = v_n^{ini} \times t_1 \qquad (1)$$

Where;

t_1=Perception and reaction time by FV , v^{ini}=Initial FV speed ,

D_1=Distance travelled by the FV from the initial decision-to-overtake point to pull out.

$$D_1' = v_{n-1} \times t_1 \qquad (2)$$

Where;

D_1' = the distance covered by LV during the reaction time $\left(t_1\right)$

$$t_2 = -\frac{v^{max}}{k \times a^{max}} \times \ln\left(\frac{v^{max} - v_n^{des-ov}}{v^{max} - v_n^{ini}}\right) \qquad (3)$$

Where;

v^{max} =Maximum achievable speed of the FV ,

a^{max} =Maximum achievable acceleration of the FV from stopped position ,

K =Proportion of maximum acceleration employed by the driver for overtaking ,

t_2 =Time for FV to pull out and attain its desired overtaking speed ,

$v_n^{des\text{-}ov}$ =Desired overtaking speed of the FV .

$$D_2 = v^{max} \times t_2 + \frac{v^{max}}{k \times a^{max}} (v^{max} - v^{ini}) \times (e^{\frac{-k \times a^{max}}{v^{max}} \times t_2} - 1) \qquad (4)$$

Where;

D_2 =Distance travelled by the FV from pull-out to the point where desired overtaking speed is achieved

$$D_2' = v_{n-1} \times t_2 \qquad (5)$$

Where;

D_2' = the distance covered by LV during the time (t_2) ,

v_{n-1} = Constant LV speed

$$t_3 = \frac{HW^{ret} + L_{n-1} + HW^{ini} + L_n - (D_1 + D_2 - D_1' - D_2')}{v_n^{des-ov} - v_{n-1}} \qquad (6)$$

Where;

L_n = Length of overtaking vehicle ,

L_{n-1} = Length of overtaken vehicle,

HW^{ret} = Distance headway for pull back (rear bumper of FV and front bumper of LV)

HW^{ini} = Initial distance headway between front bumper of the FV and rear bumper of LV

t_3 = The time elapsed by FV to pass LV and completing the maneuver

$$D_3 = t_3 \times v_n^{des-ov} \qquad (7)$$

Where;

D_3 = Distance travelled by the FV to achieve safe separation while returning to its normal travel lane.

$$D_{OT} = D_1 + D_2 + D_3 \qquad (8)$$

Where;

D_{OT} = Total overtaking distance.

Nile Journal of
Architecture & Civil Engineering
Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

$$T_{OT} = t_1 + t_2 + t_3 \qquad (9)$$

Where;

T_{OT} = Total overtaking duration.

$$D_{OP} = T_{OT} \times v_{OP} \qquad (10)$$

Where;

V_{OP} = Constant speed of opposing vehicle during the FV overtaking maneuver,

D_{OP} = The distance covered by opposing vehicle during the FV overtaking maneuver.

$$TTC = \frac{D - (D_{OT} + D_{OP})}{V_{OP} + v_n^{des-ov}} \qquad (11)$$

Where; TTC = Time-To-Collision.

Tang et al. (Tang et al. 2007) proposed a new overtaking model conducted on a 15-km highway in China. This model depends on spacing between vehicles before and after overtaking, speed of overtaking and overtaken vehicles and the reactive delay time for deceleration; acceleration and lane changing.

The main purpose of this research is to develop a behavioral overtaking model for TLTW Egyptian roads by modifying Ghods' overtaking gap-acceptance model to be representative for Egyptian conditions and then investigate whether the modified new model is representative for real-world collected overtakes compared to Ghods' and Tang's models or not using hypothesis T-test.

2- METHODOLOGY

Selected three TLTW Egyptian roads in Dakahila Governorate are studied. The data is collected by videotaping and traffic parameters needed on overtaking maneuvers are extracted. A new modified overtaking model is developed to represent Egyptian conditions. The model is divided into two main parts; the first part contains a condition that is modified on Ghods' model for accepting/ rejecting overtaking decision. If the overtaking decision is accepted, overtaking duration and corresponding distance will be calculated by the modified model and then the results are compared to other models and actual observed overtakes.

3- STUDY AREA AND DATA COLLECTION

Three sites from TLTW roads within Mansoura city in Egypt were used in this analysis. The camera was placed at a high vantage location to capture the moving traffic of the entire width in both directions. The first site (i.e. site S1) is from the Mansoura-Damietta TLTW road that connects Mansoura to Damietta city. Two hours video (12 PM to 2 PM) of the traffic is captured for both directions. The second site (i.e. site S2) is from the Mansoura-Dikirnis TLTW road. A one-hour (12 PM to 1 PM) traffic video was captured for both directions. Another one-hour (12 PM to 1 PM) traffic video was captured for both directions at the same monitoring point. The third site (i.e. site S3) is from the Mansoura- Aga TLTW road. Four hours video (12 PM to 4 PM) of the traffic at the third location is captured for both directions. **Table 1** illustrates geometric properties of the three sites. The TLTW roads are classified into three classes based on their functionality. Both of the study sites are rural collector roads passing through different cities which can be classified as "Class II" TLTW roads, according to HCM (TRB 2016). **Figure 2** shows the three studied locations.

Table 1: Geometric Properties and date of data collection

Road	Site S1	Site S2	Site S3
Collection date	June 17, 2019	April 19, 2019 , March 15, 2021	June 15, 2021
Paved road width	6.5 meters	6 meters	6 meters
Right shoulder width	1.5 meters	1.0 meters	1.0 meters
Left shoulder width	1.0 meters	1.0 meters	1.0 meters

