WIDTH-BASED CELL TRANSMISSION MODEL (WCTM) FOR HETEROGENEOUS AND UNDISCIPLINED TRAFFIC STREAMS

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Background

- Traffic streams in many developing countries consist of various modes of transport, with high heterogeneity in vehicles and driver behavior
- Modeling these types of traffic streams, where traffic rules (speed-limit, lane discipline, etc.) are not strictly followed is a complex task
- There is a lack of traffic flow models that model the behavior of heterogeneous and undisciplined traffic streams
- Higher number of motorbikes and lack of traffic rules enforcement result in weak/no lane-discipline

Undisciplined & Heterogeneous Traffic

Bangkok, Thailand

https://www.thaivisa.com/forum/topic/638644-bangkok-gears-up-for-school-traffic-chaos/

London, United Kingdom

https://www.telegraph.co.uk/news/2016/08/26/bank-holiday-getaway-begins-with-worst-tailbacks-in-a-decade-pre/

Undisciplined & Heterogeneous Traffic

Delhi, India

https://www.livemint.com/Money/VX3SyEKsUZ8kYIldFVQXYL/What-is-the-daily-traffic-jam-costing-you.html

Houston, United States

https://patch.com/texas/houston/houston-we-have-freeway-congestion-problem

Undisciplined & Heterogeneous Traffic

Dhaka, Bangladesh

https://www.dhakatribune.com/bangladesh/dhaka/2018/07/05/dhaka-loses-3-2m-working-hours-to-traffic-congestion-daily

Dublin, Ireland

https://www.independent.ie/business/irish/revealed-dublin-ranked-worse-than-london-or-paris-for-road-congestion-34563994.html

Undisciplined & Heterogeneous Traffic

Karachi, Pakistan

Undisciplined & Heterogeneous Traffic

- Existing literature models and simulates traffic in lanes defined on a road, which is good for traffic streams with lane discipline
- In contrast to traffic streams with lane-discipline, the heterogeneous and undisciplined traffic streams :
  - Number of traffic lanes observed vary with traffic volume
  - Number of actual traffic lanes are much higher than the marked number of lanes at higher traffic volume
  - Drivers tend to utilize every inch of available space on the road (motorbikes only need around 3 ft space to maneuver)

WIDTH-BASED CELL TRANSMISSION MODEL (WCTM)

- This research models all the parameters of CTM and flow-density FD as continuous variables along the width of the road in contrast to existing literature which models these variables as discrete variables (number of lanes or entire width as an integral multiple of lane numbers).
- This research also models the width as a function of time (to model reduction in width due to incident, parking, encroachments) and space (to model cell-to-cell variation in width along a road segment).

WHY WCTM?

i) Due to encroachments and illegal parking, the number of physical lanes is uncertain.

ii) The road widths are not uniform and abrupt change is observed on various arterials. (If the width of a road segment from one cell to another change abruptly, which cannot be termed as a change of one complete lane, it will still contribute to increasing capacity, critical density and holding capacity. For example an increase of width from one cell to another of 3-4 ft can easily accommodate a lane of motorbikes.)

iii) Even when the road widths are uniform and there is a certain number of physical lanes, the number of actual traffic lanes vary with traffic conditions.

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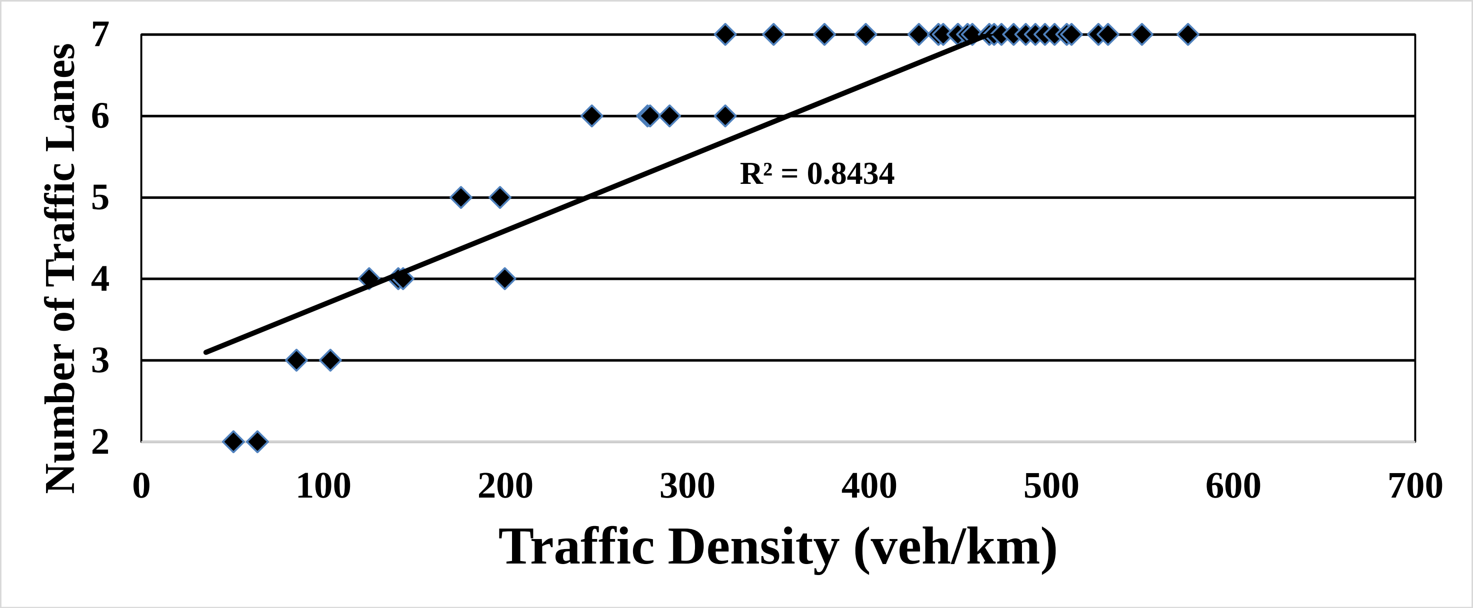


