DESIGN OF MULTI-PATH TRAFFIC PROGRESSION FOR CONGESTED ARTERIALS WITH CONNECTED LOCAL PROGRESSION BANDS

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Abstract

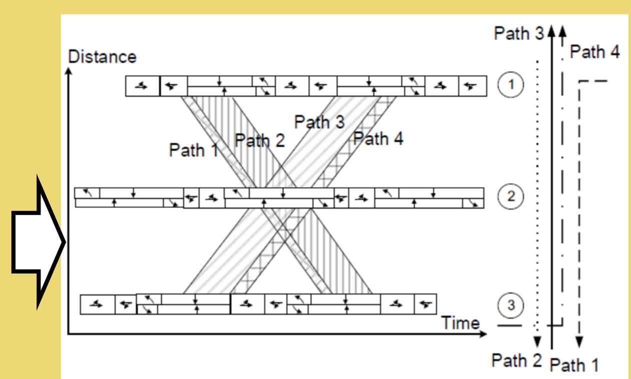
- Most congested urban arterials are likely to comprise **multiple dominant path flows** in addition to its through traffic.
- A signal plan maximizing progression often suffers from **mutual blockage** between the through vehicles and turning flows.
- This study proposes a model for design of a progression band for each candidate path along the target arterial with each intersection's **volume counts**. The proposed model will
  - ✓ generate optimal **offsets** and **phase sequences**
  - ✓ construct local **progression bands** for vehicles on **all local paths**, constituted by a pair of each link's upstream flow-in and downstream flow-out movements.
  - ✓ optimally **connect** the bands on two neighboring links
- Key information to be estimated in the proposed model includes: the impeded duration within a local path's progression band due typically to **mutual queue blockage**, and estimated vehicle **volume within each designated progression band**.
- Extensive simulation experiments confirm that the proposed model can produce progression for **all local and multi-link path flow**s, and yield the overall optimized state for the arterial with the MOEs of total weighted progression bands, number of vehicle stops, and the total traffic delay.

Critical Issues

- Urban arterials are often plagued by **mutual queue blockage between turning and through vehicles**, and excessively long delays for both through and turning movements. Key contributors to such bottlenecks include: queue spillback from tuning bay, through queue on short links, and ineffective progression for through or turning flows.
- The popular design notion of providing **two-way signal progression** cannot adequately account for all above congestion contributors
- A recent study by Yang et al. (2015) indicates the need of providing **multipath progression** for all primary path flows along the arterial. But it requires the information of the path-flow volumes, which are difficult to collect with most existing data collection devices.

Yang et al.

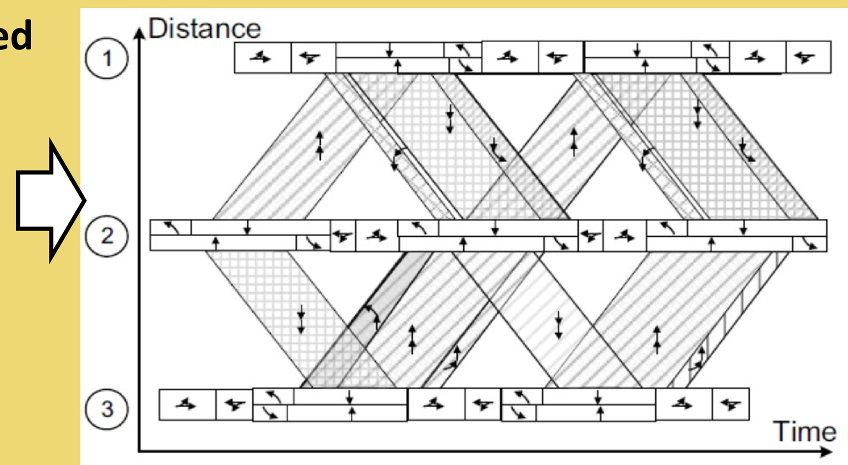
Path flow



- This study has proposed a model to construct progression bands for all candidate paths, based only on each intersection's **turning volume counts** and **geometric features**.

