IBM **Research** – Business Analytics and Mathematical Sciences

Monitoring Entire-City Traffic using Low-Resolution Web Cameras

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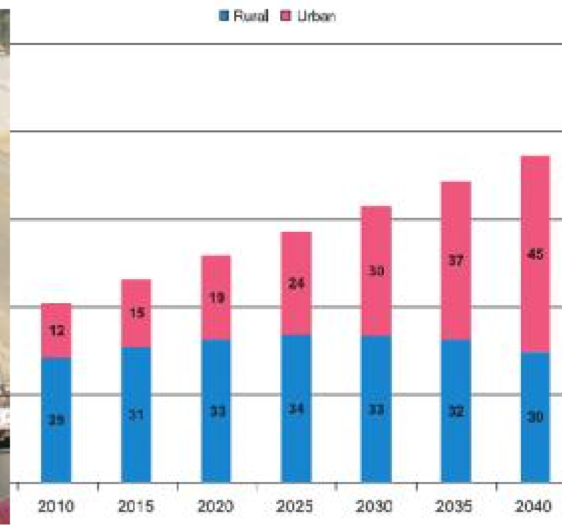
Need lightweight Intelligent Transportation System (ITS) for developing countries

Day-to-day congestion



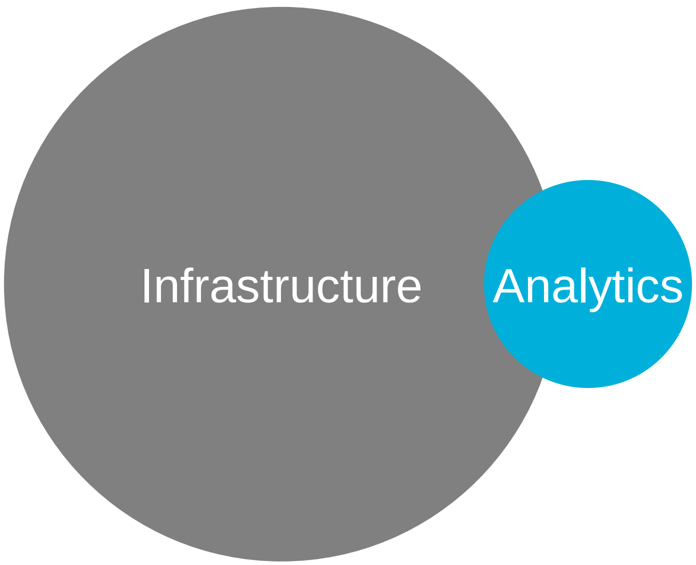
Rapidly growing urban traffic

Natural disaster

Transportation infrastructure is premature

We propose a “Frugal innovation” approach that requires no expensive infrastructure but using cheap Web cameras