Nile Journal of

Architecture & Civil Engineering

Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

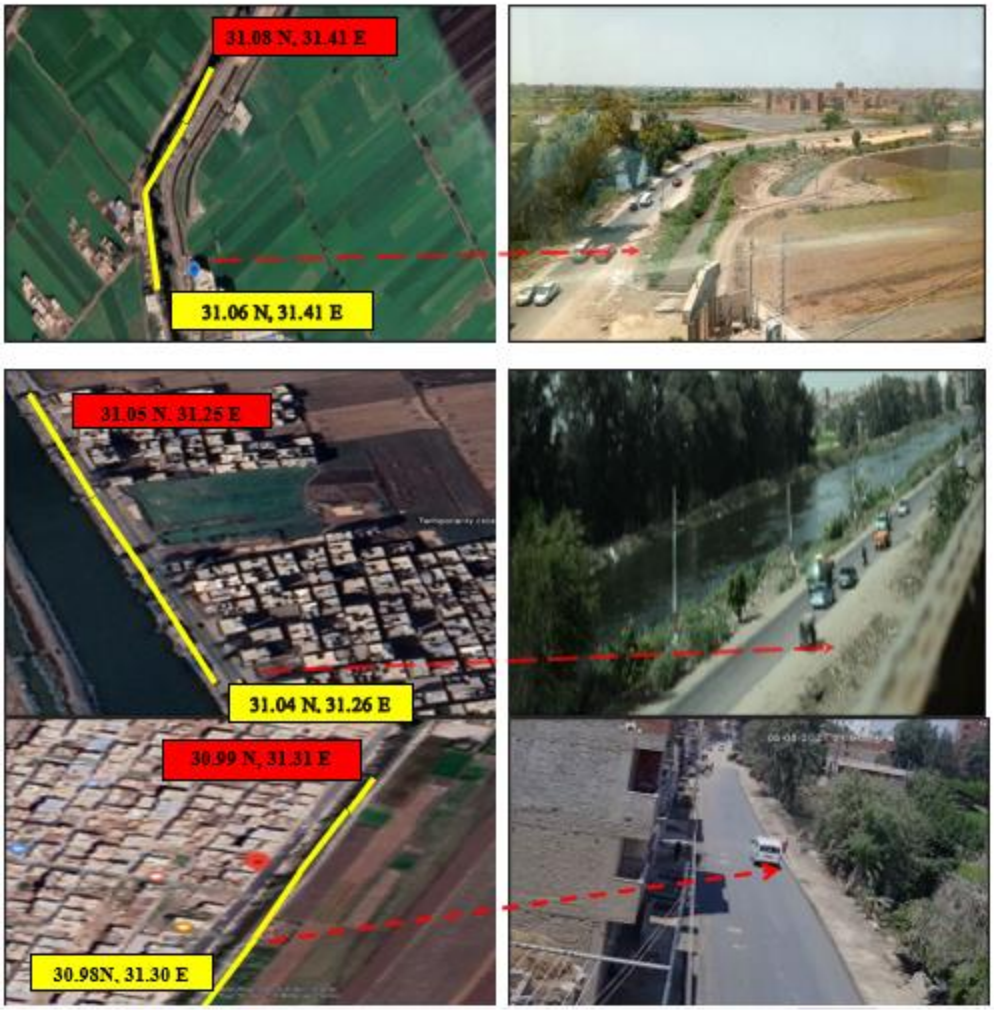


Figure 2: Location Coordinates from Google Earth and Snap Shota of the three studied Sites

Traffic composition for the three studied sites is shown in **Figure 3.** Pick-up commercial vehicles have the highest percentage of traffic composition (about 40%-45%) while Taxi have the lowest percentage (about 2%) of traffic composition. Speed distribution for the three studied sites is shown in **Figure 4.** The speed distributions are closer to be normally distributed for the three studied sites. Road Charactertics are observed for studied sites (S1 to S3) during eight -hours videotaping as in **Table 2.**

Nile Journal of
Architecture & Civil Engineering
Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

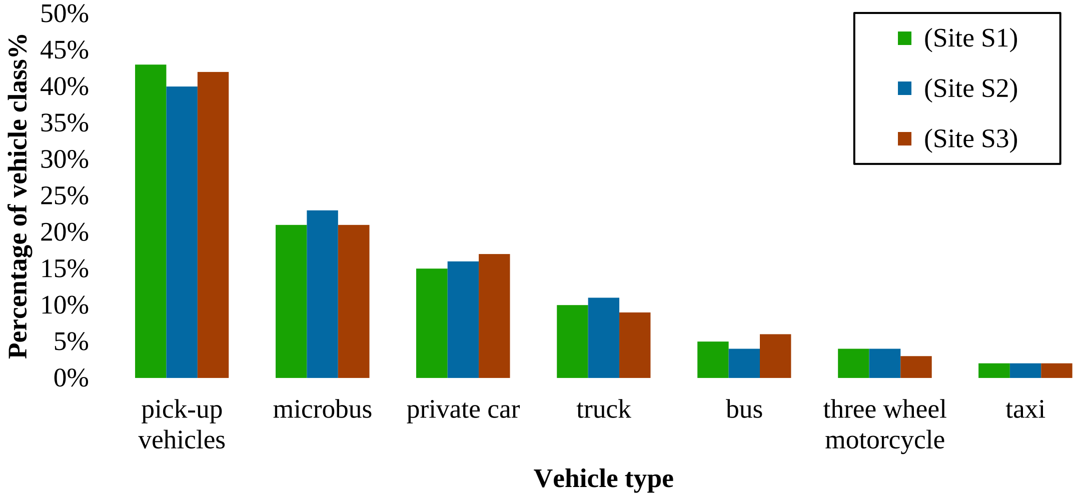


Figure 3: Traffic composition for the three studied sites

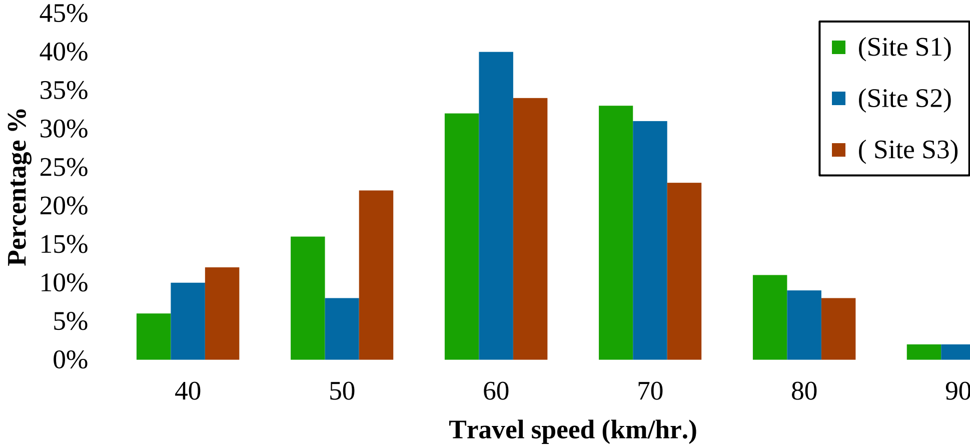


Figure 4: Speed distribution of the three studied sites (S1 to S3)

