City-scale Pollution Aware Traffic Routing by Sampling Multiple Max Flows using MCMC

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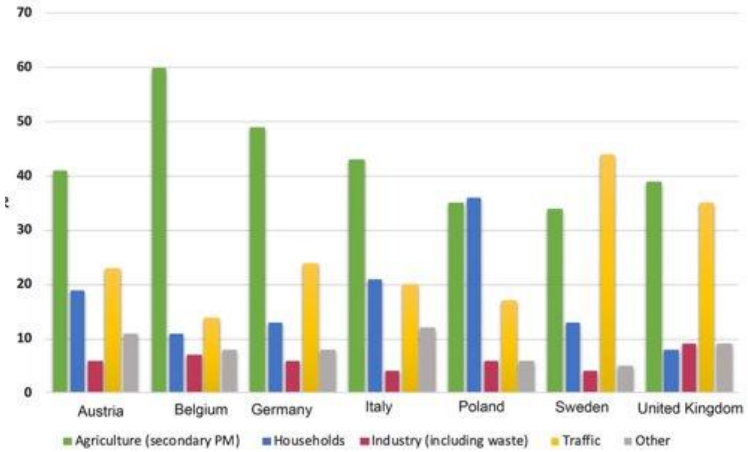
Traffic Pollution

- Long term exposure to high amounts of air pollution can be fatal.
- High volume of road traffic is a major cause of air pollution.
- Vehicles using the same roads frequently will lead to concentration of pollution along those roads.

Air Pollution Kills Far More People Than Covid Ever Will

More than 10 million people die every year from a problem that doesn't receive the attention it should.

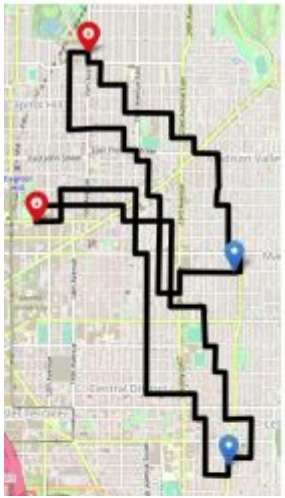
Bloomberg, 2021



Data source: Kiesewetter and Amann (2014)
https://link.springer.com/article/10.1007/s13280-020-01450-5#ref-CR34

Traffic Routing Policy as an Integer MaxFlow

- Consider road network as a graph. Edge capacities/weights being the number of lanes. Multiple sources and destinations.
- Integer Maxflow solution optimally uses the road capacity.
- Routing using Maxflows can be done, by randomly choosing a path.

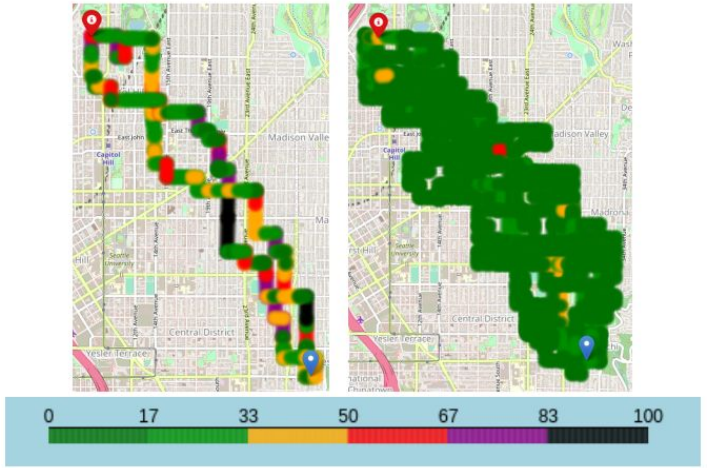


Problem: Routing is done only through a few paths, resulting in high concentration of pollution in certain areas.

Solution: Sample Integer Maxflows

- Sample Multiple Maxflows.
- Goal
  a. Minimize Travel Times
  b. Obtain diverse Maxflows

- Change the maxflow used for routing at specific intervals.