Variation in traffic lanes with traffic density on University Road, Karachi (Originally 3-lanes road after parking)

WHY WCTM?

iv) Zheng et al. (2015) and references cited by the authors concluded that no consistent relationship exists between lane width and capacity of multilane urban arterials. However, for traffic streams with no lane-discipline and about half of the traffic consisting of motorbikes, the increase in width is expected to significantly affect the flow variables.

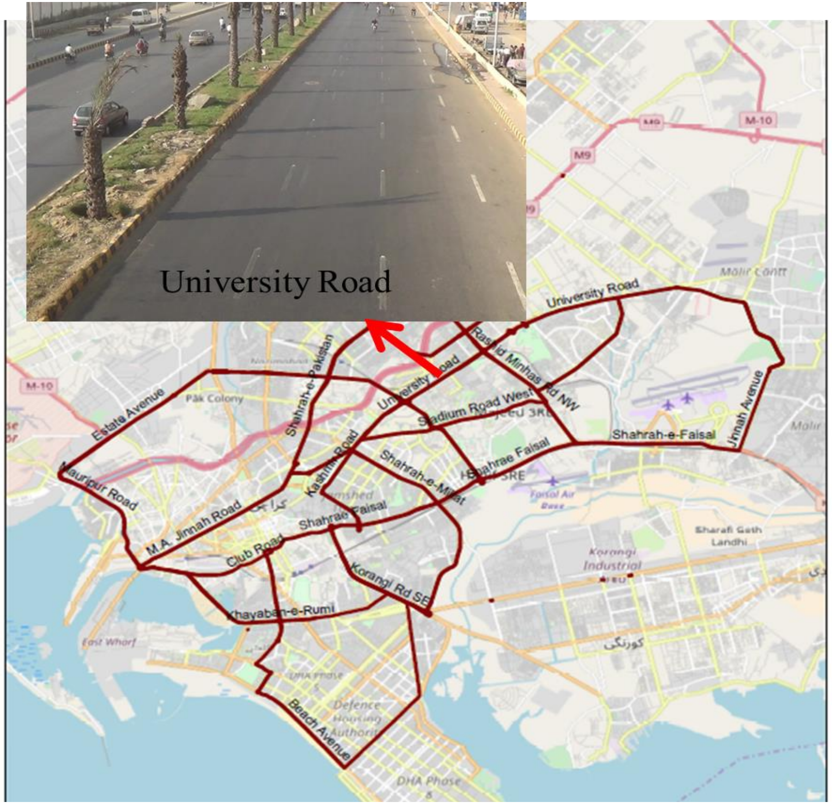
Zheng, J., J. Sun, and J. Yang. Relationship of lane width to capacity for urban expressways. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2483, 2015, pp. 10-19.

WHY WCTM?

The main contribution of this research is to model traffic flow, density, capacity-flow, critical density, and jam-density as continuous variables (in lateral direction), while the existing modeling approaches model these variables as discrete variable in lateral direction

Data Collection

- Width-based Fundamental Diagram was developed for a selected arterial (University Road) in Karachi, Pakistan.
- It is a 4-lanes (one lane occupied by illegally parked vehicles) urban arterial which is part of a signal-free corridor
- Manual extraction of traffic flow and density data from video recorded from a pedestrian bridge during October 23-27, 2017 from morning to evening.