Table 2: Road Charactertics for both directions of three studied sites for both directions

site	Site S1		Site S2		Site S3	
	NB	SB	EB	WB	NB	SB
Average Traffic flow (veh. /hr.)	182	265	201	278	308	322
Section length (m)	375		205		220	
Lane width (m)	4.5	4.5	4	4	4	4
Maximum speed (km. /hr.)	94.33	91.12	94.79	91.46	90.14	90.86
Average travel speed (km. /hr.)	58.72	57.06	56.31	55.21	50.60	50.00
Average travel time (sec.)	22.99	23.65	13.11	13.37	15.72	15.52

Nile Journal of

Architecture & Civil Engineering

Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

Average headway (sec.)	19.91	13.16	19.76	13.22	13.21	13.22
Average density (veh. /km)	3.32	4.91	4.00	5.34	6.10	6.43

Based on the video tape recording, each road section is divided into equal mini- section from start point to end point of the studied road section. a section of 5.0 meters was selected, taking into consideration the scale between the video and the real world. This is done by drawing two lines that represent the 5.0 meters on a transparent paper attached to the computer screen. For each vehicle, two times are extracted, at the beginning (t_1) and at the end (t_2) of the 5.0 meters section, as the front bumper of the vehicle passes through them. The vehicle speed was then estimated by dividing the distance (i.e., 5.0 meters) by the time differences (i.e. “t_2-t_1), also acceleration/ deceleration were estimated by dividing speed by time difference for each vehicle. Overtaking collected data including (number of observed overtakes, desired overtaking speed, maximum acceleration, spacing between overtaking vehicle and overtaken vehicle, average speed difference between the two vehicles and average time –to-collision) is investigated during the eight hours for each site as shown in the following **Table 3.**

Table 3: Overtaking data for the three studied sites to both directions

site	**Site S1**		**Site S2**		**Site S3**	
	NB	**SB**	**EB**	**WB**	**NB**	**SB**
Number of overtakes for 1st hour	15	18	14	15	11	9
Average spacing between overtaking and overtaken vehicles (m)	27.01	25.52	12.36	12.60	11.27	11.97
Average gap distance between overtaking vehicle and opposing vehicle (m)	118.65	134.11	69.42	74.33	188.40	189.2
Average speed difference (km. / hr.)	24.67	26.30	22.01	27.98	14.02	14.12
Average desired speed (km. / hr.)	76.41	71.42	69.29	72.50	52.57	52.94
Average observed overtaking duration (sec.)	4.85	4.92	3.91	3.99	4.53	4.42
Average observed overtaking distance (m)	97.11	97.31	64.79	64.88	55.67	55.50
Average Time-To-Collison (TTC) (sec.)	3.43	3.64	2.00	2.44	4.17	4.22

4- CRITERIA FOR ACCEPT/ REJECT OVERTAKES BY GHODS’ AND MODIFIED MODELS

In order to calibrate overtaking gap acceptance model based on driver’s perception of time-to-collision (i.e. Ghods’ Model), overtaking distances and corresponding durations that extracted from videotaping overtakes must be calculated. The perceived time-to-collision “TTC_P” is assumed to combine all physical attributes that takes into account an estimate of overtaking distance in initiating gap-acceptance decision. (Ghods 2013)

For a given distribution of critical time-to- collision (TTC_{cirt}), the gap-acceptance function is defined as the probability that a randomly selected driver will accept an available "perceived" (TTC_p). For accepting gaps, the available TTC_p must exceed the critical value for the overtaking driver TTC_{crit}. It can be expressed as a random variable with the mean of actual (i.e. observed) TTC plus a random error term. Moreover, the error term in gap perception is defined as the difference between the measured value for TTC and its perceived value for accepted gaps according to *Equation (12)* (Ghods 2013).

$$TTC_p = TTC_{(actual)} + Error \quad \text{……………………………………..} \qquad (12)$$

Furthermore, it is assumed that for each driver has a critical minimum acceptable gap "TTC_{crit}" for overtaking which is normally distributed with the mean critical TTC "$TTC_{crit\,(avg.)}$" for overtaking model. Then, critical value of TTC can be expressed as *Equation (13)* (Ghods 2013). $TTC_{crit\,(avg.)}$ and its corresponding error are calculated for the three studied sites as shown in **Table 6**

$$TTC_{critical} = TTC_{critical\,(Avg.)} + Error \quad \text{……………………………..} \qquad (13)$$

To modify Ghods' overtaking gap-acceptance model to be representative for Egyptian conditions, the same criteria of Ghods' model will be applied except the value of perceived time-to-collision (TTCp) which controls on the decision of accept / reject overtaking. It is modified according to the following *Equation (14)* :

$$TTC_p(\text{modified}) = TTC_p(Ghods) \pm \delta \quad \text{…………………} \qquad (14)$$

Where,

TTC_p (modified): is the modified value convenient to Egyptian conditions,

TTC_p (Ghods): is the value of (TTC_p) mentioned on Ghods' gap-acceptance criteria,

δ is a term that achieves acceptable safety margin for overtaking under Egyptian conditions that is calculated according to the following *Equation (15):*

Nile Journal of
Architecture & Civil Engineering
Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

$$\delta = \frac{D_{n-1}}{v_{n-1}} - \frac{D_{n-1}}{v_{cri.}} \quad (15)$$

Where,

D_{n-1} = the distance between overtaken vehicle and opposing vehicle during overtaking process,

v_{n-1} = the actual speed of overtaken vehicle during overtaking process,

$v_{cri.}$ = the maximum acceptable speed of overtaken vehicle for collected accepted overtakes

5- CALIBRATION RESULTS OF THE COMPARATIVE OVERTAKING GAP-ACCEPTANCE MODELS

About 201 overtaking attempts are extracted from video camera on the three sites for total eight hours, only 82 of them overtook successfully but the others 119 of them failed to overtake. An aborted overtaking maneuver was defined as when the driver was completely or partially in the opposite lane but did not succeed in overtaking the front leader vehicle and decided to abort the maneuver and return to the original lane.