Cityscale Maxflow Sampling using MCMC

- Standard algorithms provide one max flow solution.
- Make multiple small random changes to it until it becomes different enough.
- Scalable for larger areas.

Markov Chain Transition for Sampling Maxflow in Planar Graph

1. Choose random path in maxflow.
2. Choose random face of planar graph.
3. Reroute along the face with probability

$$\propto \min \{ 1 , \lambda^{f(x)} \}$$

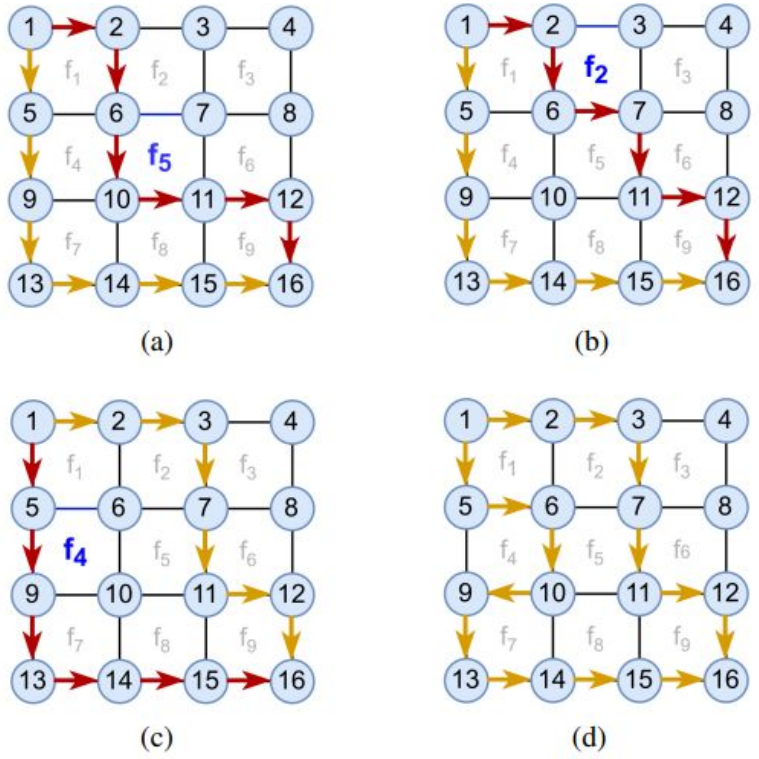
where $f(x) = \alpha * |x| + (1 - \alpha) * k^2$

|x| : total length

k : diversity of Maxflows

Uses similar ideas from Motanari & Penna for sampling paths in planar graphs.

Montanari, S.; and Penna, P. 2015. On Sampling Simple Paths in Planar Graphs According to Their Lengths. Mathematical Foundations of Computer Science 2015



EMF-MCMC: Sampling Multiple Maxflows Directly

- Previous work (MaxFlow-MCMC, AAAI'23) used a MC for sampling a single MaxFlow.

  Shreevignesh S., Praveen P., and Girish V., City-scale pollution aware traffic routing by sampling max flows using mcmc. (to appear in AAAI 2023), 2023

- Multiple Maxflows where sampled, by running it multiple times and keeping diverse Maxflows.

- The process was not fast enough.

This Work: EMF-MCMC construct a Markov Chain which can directly sample multiple diverse Maxflows on one shot.