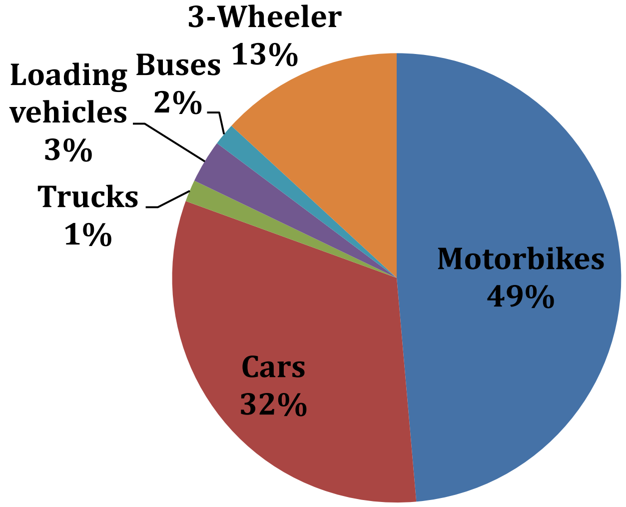


Data Collection

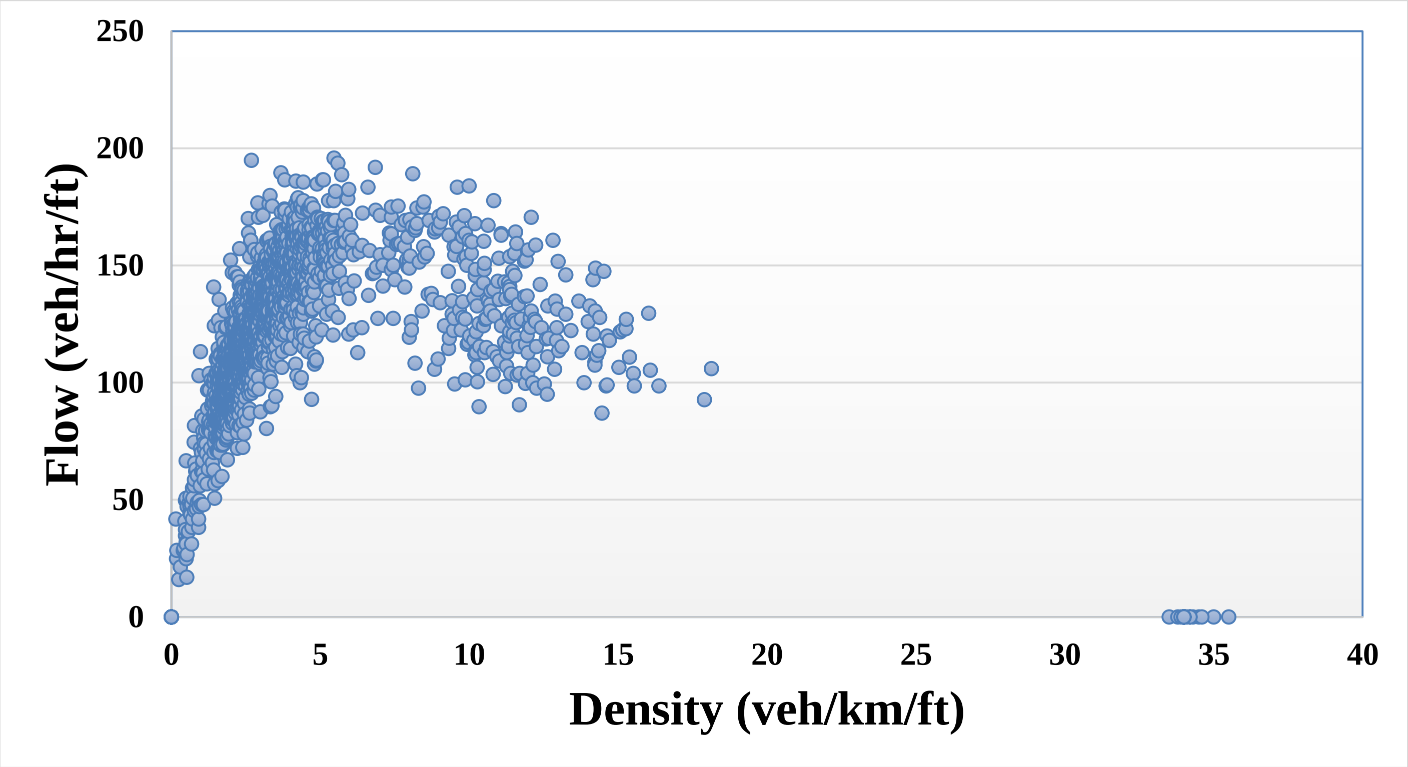
- Traffic for each minute was counted in six different modes (cars, motorbikes, bus, rickshaw, loading pickup, and trucks)
- 10 screenshots were captured at intervals of 6 seconds each with a trap length of around 200 ft, to estimate the corresponding traffic density for each minute.
- Each data point in the FD represents per minute flow (converted into the equivalent hourly flow) and corresponding average traffic density for that minute
- The classified counts of flow and density were converted into equivalent Passenger Car Units (PCUs)