Proposed

Volume count

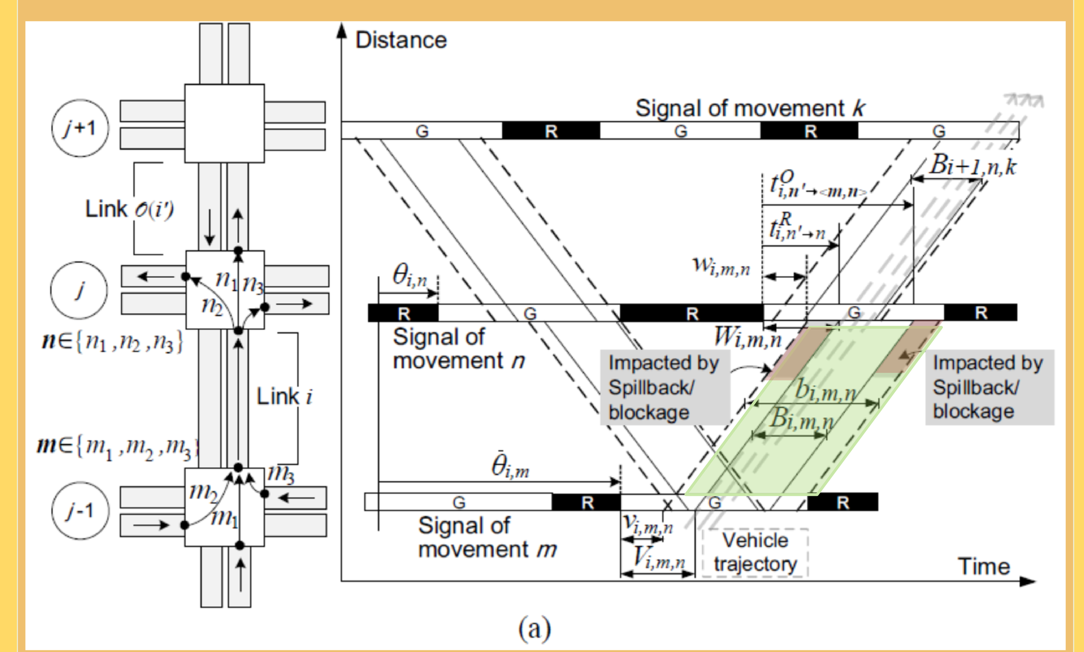


- One shall first design the progression band for traffic flows along each **local path**, constituted by the through and turning (from crossing streets) vehicles from each link's upstream intersection and moving out via either through or turning movements at the its downstream intersection. The above Figure shows an example.
- By **optimizing the connection between two neighboring links' local bands for through movement**, one can then extend the local bands for various local traffic movements to establish the progression bands for multi-path flows over multiple links of the congested arterial without knowing their O-D or path volume information.

Model Formulations

- To ensure the progression for each local path on a link between two adjacent intersections, one can formulate the following constraints for **local paths** (same notion as for MAXBAND but for paths)

Key notations for formulating local progression bands



- **Progression for each local path**

$$v_{i,m,n} + b_{i,m,n} \le \phi_{i,m} \quad \forall <m,n> \in \mathcal{L}_i \quad \forall i$$
$$w_{i,m,n} + b_{i,m,n} \le \phi_{i,n} \quad \forall <m,n> \in \mathcal{L}_i \quad \forall i$$
$$w_{i,m,n} \ge \tau_{i,n} \quad \forall <m,n> \in \mathcal{L}_i \quad \forall i$$

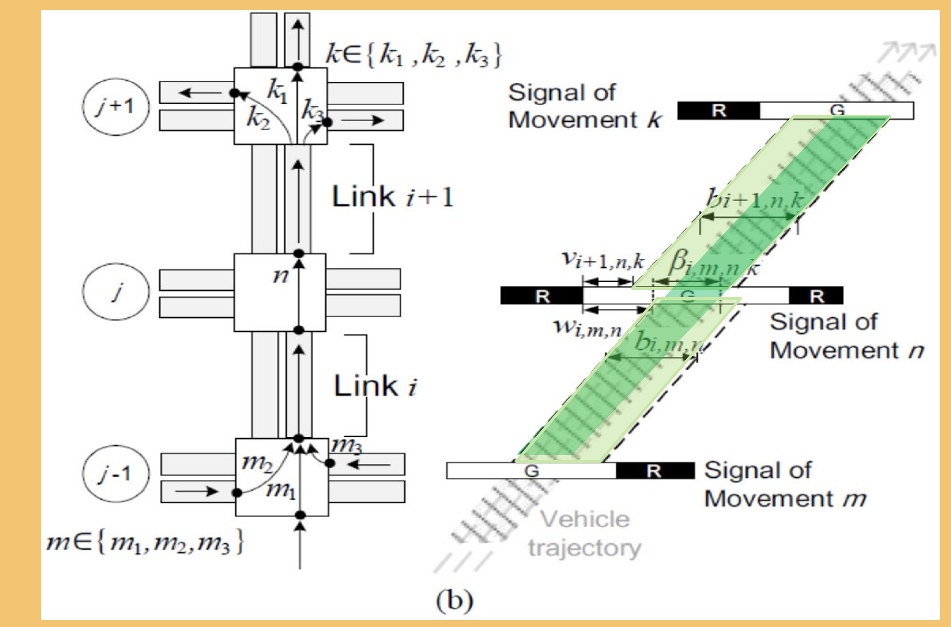
Only some path flows are selected (by $y_{i,m,n}$)for progression:

$$\bar{\theta}_{i,m}+v_{i,m,n}+T_{i,m,n} \ge \theta_{i,n}+w_{i,m,n}+K_{i,m,n} \times c\text{-}M\,(1\text{-}y_{i,m,n})$$
$$\bar{\theta}_{i,m}+v_{i,m,n}+T_{i,m,n} \le \theta_{i,n}+w_{i,m,n}+K_{i,m,n} \times c\text{-}M\,(1\text{-}y_{i,m,n})$$

- **Connected progression bands:** defined as the overlapped duration of the two adjacent local bands

$$\beta_{i,m,n,k} = \min\{w_{i,m,n}+b_{i,m,n},\ v_{i+1,n,k}+b_{i+1,n,k}\}\text{-}\max\{w_{i,m,n},\ v_{i+1,n,k}\}$$

band w/o mutual blockage



- **The effective local bands not interrupted by the queue spillbacks:** For a left-turn movement from the arterial to a crossing street, its local band is likely to be impeded by the through queues at the link's downstream intersection. The turning queue spillback can in turn interrupt the through bands.

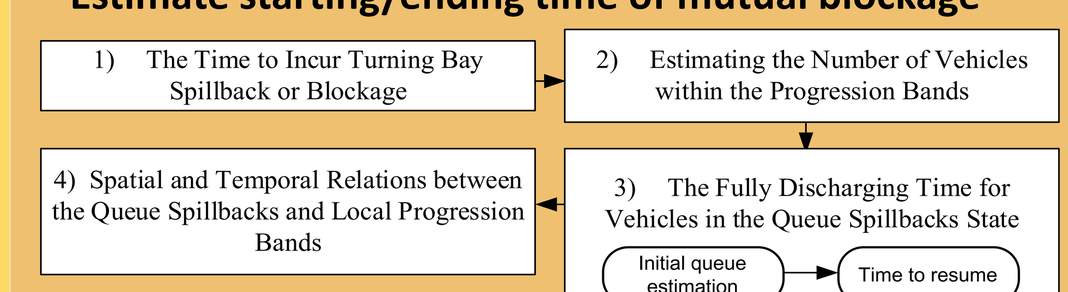
$$V_{i,m,n} \ge v_{i,m,n} \quad \forall <m,n> \in \mathcal{L}_i\ \forall i$$
$$W_{i,m,n} \ge w_{i,m,n} \quad \forall <m,n> \in \mathcal{L}_i\ \forall i$$
$$V_{i,m,n} + B_{i,m,n} \le v_{i,m,n} + b_{i,m,n} \quad \forall <m,n> \in \mathcal{L}_i \forall i$$
$$W_{i,m,n} + B_{i,m,n} \le w_{i,m,n} + b_{i,m,n} \quad \forall <m,n> \in \mathcal{L}_i\ \forall i$$

The above ensures that the effective local band is less than the local progression band.

- overlapped portion that allows vehicles to progress over consecutive links.

$$\beta'_{i,m,n,k} = \min\{W_{i,m,n}+B_{i,m,n},\ V_{i+1,n,k}+B_{i+1,n,k}\}\text{-}\max\{W_{i,m,n},\ V_{i+1,n,k}\}$$