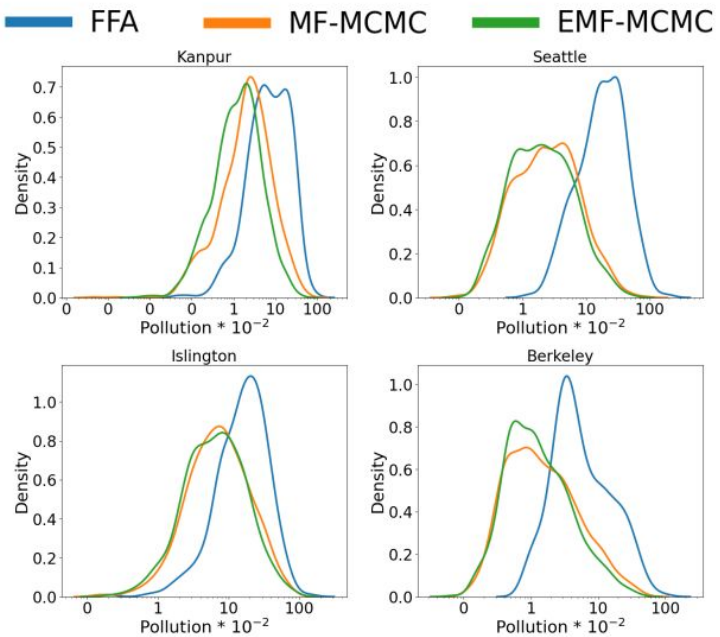
Algorithm 1 $M_{\text{flowset}}(x)$ defines a step of the *Markov Chain* on current state x.

faces = set of all internal faces in the planar graph
mf_set = the current set of integer max flows
$b \leftarrow \text{Uniform}(\{0, 1\})$
if $b == 1$ **then**
  $mf \leftarrow \text{Uniform}(mf\_set)$
  paths = set of paths in mf
  $f \leftarrow \text{Uniform(faces)}$, $p \leftarrow \text{Uniform(paths)}$
  if f, p do not share an edge **or** rerouting p through f violates capacity **then**
    return x
  else
    $y \leftarrow \text{reroute}(p, f)$
    return y with probability $\min\{1, \frac{\lambda^{f(y)}}{\lambda^{f(x)}}\}$ where $f(x)$ and $f(y)$ are calculated for x and y according to equation 1
    return x
  end if
end if

Results: Reducing Severe Pollution.

- Realworld Maps from OpenStreetMaps.
- SUMO traffic simulator for simulating traffic and obtain the emission values.
- Pollution heatmap for using 1 max flow solution for 7 hours (left) and 7 different max flow solutions for 1 hour each.

Map name	Sq. km	Edges	Nodes	s, t Pairs
Seattle	25.16	18699	14939	2
Berkeley	82.90	30808	24864	1
Kanpur	18.50	29956	20707	1
Islington	14.90	5382	2367	2



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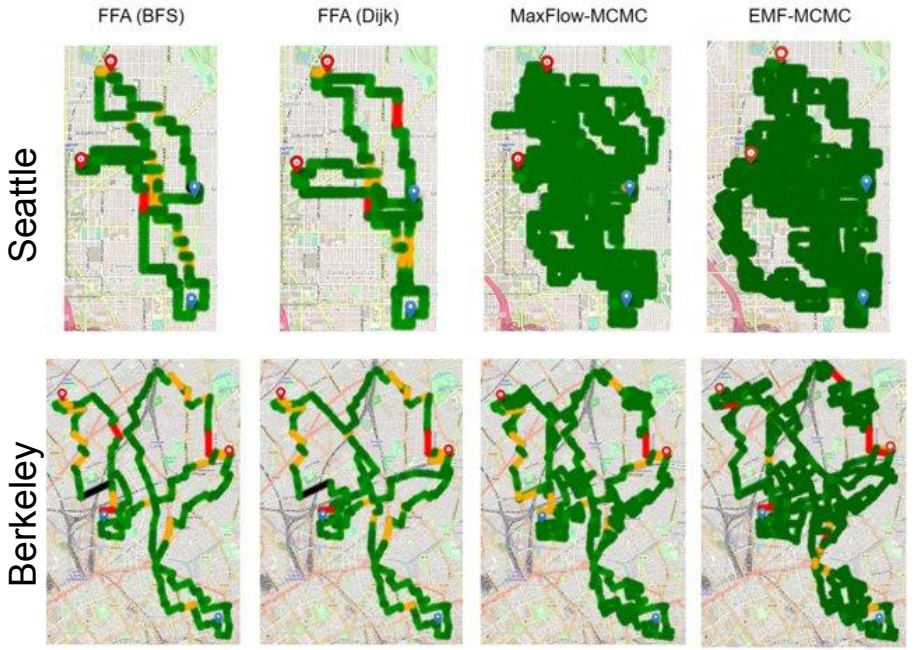


Results: Travel Distance, Pollution (Avg, Max, Total)

- There is only slight increase in distance traveled.
- Average and Maximum pollution comes down significantly.
- There is a slight increase in total pollution.