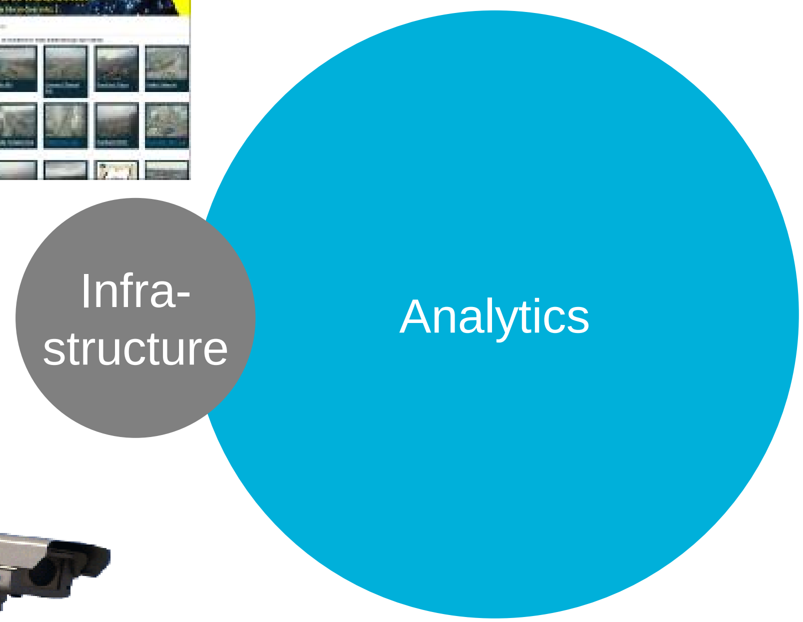
Standard approach



Data quality: High

Cost: Very High

Frugal approach

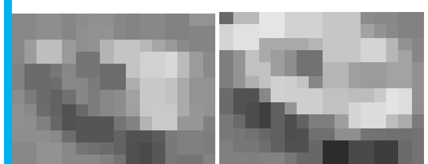


Data quality: Very low

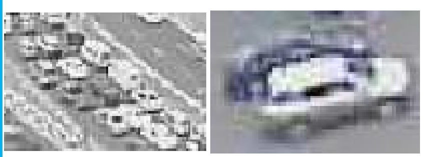
Cost: Very cheap !

Two technical hurdles: image quality and partial observations

1. Images taken by Web-camera are Very Low-Quality



Very low resolution



Overlapped

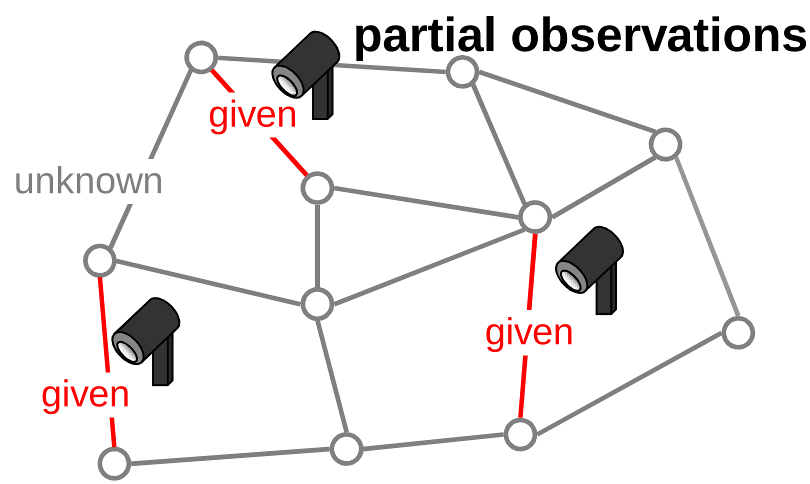
2. Web cameras only covered very limited areas

Two key analytics tasks for solving the problems: visual analytics and network analytics

1. Visual analytics for solving the first challenge

→ Estimate # of vehicles and average velocity

2. Network analytics for solving the second challenge



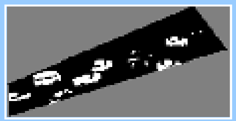
→ Estimate traffic flow <u>on no-cam links</u>

Visual analytics

We have developed two image processing technologies for estimating traffic information from Web-cams

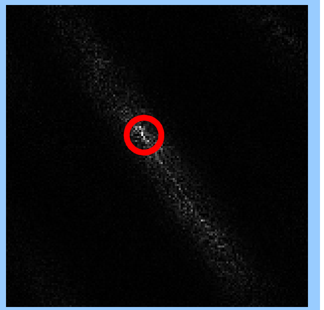
Number of Vehicles

Area-based vehicle counting technology



Average Velocity

Cross-correlation-based velocity estimation technology



Focus on vehicle-counting

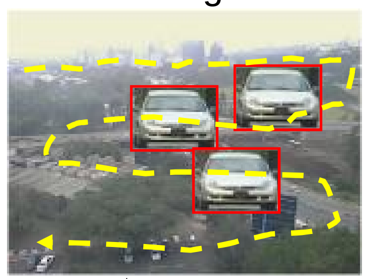
Standard vehicle-counting methods are not applicable for analyzing web-cam images due to low image quality

Two Standard Approaches

Template matching

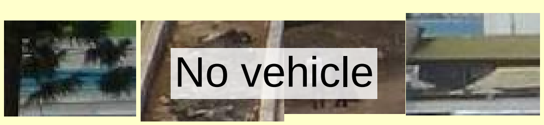
Template of
•vehicles
•windshields
•headlights