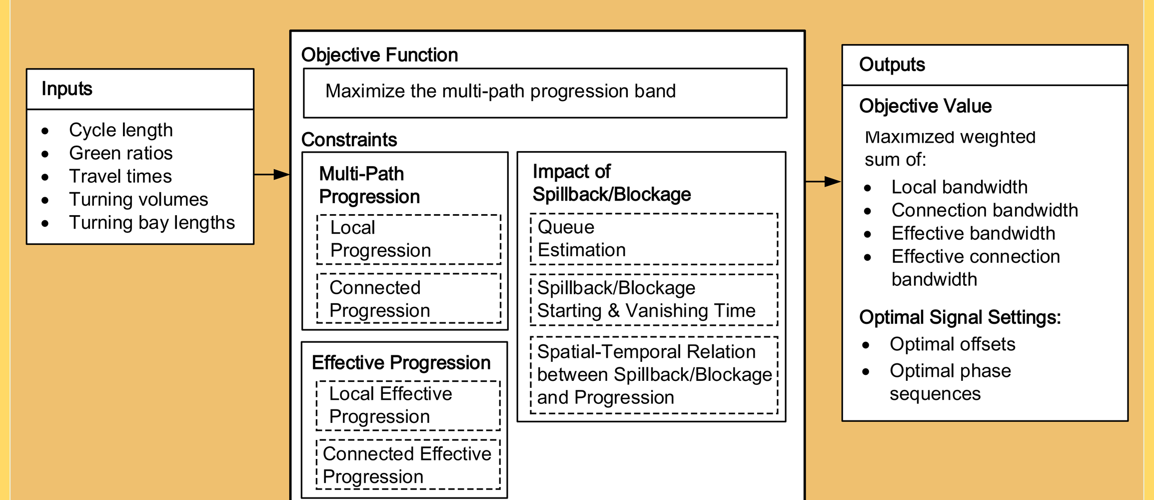
- **Estimate starting/ending time of mutual blockage**



- **Objective function**

The objective of the proposed model will maximize the sum of all bandwidths for the selected local paths weighted by their corresponding volumes.

$$Max \sum \mu_{1,i,m,n} \times B_{i,m,n}+\sum \mu_{2,i,m,n} \times \beta'_{i,m,n,k}+ \sum \mu_{3,i,m,n} \times (b_{i,m,n}\text{-}B_{i,m,n})+\sum \mu_{4,i,m,n}\,(\beta_{i,m,n,k}\text{-}\beta'_{i,m,n,k})$$

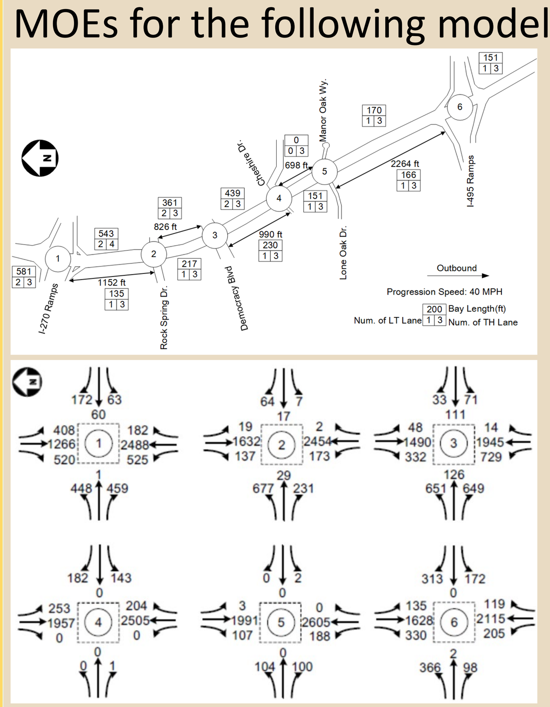


Case Study

The Case study contains two parts:

- Simulation experiments to ensure the effectiveness of the proposed model in a real-world system
- Numerical analysis to demonstrate the effectiveness of the formulated constraints

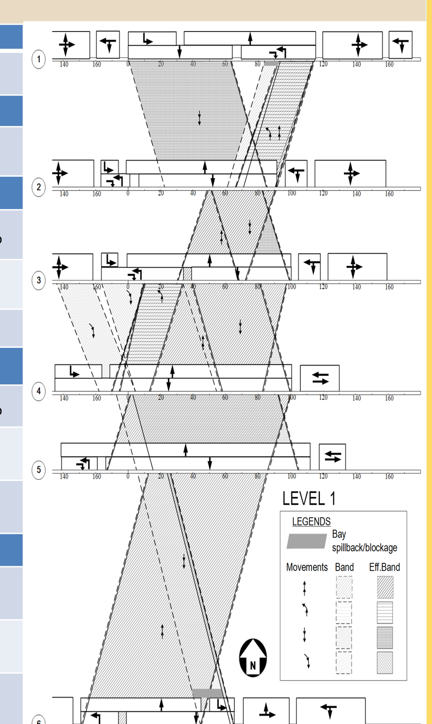
Experiment 1: Using VISSIM 9, this study has collected the MOEs for the following models for comparison:



- **MULTIBAND**: state-of-the-art model
- **Model 1**: proposed model, but excluding the constraints related to turning-in flows from the crossing streets.
- **Model 2**: proposed model with all essential constraints in the formulations.