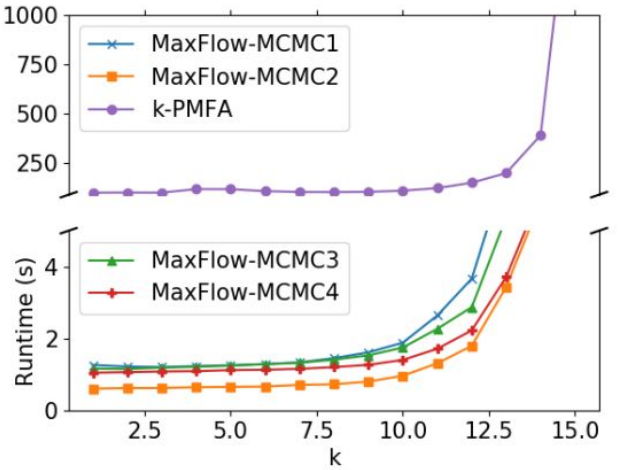
City	Traffic Policy	Length avg (m)	Pollution (NOx_{nm} in mg) avg	max * 10^{-3}	total * 10^{-4}
Berkeley	FFA(BFS)	8528	945	10.2	57.4
	FFA(Dij)	8001	718	8.5	54.3
	MCMC(3)	9457 ± 40	462 ± 4	6.7 ± 0.2	66.5 ± 0.4
	MCMC(7)	9456 ± 19	316 ± 2	5.7 ± 0.2	66.7 ± 0.2
Islington	FFA(BFS)	4723	2048	13.7	62.7
	FFA(Dij)	4930	2047	13.7	65.3
	MCMC(3)	4976 ± 10	1369 ± 5	8.0 ± 0.1	67.5 ± 0.2
	MCMC(7)	4945 ± 7	1150 ± 4	7.6 ± 0.0	67.0 ± 0.1
Seattle	FFA(BFS)	3270	2402	18.2	57.6
	FFA(Dij)	2133	1999	10.0	55.4
	MCMC(3)	3914 ± 27	856 ± 11	12.8 ± 0.9	77.3 ± 1.2
	MCMC(7)	4041 ± 24	512 ± 9	12.3 ± 0.8	83.6 ± 1.1
Kanpur	FFA(BFS)	4628	1152	8.8	48.0
	FFA(Dij)	4248	922	8.8	44.2
	MCMC(3)	4513 ± 4	597 ± 4	6.6 ± 0.1	50.6 ± 0.2
	MCMC(7)	4512 ± 4	444 ± 2	5.9 ± 0.1	50.7 ± 0.1

Results: Fast Runtime

Order of magnitude faster compared to our previous work Maxflow-MCMC (AAAI'23) and k-PMFA.

Sreeja K., Soumya V., and Praveen P., Towards a better management of urban traffic pollution using a pareto max flow approach, Transportation Research Part D: Transport and Environment 79 (2020).

Map	Maxflow-MCMC(s)	EMF-MCMC(s)	Speed
Berkeley	80726 ± 8083	3565 ± 24	22.64 times
Islington	18462 ± 2578	76 ± 0	242.92 times
Seattle	17600 ± 3698	163 ± 1	107.97 times
Kanpur	53086 ± 6609	2292 ± 9	23.16 times



Thanks!

Questions?

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Project: https://sshreevignesh.github.io/MCMCProjectPage/

IEEE ITSC 2023 BILBAO

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