Data Collection

- In total, 2100 data points were collected from analysis of recorded video,
  - 35-hrs of traffic count over a period of five days.
  - Traffic density was manually extracted by analysis of 21,000 screenshots
  - In total, 207,392 vehicles were counted



Width-based Flow-Density FD



Width-based Flow-Density FD

- Despite recording traffic on five days, including evening peak-hours, the value of jam-density or near jam-density could not be obtained from University Road.
- The regression analysis based on the collected data was leading to an unexpectedly high jam-density.
- Therefore, the values of jam-density were obtained from a signalized intersection.
- Approximately, 30 data points were collected at the signalized intersection when the trap length was filled with vehicles and vehicles were stopped.
- This would be comparable to the density (jam-density) of vehicles on a mid-block segment when there will be no flow of traffic.

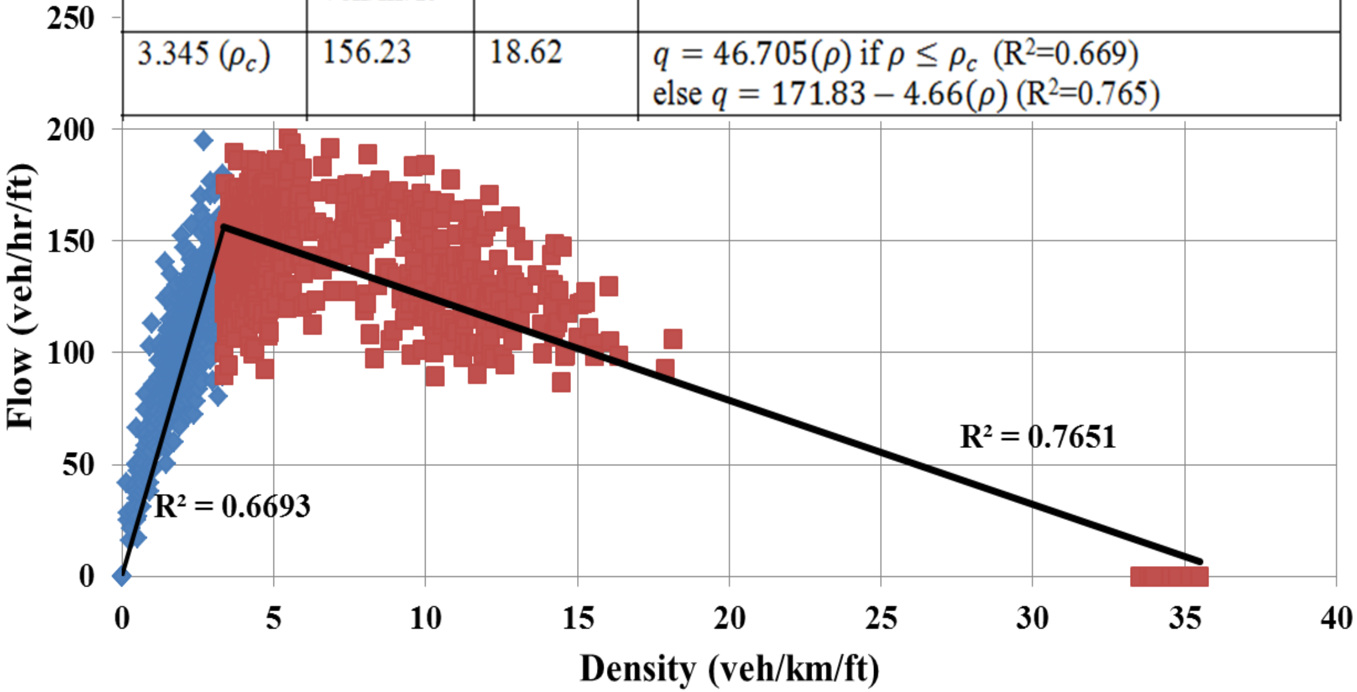
Width-based Flow-Density FD

- *'Segmented'* package in *R* developed by Muggeo (2008, 2017) for optimal breakpoint estimation is employed
- *'Segmented'* is useful in estimation of breakpoints and linear regression analysis.
- It estimates optimal breakpoints for developing piecewise-linear relation that yields a minimum mean-square error.
- Different number of breakpoints from 1-5 were tested to determine the piecewise linear flow-density relation that fits best with the collected data