The parameter estimates for the critical residual gaps for Ghods' model is shown in **Table 4.**

Table 4: Average critical TTC and corresponding errors for all studied sites by Ghods' model

Site	**Site S1**		**Site S2**		**Site S3**	
Parameter	$\overline{TTC}_{cirt.}$	(e_n)	$\overline{TTC}_{cirt.}$	(e_n)	$\overline{TTC}_{cirt.}$	(e_n)
Mean	2.54	0.53	1.04	1.36	1.00	0.89
STDV.	±0.83	±0.90	±0.45	±0.19	±0.39	±0.26

A summary of critical speeds as well as the average, standard deviation, minimum, and maximum estimates of measured values of (δ) for all successful observed overtakes for each direction of the three studied sites are shown in **Table 5.**

Table 5: Summary of measured estimates of "δ" and critical speed of the three studied sites for both directions

Site	**Site S1**	**Site S2**	**Site S3**

Nile Journal of

Architecture & Civil Engineering

Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

		NB	SB	EB	WB	NB	SB
$V_{crit.}$ (Km/hr.)		50.00		48.00		50.00	
δ	Mean	1.82	7.17	3.30	2.34	7.66	6.17
	Maximum	6.12	10.58	8.87	8.56	9.40	9.80
	Minimum	0	0	0.97	1.71	4.55	2.60
	STDV.	±1.93	±4.49	±2.75	±3.98	±2.43	±2.98

It is obvious from **Table 6** that the modified Ghods' condition are accepted by 100% for all of successful observed overtakes for the three sites rather than the original condition related to time –to –collision mentioned on (Ghods 2013) that is matching to actual observed overtakes by 79.12%. Then, the modified overtaking gap-acceptance condition is more representative than Ghods' model for TLTW Egyptian roads.

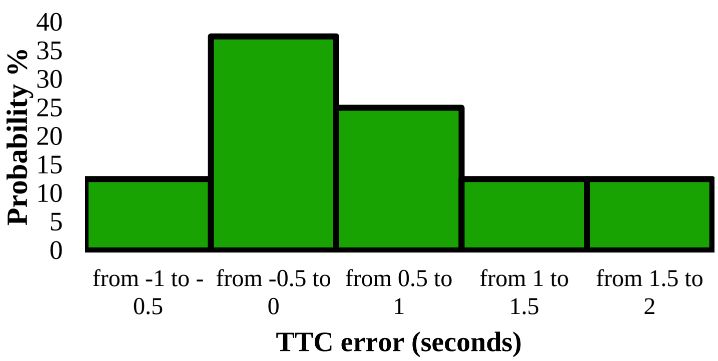
Moreover, the average percent overtaking gap-acceptance for observed successful overtakes were 20% for site S1, 7% for site S2 and 9% for site S3 according to the TWOPAS model. Then, the outputs of this model did not represent the actual observed overtakes under Egyptian conditions.

Table 6: A sample of the collected Processed disaggregate overtaking data from video cameras

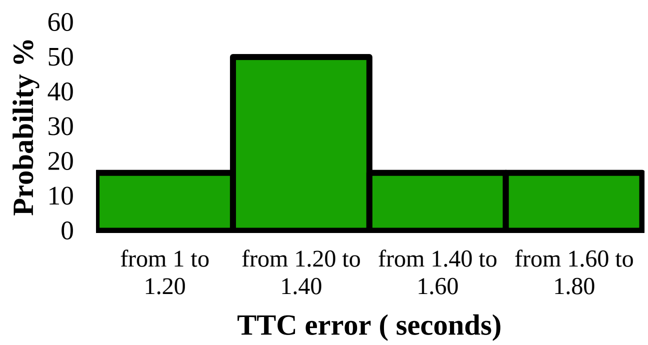
#	Overtaken vehicle type	Overtaking vehicle type	Speed of overtaken vehicle (km/hr.)	Speed of overtaking vehicle (km/hr.)	Opposing vehicle speed (km/hr.)	T_{OT} (sec.)	D (Act.) (m)	Actual TTC (sec.)	TTC_p (sec.)	Decision (0:reject) (1:accept)	TTC_p modified (sec.)	Decision (0:reject) (1:accept)	TWOPAS Model (% accept)
Site S1													
NB direction													
1	Truck	Truck	37.27	67.92	54.56	5.09	283.8	**2.84**	**2.87**	**1**	**8.99**	**1**	**19%**
2	Pick-up	Pick-up	47.38	72	40.01	5.09	371.6	**5.32**	**4.40**	**1**	**5.84**	**1**	**20%**
3	Pick-up	Microbus	48.6	60.01	46.03	7.82	375	**2.77**	**2.44**	**0**	**3.20**	**1**	**16%**
4	Truck	PC	50.04	72	44.67	6.63	372.9	**3.57**	**4.36**	**1**	**4.36**	**1**	**16%**
SB direction													
5	Truck	Truck	37.51	56.26	54.56	8.71	367	**2.85**	**3.89**	**1**	**11.71**	**1**	**21%**
6	Truck	Microbus	35.34	56.22	54.16	8.71	369.8	**2.94**	**4.53**	**1**	**14.39**	**1**	**22%**
7	Truck	Pick-up	32.14	70.01	45.10	4.54	369.8	**6.33**	**6.55**	**1**	**16.41**	**1**	**24%**
Site S2													
EB direction													
8	Pick-up	Microbus	45.01	62.03	36.02	5.81	204.6	**1.19**	**0.68**	**0**	**1.65**	**1**	**6%**
9	Tractor	Microbus	36.00	45.91	41.87	6.64	202.6	**1.04**	**0.14**	**0**	**5.05**	**1**	**8%**

10	Tractor	PC	30.00	43.90	41.77	6.76	205	**1.44**	**1.39**	**1**	**10.25**	**1**	**9%**
11	PC	Pick-up	43.91	75.00	40.01	3.29	205	**2.52**	**2.18**	**1**	**3.53**	**1**	**5.8%**
12	Pick-up	PC	42.92	75.00	26.87	3.53	205	**2.66**	**2.36**	**1**	**4.08**	**1**	**5.9%**
WB direction													
13	Tractor	Private car	30.00	72.00	39.14	2.70	202.7	**3.14**	**3.14**	**1**	**11.70**	**1**	**7%**
14	Three wheel motorcycle	Microbus	40.01	54.54	46.16	5.49	205	**1.40**	**0.56**	**0**	**3.56**	**1**	**6.1%**
15	Pick-up	Microbus	35.30	71.89	41.87	3.08	201.7	**2.71**	**2.68**	**1**	**7.68**	**1**	**6.8%**
Site S3													
NB direction													
16	Pick-up	PC	30.00	43.90	27.70	9.49	205	**0.12**	**-0.6**	**0**	**8.01**	**1**	**12%**
17	PC	Microbus	32.14	52.94	43.90	4.17	175	**2.04**	**2.09**	**1**	**8.69**	**1**	**15%**
18	PC	Three Wheel Motorcycle	37.5	50.00	40.90	4.31	200	**3.06**	**1.45**	**1**	**5.99**	**1**	**8%**
19	Bus	PC	35.29	48.65	40.00	3.96	194	**3.29**	**2.02**	**1**	**7.66**	**1**	**7%**
SB direction													
20	Microbus	Three Wheel Motorcycle	41.86	60.00	25.71	3.28	200	**4.40**	**1.89**	**1**	**4.57**	**1**	**9%**
21	Microbus	Truck	35.29	50.00	24.00	4.12	177	**4.06**	**1.94**	**1**	**7.03**	**1**	**8%**
22	Three Wheel Motorcycle	Pick-up	36.73	50.00	25.53	4.21	190	**4.42**	**1.83**	**1**	**6.56**	**1**	**8%**