Identify independent vehicles by scanning over the image



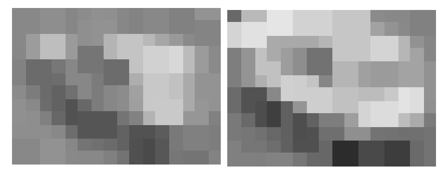
Feature-based classification

Training data

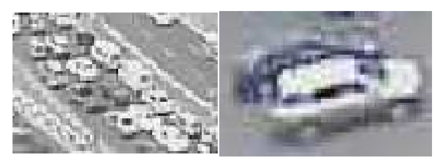


Build a binary classifier for image patches

Identification of independent vehicles is impossible for web-cam images, due to



Very low resolution



overlapped

We developed a new algorithm focused on area of vehicles

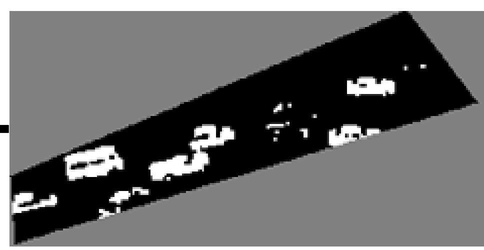
This is **not** based on techniques identifying independent vehicles

Input image

Manually choose a focused area

Optimized binarization

Compute the white area

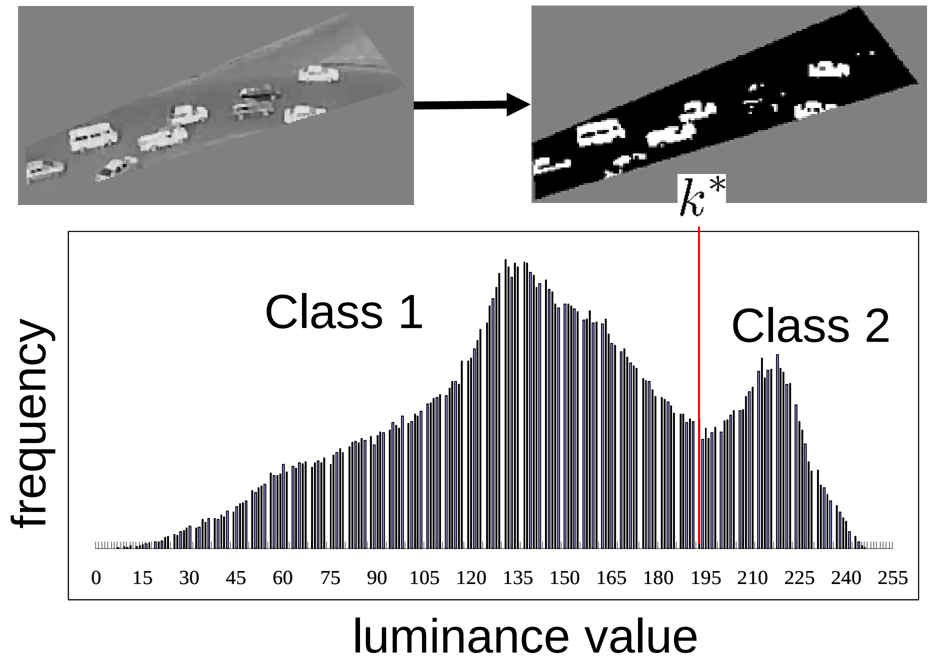


Regression function for the white area

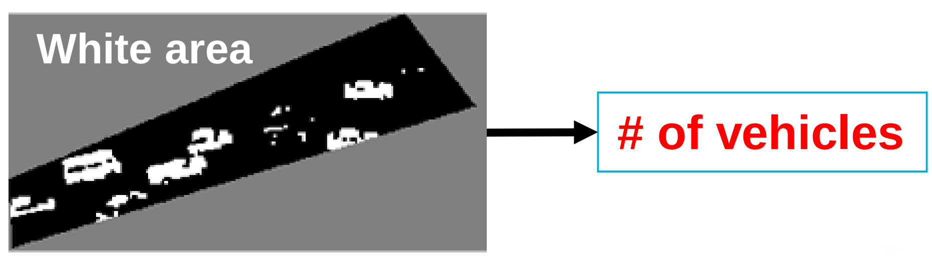
→ **# of vehicles**

Area-based vehicle counting technology

- **Optimized binarization**
  - Determine the binarization threshold k^*
  - Choose the threshold so that the inter-class variance is maximized
    - C.f. Otsu, IEEE Trans. Syst Man Cybern, 1979