Muggeo, V. M. Segmented: an R package to fit regression models with broken-line relationships. *R news,* Vol. 8, No. 1, 2008, pp. 20-25.
Muggeo, V. M., and M. V. M. Muggeo. Package 'segmented'. *Biometrika,* Vol. 58, 2017, pp. 525-534

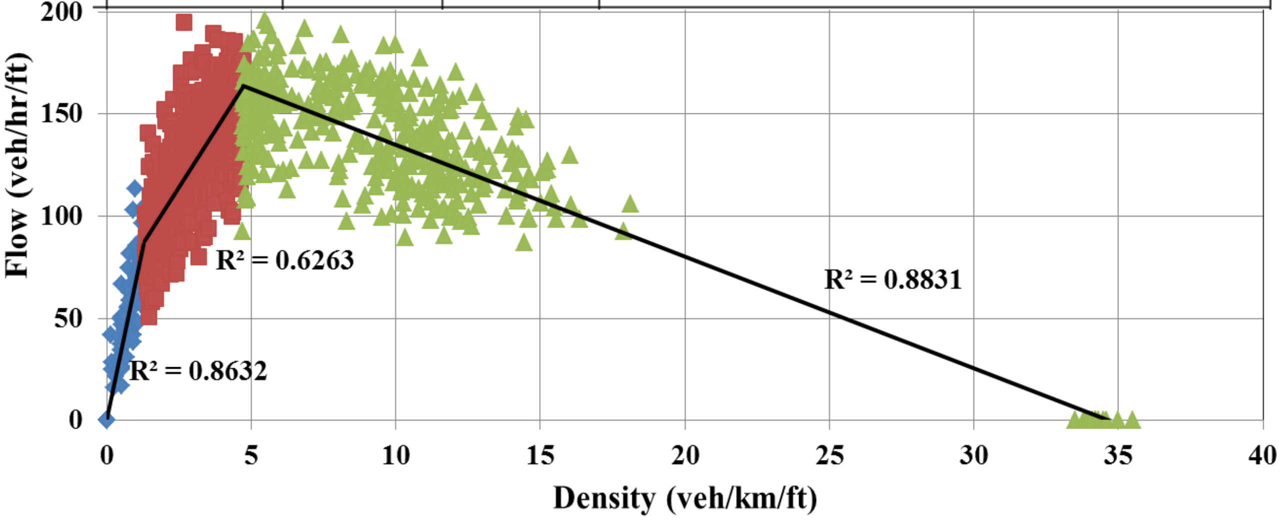
Width-based Triangular FD

Breakpoint (s)		Residual Standard Error	Mathematical Flow-Density Model
Density veh/km/ft	Flow (q) veh/hr/ft		
3.345 (ρ_c)	156.23	18.62	$q = 46.705(\rho)$ if $\rho \leq \rho_c$ (R^2=0.669) else $q = 171.83 - 4.66(\rho)$ (R^2=0.765)