Figure 5 illustrates the distribution of TTC errors for a sample of overtaking accepted gaps in the videotaped data for the first two sites (S1 and S2) using Ghods' gap-acceptance model. **Figure 6** illustrates the distribution of TTC errors for a sample of overtaking accepted gaps in the videotaped data for the first two sites (S1 and S2) using modified Ghods' gap-acceptance model.



(a)



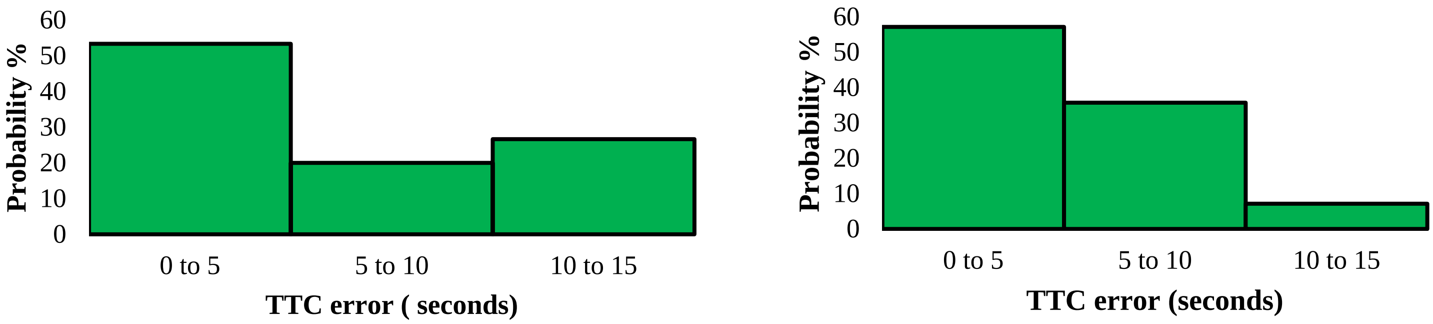
(b)

Nile Journal of

Architecture & Civil Engineering

Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

Figure 5: Error distribution estimated from observed accepted gaps for Ghods' model (a) Site S1, (b) Site S2



(a) (b)

Figure 6: Error distribution estimated from observed accepted gaps for modified Ghods' model (a) Site S1, (b) Site S2

6- VALIDATION OF A MODIFIED OVERTAKING GAP-ACCEPTANCE MODEL FOR THE THREE STUDIED SITES

For the modified overtaking gap-acceptance model, the 82 successful observed overtakes are used for calibration, the others 119 failed overtakes are used for validation based on the modified criteria. All observed aborted overtakes which the driver was completely or partially in the opposite lane are recorded and examined by Ghods' gap-acceptance and modified models. A sample of 31 collected processed aborted overtaking data is shown according to the modified Ghods' gap-acceptance model and Ghods' gap-acceptance model for the three sites in

Table *7*.

Table 7: A sample of the collected aborted overtakes extracted from video cameras

#	Overtaken vehicle type	Overtaking vehicle type	Speed of overtaken vehicle (km/hr.)	Speed of overtaking vehicle (km/hr.)	Opposing vehicle speed (km/hr.)	Initial gap (m)	D (Act.) (m)	TTC $_p$ (sec.)	Decision (0:reject) (1: accept)	TTC $_p$ modified (sec.)	Decision (0:reject) (1:accept)
Site S1											
NB direction											