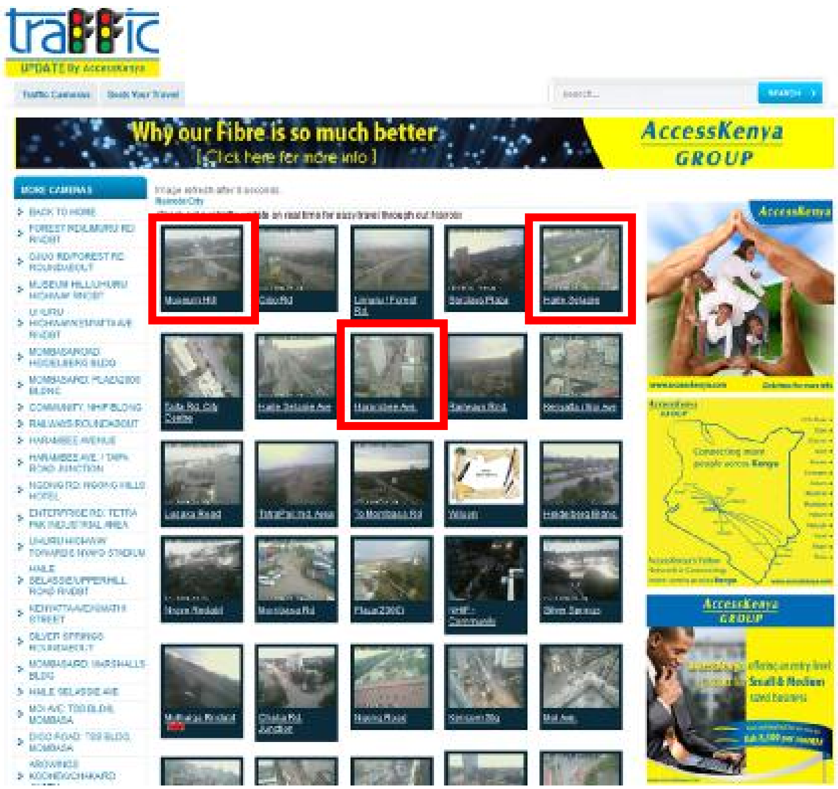


- **Regression-based vehicle-counting**
  - Propose a simple regression model, which is a linear model between the white area x and the number of vehicles y as y = ax + b
  - Determine the parameters a and b, based on the training data



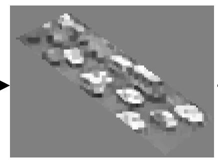
$$(a^*, b^*) = \arg\min_{a,b} \sum_{n=1}^{N} \left(y^{(n)} - ax^{(n)} - b\right)^2$$

[Vehicle counting] Evaluation using real web-cam images

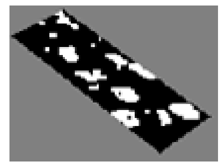


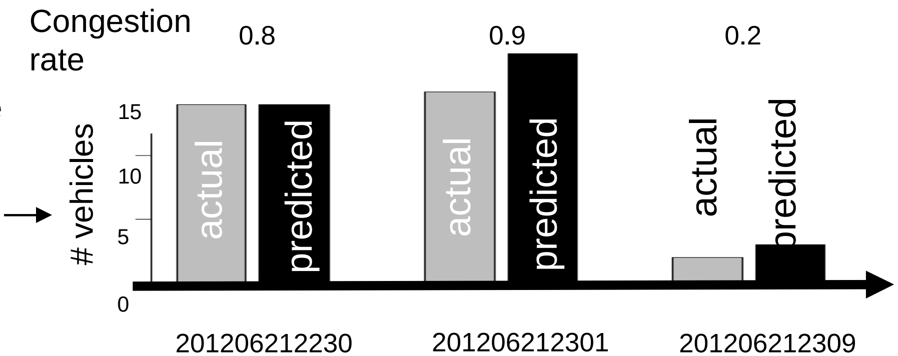
[Vehicle counting] Evaluation using real web-cam images