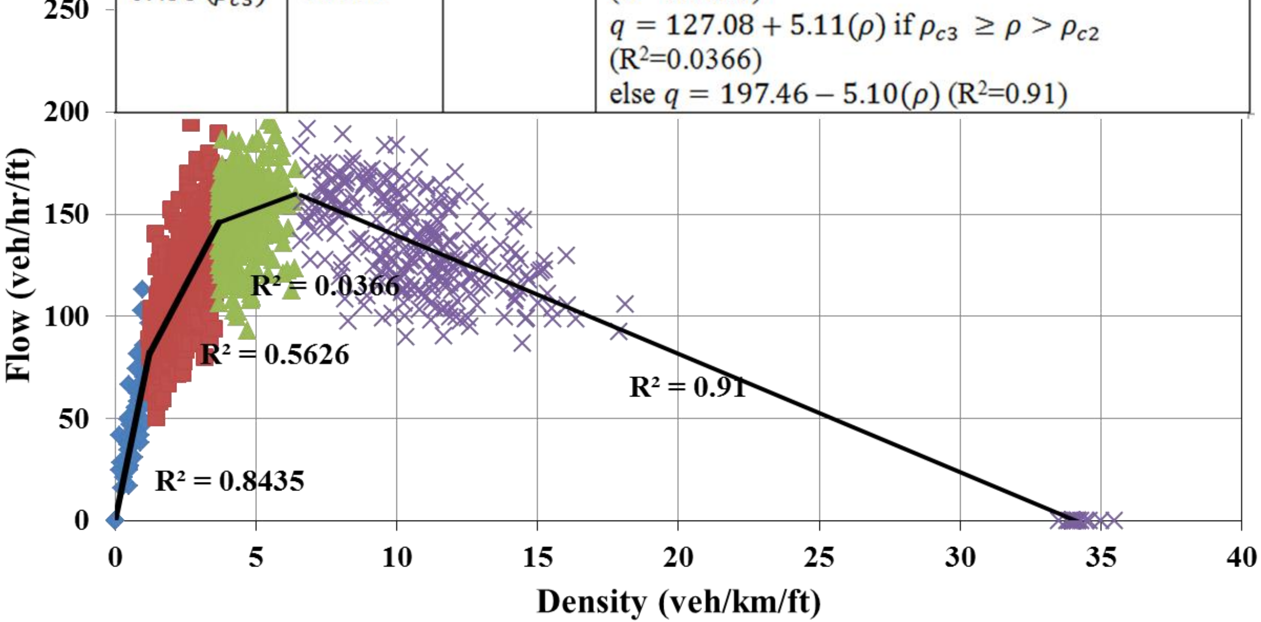
Width-based Quadrilateral FD

Breakpoint (s)		Residual Standard Error	Mathematical Flow-Density Model
Density (ρ) veh/km/ft	Flow (q) veh/hr/ft		
1.307 (ρ_{c1}) 4.708 (ρ_{c2})	87.82 163.75	15.44	$q = 67.192(\rho)$ if $\rho \leq \rho_{c1}$ (R^2=0.863) $q = 58.629 + 22.33(\rho)$ if $\rho_{c2} \geq \rho > \rho_{c1}$ (R^2=0.6263) else $q = 189.42 - 5.4548(\rho)$ (R^2=0.8831)



Width-based Pentagonal FD

Breakpoint (s)		Residual Standard Error	Mathematical Flow-Density Model
Density (ρ) veh/km/ft	Flow (q) veh/hr/ft		
1.219 (ρ_{c1}) 3.696 (ρ_{c2}) 6.458 (ρ_{c3})	82.05 145.94 160.08	15.01	$q = 67.312(\rho)$ if $\rho \leq \rho_{c1}$ (R^2=0.8435) $q = 50.627 + 25.79(\rho)$ if $\rho_{c2} \geq \rho > \rho_{c1}$ (R^2=0.5626) $q = 127.08 + 5.11(\rho)$ if $\rho_{c3} \geq \rho > \rho_{c2}$ (R^2=0.0366) else $q = 197.46 - 5.10(\rho)$ (R^2=0.91)



Comparison of Width-based FDs

Number of Break Points	Breakpoint (s)		Residual Standard Error	Mathematical Flow-Density Model
	Density veh/km/ft	Flow (q) veh/hr/ft		
1 (Triangular FD)	3.345 (ρ_c)	156.23	18.62	$q = 46.705(\rho)$ if $\rho \leq \rho_c$ (R^2=0.669) else $q = 171.83 - 4.66(\rho)$ (R^2=0.765)
2 (Quadrilateral FD)	1.307 (ρ_{c1}) 4.708 (ρ_{c2})	87.82 163.75	15.44	$q = 67.192(\rho)$ if $\rho \leq \rho_{c1}$ (R^2=0.863) $q = 58.629 + 22.33(\rho)$ if $\rho_{c2} \geq \rho > \rho_{c1}$ (R^2=0.6263) else $q = 189.42 - 5.4548(\rho)$ (R^2=0.8831)
3 (Pentagonal FD)	1.219 (ρ_{c1}) 3.696 (ρ_{c2}) 6.458 (ρ_{c3})	82.05 145.94 160.08	15.01	$q = 67.312(\rho)$ if $\rho \leq \rho_{c1}$ (R^2=0.8435) $q = 50.627 + 25.79(\rho)$ if $\rho_{c2} \geq \rho > \rho_{c1}$ (R^2=0.5626) $q = 127.08 + 5.11(\rho)$ if $\rho_{c3} \geq \rho > \rho_{c2}$ (R^2=0.0366) else $q = 197.46 - 5.10(\rho)$ (R^2=0.91)

There was no significant improvement in Residual Standard Error when number of Break Points are increased beyond 3.