Nile Journal of

Architecture & Civil Engineering

Journal Webpage: https://njace.journals.ekb.eg/publisher

Volume 5, January 2025

1	Pick-up	Private car	60.01	90.23	66.23	10.10	286.66	**2.34**	**0**	**-0.97**	**0**
2	Private car	Private car	63.32	79.23	38.77	9.98	296.4	**-2.35**	**0**	**-6.44**	**0**
3	Taxi	Private car	59.88	80.55	46.43	8.89	349.9	**3.23**	**1**	**-1.30**	**0**
4	Truck	Pick-up	47.89	75.56	47.11	12.78	107.67	**-2.23**	**0**	**-1.79**	**0**
5	Pick-up	Pick-up	44.88	73.46	45.55	14.71	109.87	**-1.80**	**0**	**-1.30**	**0**
6	Microbus	Pick-up	53.89	71.56	47.21	8.42	230.34	**-6.62**	**0**	**-7.81**	**0**
7	Truck	Pick-up	56.33	73.44	61.55	19.23	220.50	**-6.92**	**0**	**-10.41**	**0**
SB direction											
8	Private car	Private car	63.55	85.01	39.21	8.54	365.21	**3.32**	**1**	**-2.10**	**0**
9	Bus	Private car	65.32	79.29	48.67	9.44	291.44	**0.52**	**0**	**-4.16**	**0**
10	Truck	Truck	47.19	90.16	47.13	20.78	198.76	**0.59**	**0**	**1.40**	**0**
11	Microbus	Microbus	63.19	77.54	42.14	9.49	289	**0.49**	**0**	**-3.67**	**0**
12	Truck	Private car	51.87	79.22	49.14	10.02	335.02	**3.39**	**1**	**2.48**	**0**
13	Private car	Pick-up	56.33	69.45	45.32	9.50	291	**-8.50**	**0**	**-10.66**	**0**
Site S2											
EB direction											
14	Private car	Private car	55.01	91.54	69.23	9.87	197.50	**1.09**	**1**	**-0.50**	**0**
15	Microbus	Private car	55.12	76.23	70.44	8.66	198.65	**-0.49**	**0**	**-1.73**	**0**
16	Private car	Private car	48.15	68.14	72.56	8.67	109.22	**-2.24**	**0**	**-1.93**	**0**
17	Microbus	Pick-up	64.90	79.56	41.21	8.15	200	**-1.20**	**0**	**-2.68**	**0**
18	Truck	Truck	47.89	71.56	47.11	12.75	107.65	**-2.35**	**0**	**-2.19**	**0**
19	Pick-up	Pick-up	54.23	76.32	46.22	7.05	158.43	**-0.56**	**0**	**-1.81**	**0**
20	Pick-up	Pick-up	69.93	90.65	65.55	9.23	195.50	**-1.36**	**0**	**-6.05**	**0**
WB direction											
21	Truck	Private car	50.43	82.76	69.62	11	123	**-1.82**	**0**	**-2.14**	**0**
22	Private car	Microbus	51.34	83.12	66.32	10.78	114.54	**-1.91**	**0**	**-2.36**	**0**
23	Pick-up	Truck	47.19	75.16	44.12	12.05	109.76	**-3.92**	**0**	**-3.76**	**0**
24	Truck	Pick-up	63.19	90.26	49.21	9.05	293.34	**2.96**	**1**	**-0.42**	**0**
25	Microbus	Microbus	49.29	75.22	48.14	10.16	111.65	**-3.68**	**0**	**-3.83**	**0**
Site S3											
NB direction											
26	Private car	Microbus	55.12	76.26	70.44	8.69	198.06	**0.44**	**0**	**-1.89**	**0**
27	Pick-up	Microbus	53.89	69.56	47.21	8.40	218.00	**1.01**	**1**	**-0.10**	**0**
28	Microbus	Microbus	41.23	67.33	49.56	4.18	119.34	**-1.50**	**0**	**0.20**	**0**
SB direction											
29	Pick-up	Pick-up	54.23	66.23	46.22	7.08	208.47	**1.39**	**1**	**0.30**	**0**
30	Microbus	Microbus	44.23	65.13	50.22	4.88	135.34	**-0.44**	**0**	**0.83**	**0**
31	Microbus	Taxi	42.50	59.12	50.14	8.81	77.55	**-2.65**	**0**	**-1.81**	**0**

7- ANALYSIS OF MODIFIED MODEL COMPARED TO GHODS' AND TANG'S MODELS

After using a modified Ghods' overtaking gap-acceptance model for accept / reject overtaking, the overtaking time and overtaking distance have been calculated for all acceptable overtakes. The overtaking duration and its corresponding distance are calculated by proposed modified overtaking model and other selected two models (i.e. Ghods' model and Tang's model and then their results have been compared.

Nile Journal of

Architecture & Civil Engineering

Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

To modify Ghods' overtaking model to be representative for real-world observed overtakes, the same criteria of Ghods' model will be applied except the values of overtaking durations and overtaking distances which are modified by multiplying by constant value equals 0.8 according to the following Equations *(16)* and *(17)* :

$$OT\ (\text{mod}\,ified\,) = OT\ (Ghods\,) * 0.8 \quad (16)$$

$$OD\,(\text{mod}\,ified\,) = OD\,(Ghods\,) * 0.8 \quad (17)$$

Where,
OT is overtaking time (seconds), OD is overtaking distance (meters),

Table 8 provides a summary of the average, standard deviation, minimum, and maximum estimates of the overtaking attributes for the video-recorded segments by the three studied models compared to observed results.

Figure 7 illustrates the relationship between overtaking distances and overtaking durations for all observed overtakes on the three sites using Ghods', Tang's and a modified models. For sites S1, S2 and S3 there were 82 overtakes had been observed for eight hours videotaped. It was obvious that Exponential function was representative for the relationship between overtaking distance and overtaking duration using Ghods' and modified models for all sites. However, 2nd polynomial function was representative for the relationship between overtaking distance and overtaking duration for Tang's model for the three sites.

Table 8: Summary of overtaking attributes using the three models of the three studied sites for the both directions

Actual results	***Ghods'***	***modified model***	***Tangs'***
4.43	4.72	3.77	**12.29**
6.98	9.49	7.59	**19.13**
3.88	2.36	1.88	**7.52**
±0.79	±1.71	±1.19	**±3.29**
4.45	4.77	3.81	**12.12**
6.94	9.40	7.52	**19.04**
3.81	2.39	1.91	**7.34**
±0.77	±1.66	±1.12	**±3.23**
55.47	60.34	48.27	**119.82**
100.4	129.02	103.21	**213.39**
34.46	27.39	21.91	**30.62**
±14.60	±21.11	±16.01	**±48.18**
55.77	60.98	48.78	**116.60**
99.14	129.32	103.45	**215.32**
34.12	27.27	21.81	**30.68**
±14.30	±21.12	±16.42	**±46.98**

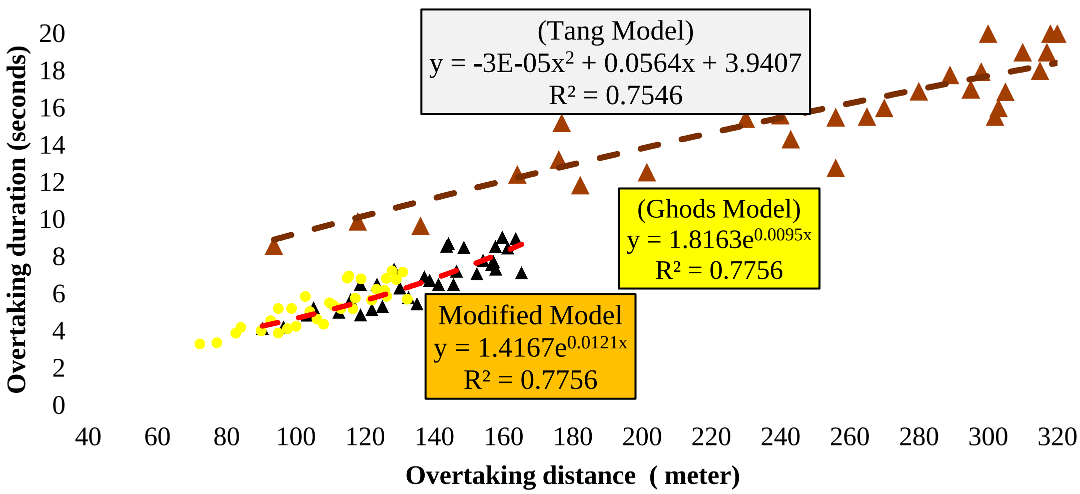
Nile Journal of
Architecture & Civil Engineering
Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