	Average delay (s/veh)			Average # of stops (-/veh)		
	MULTI-BAND	Model 1	Model 2	MULTI-BAND	Model 1	Model 2
Network [a]						
	145.5	**139.8 (-3.9%)**[b]	**137.1 (-5.8%)**[b]	**3.13**	**2.85 (-8.9%)**[b]	**2.82 (-9.9%)**[b]
Through on the Arterial						
Overall	214.7	196.7 (-8.4%)[b]	190.5 (-11.3%)[b]	4.38	3.49 (-20.3%)[b]	3.46 (-21.0%)[b]
SB	168.6	94.0	166.4	3.31	1.71	3.55
NB	243.4	226.4	205.9	5.05	3.57	3.39
Turning-out Streams from Arterial						
Overall	198.6	181.4 (-8.7%)[b]	185.8 (-6.5%)[b]	4.00	2.94 (-26.5%)[b]	2.93 (-26.8%)[b]
SB to crossing streets	101.9	94.0	91.6	2.24	1.71	1.92
NB to crossing streets	249.8	226.3	232.8	4.93	3.57	3.44
Turning-in Streams from Crossing Streets						
From Democracy Rd. EB	157.5	156.4	148.2	4.24	4.61	4.47
Left turn from I-495 ramp EB	258.2	264.8	229.5	4.55	4.98	4.28
Right turn from I-495 ramp WB	147.1	124.3	118.0	3.85	3.64	3.24

Notes: [a]Network-wide MOEs shows lower delays and number of stops than other three listed categories since it is averaged over MOEs of all streams including those leaving the network immediately via unsignalized right-turn ramps.
[b]Values in parenthesis show percentage change comparing the MOE generated by MULTIBAND.



Experiment 2 : ***Evaluating the design with turn-in volumes and variable phase sequence***. Four levels of volume scenarios (turning volume from high to low) are designed to show benefit from **variable phase sequences** and accounting for turning-in volumes from side streets

- **Turning volumes may affect the through bandwidths**
- **Necessity of incorporating the impacts from the potential spillbacks in signal design:** reducing the potential interference from the queues with the following logic:

•**Circumventing the left-turn queue spillback:** Left figure shows that the leading northbound left-turn phase at intersection 3 allows the left-turn queue to be fully discharged over the first 11 seconds of the cycle

•**Minimizing the impacts of queue spillback (if not inevitable):** limited to merely 10 seconds (from 83 to 93 sec of cycle) for intersection 1

•**Reducing the impacts of long through queues on the left-turn movements:** Path flows taking the northbound left-turn at intersection 3 have received their progression bands at 11 sec of the cycle while the through queue already vanishes, so blockage to left-turners is averted.

- **Generating a Wider Band with Variable Phase Sequences**

	Average Through Bandwidth [sec]		Average Connection Bandwidth [sec]	
	Fixed Seq.[a]	Var Seq.[a]	Fixed Seq.[a]	Var Seq.[a]
Level 1 (Field)	114.1 (106.3)[b]	120.7 (112.8)[b]	97.4 (87.9)[c]	109.5 (99.8)[c]
Level 2	132.4 (120.6)[b]	137.8 (123.3)[b]	123.4 (111.3)[c]	131.6 (116.4)[c]
Level 3	144.5 (127.4)[b]	150.8 (126.2)[b]	136.7 (121.5)[c]	140.4 (120.6)[c]
Level 4	151.2 (133.2)[b]	157.9 (126.2)[b]	145.4 (123.3)[c]	150.4 (119.9)[c]

Notes: [a]Var. = Variable; Seq.= Phase Sequence
[b]Values shown in parenthesis are the average effective through bandwidth not impacted by spillback.[c]Values shown in parenthesis are the average effective connection bandwidth not impacted by spillback.

Conclusions

- This study has proposed an MILP model which can provide progression band for various paths along the target arterial.
- The proposed model constructed **local progression bands** for vehicles on all local paths and then design the **optimal connection** between two local through bands for neighboring links under the control objective of maximizing the total weighted progression bands for the entire arterial.
- Improved MOE in the simulation experiments comparing to MULTIBAND are due to the proposed model's embedded functions to minimize the impacts from left-turn spillback on the through-path flows, as evidenced by the reduction in delay and number of stops by 11.3% and 21.0%, respectively.