Comparison of FD Parameter Values with Some Other Studies

Author(s)	Location	Critical Density	Capacity Flow	Jam Density	Shockwave Speed	Free-flow speed
Kockelman (43)	Interstate Highway 880, US	28 vpkpl	2500 vphpl	120	20 kph	95 kph
Pedersen (44)	Highway, Atlanta, GA, US	30 vpkpl	2400 vphpl	140	21 kph	80 kph
Sumalee et al. (17)	I210-W, US	20.6 vpkpl	2125 vphpl	108	15.3 kph	102 kph
Muralidharan et al. (38)	I210-W, US	30 vpkpl	2007 vphpl	140	16.64 kph	100.5 kph
This Research (Three Breakpoints)	University Road, Karachi, Pakistan	6.48 vpkpft (71.28 vpkpl)	160 vphpft (1760) vphpl	38.7 vpkpft (425.7 vpkpl)	5.1 kph	67.312 kph
This Research (Two Breakpoints)	University Road, Karachi, Pakistan	4.708 vpkpft (51.8 vpkpl)	163 vphpft (1793) vpkpl	34.7 vpkpft (382 vpkpl)	5.4 kph	67.19 kph
This Research (One Breakpoint)	University Road, Karachi, Pakistan	3.345 vpkpft (36.8 vpkpl)	156.23 vphpft (1718.5 vpkpl)	36.8 vpkpft (404.8 vpkpl)	4.66 kph	46.705 kph

WCTM for Triangular FD

- Inflow to each cell '*i*' at time-step '*k*' for entire width 'W' of cell '*i*' is determined using:

$$Q_{i,k} = \min(W_{i-1,k} V \rho_{i-1,k}, W_{i-1,k} C, W_{i,k} C, \omega W_{i,k}(\rho_J - \rho_{i,k})) \quad \text{(i)}$$

- Based on estimated inflows, traffic densities for time-step '*k+1*' for entire road width are calculated as follows:

$$d_{i,k+1} = d_{i,k} + \frac{\mathrm{t}}{l}(Q_{i,k} - Q_{i+1,k}) \quad \text{(ii)}$$

- Traffic density per unit width of the cell is calculated which is used

$$\rho_{i,k+1} = \frac{d_{i,k+1}}{W_{i,k}} \quad \text{(iii)}$$

WCTM for Quadrilateral FD

- Equation (ii) and Equation (iii) will remain unchanged for all FDs. However, the inflow to cell is dependent on the shape of FD.
- For Quadrilateral FD based on collected data:

$$Q_{i,k} = \min(W_{i-1,k} V \rho_{i-1,k}, W_{i-1,k} C, W_{i,k} C, W_{i-1,k} \left(58.629 + 22.33\rho_{i-1,k}\right), \omega W_{i,k}(\rho_J - \rho_{i,k}))$$

- If V_1 is the slope of the first segment of the FD, a is y-intercept of the second segment, V_2 is the slope of the second line segment, and ω is the shockwave speed or slope of the last segment, the above equation can be generalized as:

$$Q_{i,k} = \min(W_{i-1,k} V_1 \rho_{i-1,k}, W_{i-1,k} C, W_{i,k} C, W_{i-1,k} \left(a + V_2\rho_{i-1,k}\right), \omega W_{i,k}(\rho_J - \rho_{i,k}))$$

WCTM for Pentagonal FD

- Similarly, the equation for inflow based on pentagonal FD is:

$$Q_{i,k} = \min(W_{i-1,k}V_1\rho_{i-1,k}, W_{i-1,k}C, W_{i,k}C, W_{i-1,k}\left(a + V_2\rho_{i-1,k}\right), W_{i-1,k}\left(b + V_3\rho_{i-1,k}\right), \omega W_{i,k}(\rho_J - \rho_{i,k}))$$

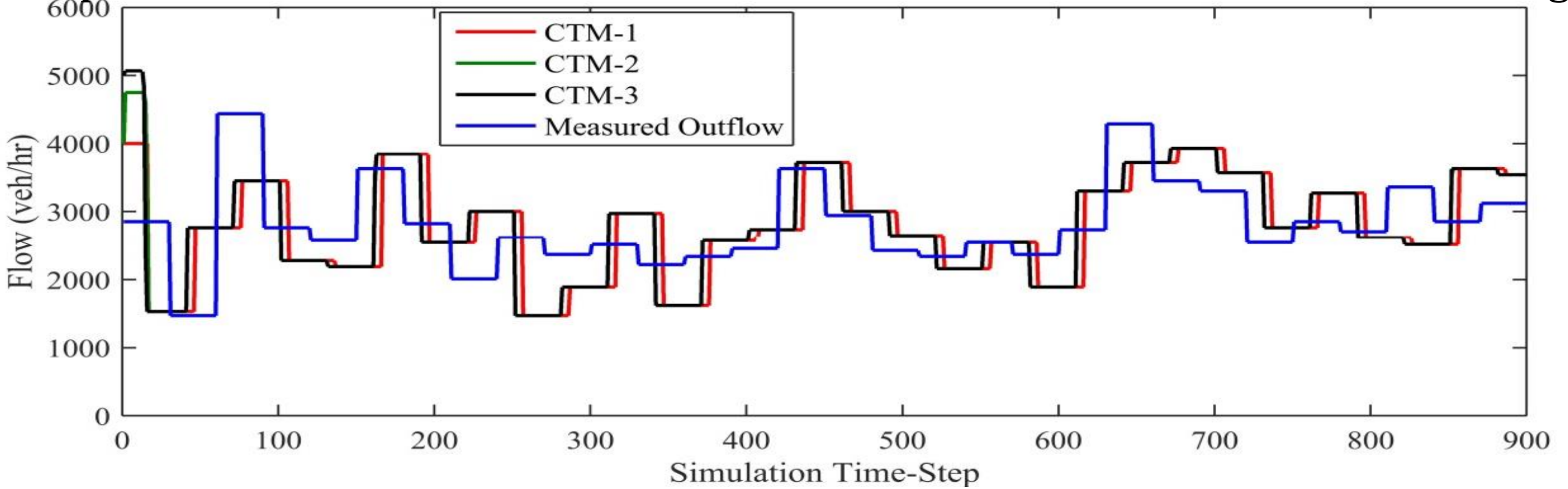
- V_1 is the slope of the first segment of the pentagonal-FD, a is y-intercept of the second segment, V_2 is the slope of the second line segment, b is y-intercept of the third segment and V_3 is the slope of the third segment.