Actual results	Ghods' model	modified model	Tangs' model	Site S2	Actual results	Ghods' model	modified model	Tangs' model	Site S3
4.88	6.68	5.34	15.36	EB	3.95	4.43	3.55	10.60	NB
6.22	8.71	6.96	20.00		5.39	6.84	5.47	15.30	
3.98	4.54	3.63	8.59		3.02	2.70	2.16	5.92	
±0.61	±1.38	±1.07	±3.44		±0.76	±1.41	±0.87	±3.17	
5.12	6.75	5.40	16.08	WB	4.02	4.40	3.52	10.15	SB
7.23	9.05	7.24	20.00		4.78	5.54	4.43	15.43	
3.89	4.59	3.67	9.66		3.50	3.89	3.11	5.72	
±0.97	±1.32	±1.13	±2.44		±0.49	±0.64	±0.83	±3.02	
101.21	140.81	112.64	225.41	EB	64.84	80.32	64.25	125.39	NB
112.11	155.67	124.53	320.11		79.32	103.70	82.96	179.30	
73.12	90.32	72.25	93.68		49.02	57.24	45.79	60.90	
±12.85	±20.87	±16.81	±68.78		±11.36	±12.77	±8.43	±30.48	
102.27	133.33	106.66	275.31	WB	69.33	79.02	63.21	114.47	SB
117.29	165.54	132.43	318.00		86.32	92.17	73.73	179.30	
78.13	92.11	73.68	136		57.12	65.61	52.49	60.20	
±16.24	±19.38	±16.11	±63.17		±8.21	±8.04	±8.13	±30.01	

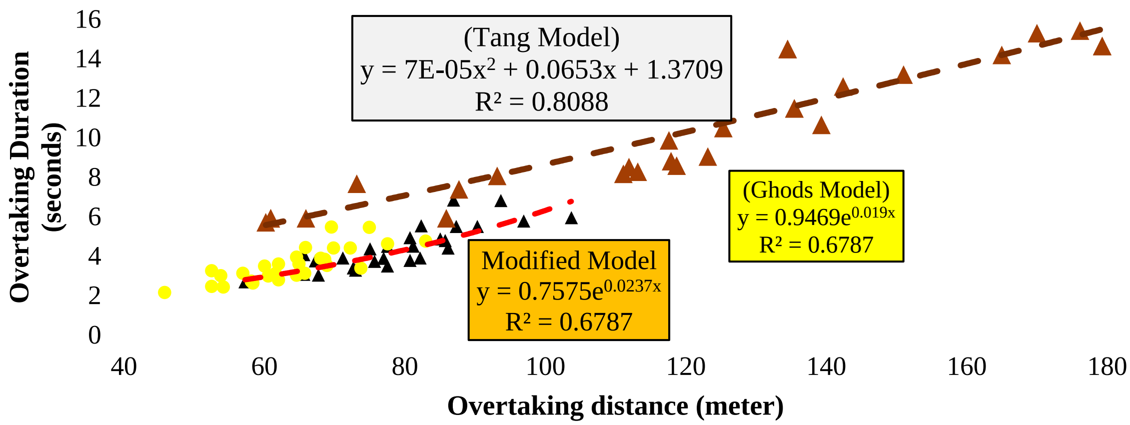
Nile Journals
Nile Journal of
Architecture & Civil Engineering
Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

Site S1	Overtaking time (sec.)								Overtaking distance (meter)							
	NB				SB				NB				SB			
	Mean	Max.	Min.	STDV.	Mean	Max.	Min.	STDV.	Mean	Max.	Min.	STDV.	Mean	Max.	Min.	STDV.

(a)



(b)



Nile Journal of

Architecture & Civil Engineering

Journal Webpage: https://njace.journals.ekb.eg/publisher
Volume 5, January 2025

(c)

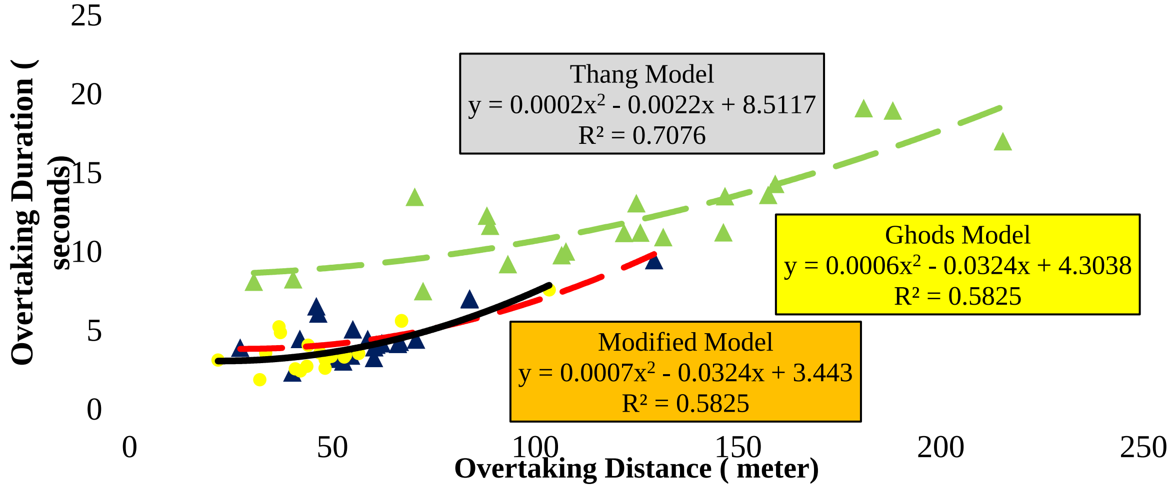


Figure 7: The relationship between overtaking distance and overtaking duration for both sites using the three models (a) Site S1, (b) Site S2 and (c) Site S3

8- HYPOTHESIS T- TEST BETWEEN FIELD OBSERVATIONS AND OUTPUTS OF THE COMPARATIVE MODELS

Hypothesis t- test is recommended to compare the average value of two populations at desired confidence level (α level) for small samples (n < 30). The calculated t- statistic value is based on degree of freedom (DF), sample size, mean and variance of the two tested populations. The t- statistic is compared to the critical t- value that is obtained from t- table (Lyles et al. 2012). Overtaking durations and distances obtained from field and outputs of the three comparative models are examined using t-test at desired significance level (α=5%). **Table 9** shows the results of t- test for examined measures of Ghods' and modified overtaking models compared to actual measures for the three sites.

Table 9: Results of Hypothesis T-test for the three comparative models on the three studied sites for both directions compared to actual observed results

Site S1								
	NB				**SB**			
Models	**Ghods' model**		**Modified Model**		**Ghods' model**		**Modified Model**	
	Overtaking duration	Overtaking distance	Overtaking duration	Overtaking distance	Overtaking duration	Overtaking distance	Overtaking duration	Overtaking distance
t-statistic	4.70	6.89	1.44	2.09	3.62	6.55	0.75	0.76
t- critical	2.13	2.13	2.13	2.13	2.12	2.12	2.12	2.12
decision	Reject H_0	Reject H_0	**Accept H_0**	**Accept H_0**	Reject H_0	Reject H_0	**Accept H_0**	**Accept H_0**
Site S2								
	EB				**WB**			

Models	Ghods' model		Modified Model		Ghods' model		Modified Model	
t-statistic	1.16	3.38	1.34	0.16	1.57	3.15	2.07	1.98
t- critical	2.12	2.12	2.12	2.12	2.14	2.14	2.14	2.14
decision	**Accept H_0**	Reject H_0	**Accept H_0**	**Accept H_0**	**Accept H_0**	Reject H_0	**Accept H_0**	**Accept H_0**
Site S3								
	NB				**SB**			
Models	**Ghods' model**		**Modified Model**		**Ghods' model**		**Modified Model**	
t-statistic	0.61	0.84	2.06	1.48	0.68	0.91	2.10	1.49
t- critical	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12
decision	**Accept H_0**	**Accept H_0**	**Accept H_0**	**Accept H_0**	**Accept H_0**	**Accept H_0**	**Accept H_0**	**Accept H_0**

As Ghods' model is rejected by T-test when it is compared to actual observed overtaking measures, Tang's model will be also rejected due to the higher differences between their outputs and actual measures than Ghods' model.

9- CONCLUSION

This paper aims to study, calibrate and validate a modified Ghods' overtaking gap- acceptance model of vehicles on Egyptian TLTW roads under mixed traffic conditions. Moreover, a comparative study has been applied and analyzed between Ghods', modified and Tang's models compared to real-world observed overtakes for estimating overtaking durations and their corresponding distances under Egyptian conditions. For this purpose, three rural TLTW roads "Class II" that located in Dakahila Governorate are studied. Eight-hour videotaped data were collected for both directions. About 201 overtaking trials are extracted from video camera on the three sites for total eight hours, only 82 of them overtook successfully but the others 119 of them failed to overtake. The 82 successful observed overtakes are used for calibration, the others 119 failed (i.e. aborted) overtakes are used for validation based on the modified gap-acceptance criteria. The overtaking attributes in case of completed and aborted overtakes have been analyzed. The main conclusions arising out of the study are as follow:

1- The modified overtaking gap-acceptance criteria is accepted for all successful observed overtakes (100%) for the three studied sites rather than the condition related to TTC mentioned on Ghods' overtaking gap-acceptance model while it matches with accepted overtakes by 79.12% Then, the modified overtaking gap-acceptance condition is more representative than Ghods' model for TLTW Egyptian conditions.
2- The two-overtaking gap-acceptance models were calibrated on 82 observed successful overtakes; average critical TTC was calculated to be (2.54±0.83) seconds, (1.04±0.35) seconds and (1.00±0.39) seconds for sites S1, S2 and S3 respectively.
3- Critical TTC, speed and distance errors were closer to be normally distributed for most of sites.
4- Based on Ghods' model, mean overtaking durations were calculated to be (6.88±1.40) sec. and (6.91±1.45) sec. for NB and SB directions of site S1 respectively while they were (4.75±1.58) sec.

and (3.79±1.04) sec. for EB and WB directions of site S2 and (4.72±1.71) sec. and (4.77±1.66) sec. for NB and SB directions of site S3 respectively. Also, mean overtaking durations were calculated to be (15.36±3.44) sec. and (16.08±2.44) sec. for NB and SB directions of site S1 respectively while they were (10.60±3.17) sec. and (10.15±3.02) sec. for EB and WB directions of site S2 and (12.29±3.29) sec. and (12.12±3.23) sec. for NB and SB directions of site S3 respectively according to Tang's model. Furthermore, they were calculated to be (5.34±1.07) sec. and (5.40±1.13) sec. for NB and SB directions of site S1 respectively while they were (3.55±0.87) sec. and (3.52±0.83) sec. for EB and WB directions of site S2 and (3.77±1.19) sec. and (3.81±1.12) sec. for NB and SB directions of site S3 respectively according to a modified overtaking model.

5- Based on Ghods' model, mean overtaking distances were observed to be (142.81±21.61) m and (133.33±20.53) m for NB and SB directions of site S1 respectively while they were (85.82±11.59) m and (72.82±11.39) m for EB and WB directions of site S2 and (60.98±21.11) m and (60.81±21.12) m for NB and SB directions of site S3 respectively. Also, mean overtaking distances were calculated to be (225.41±68.78) m and (275.31±63.17) m for NB and SB directions of site S1 respectively while they were (125.47±30.48) m and (114.11±30.02) m for EB and WB directions of site S2 and (119.82±48.18) m and (116.60±46.98) m for NB and SB directions of site S3 respectively according to Tang's model. Moreover, they were calculated to be (112.64±16.81) m and (106.66±16.11) m for NB and SB directions of site S1 respectively while they were (64.25±8.43) m and (63.21±8.13) m for EB and WB directions of site S2 and (48.27±16.01) m and (48.87±16.42) m for NB and SB directions of site S3 respectively based on a modified model.

6- Exponential function was representative for the relationship between overtaking distances and overtaking durations based on Ghods' and modified models while 2nd polynomial function was representative for the relationship between them based on Tang's model. Also, the overtaking outputs of a modified overtaking model had been examined and accepted compared to reliable outputs using hypothesis t- test so, a modified overtaking model is considered to be more representative than Ghods' and Tang's models for TLTW Egyptian roads.

7- Mean overtaking desired speeds were observed to be (76.45±6.72) km/hr. and (72.02±5.88) km/hr. for completed overtakes while they were (63.45± 7.23) km/hr. and (61.32± 7.11) km/hr. for aborted overtakes.

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