VALIDATION OF PROPOSED WCTM

- The proposed WCTM is validated for some other segments of University Road, Karachi.
- The selected segment for validation is 220m long, located approximately 2 km downstream of the location of data collection for FD.
- Traffic parameter including inflow to the segment, outflow from the segment and travel times are measured from field.
- The segment was divided into cells by keeping a constant simulation time-step of 1 second.
- Simulated and measured parameters are compared to evaluate the performance of different versions of WCTM proposed in this research

VALIDATION OF PROPOSED WCTM

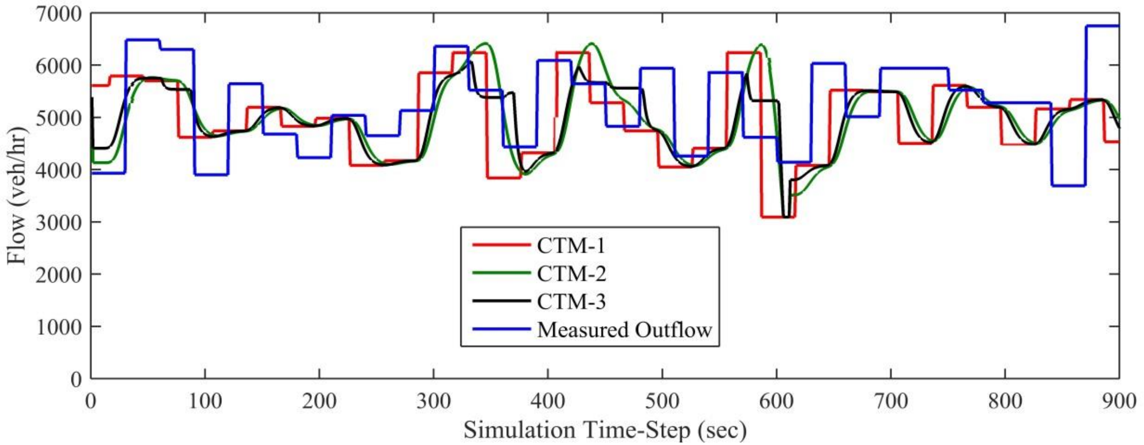
Comparison of Measured and Simulated Outflows from selected Eastbound Segment



Model	Root-Mean-Square-Error in modelled travel time
CTM-1 (Triangular FD)	4.19 sec (32%)
CTM-2 (Quadrilateral FD)	1.8 sec (13.8%)
CTM-3 (Pentagonal FD)	1.8 sec (13.8%)

VALIDATION OF PROPOSED WCTM

Comparison of Measured and Simulated Outflows from selected Westbound Segment



Model	Root-Mean-Square-Error in modelled outflow from segment
CTM-1 (Triangular FD)	1003.5 veh/hr (19.15%)
CTM-2 (Quadrilateral FD)	922 veh/hr (17.6%)
CTM-3 (Pentagonal FD)	880 veh/hr (16.8%)

Conclusions & Recommendations

- This research proposed a new concept of modelling heterogonous and undisciplined traffic streams by modelling the traffic flow parameters as the function of width and continuous in lateral direction.
- In contrast to existing triangular FD, the pentagonal FD fits better with the collected data.
- The proposed WCTM is only for midblock segments, which can be applied to any other road segments by calibrating the FD
- Further research may include modelling the behavior of such heterogeneous traffic at different types of intersections (Signalized, roundabouts, and uncontrolled intersections)