Focused area

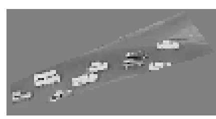


Binarized image

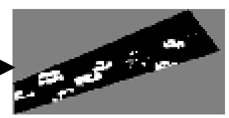


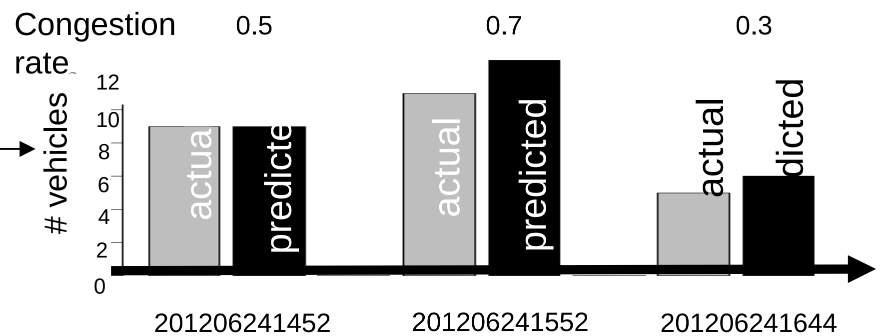


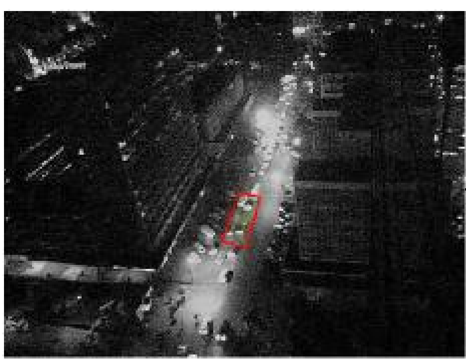
Focused area



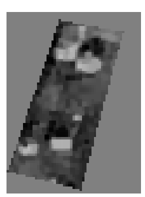
Binarized image



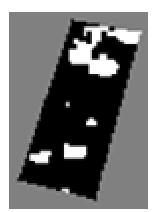


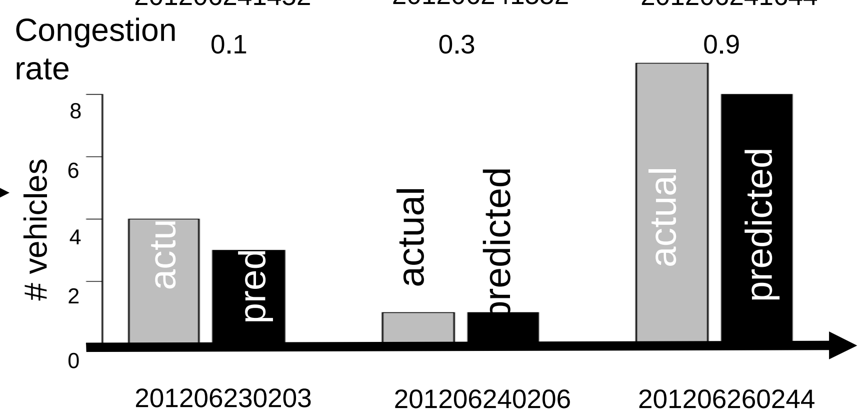


Focused area



Binarized image





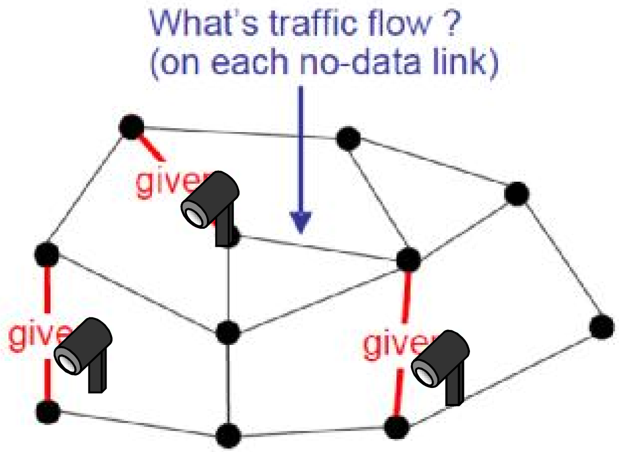
Network Analysis

A problem is the coverage of web-cams are very restricted in the whole road network

- About **5%** is covered in case of Nairobi, Kenya
  - Need to estimate rest 95% of roads from 5% observations

- Related Technologies
  - **Network tomography**
    - Estimate the demands of the origin and the destination of a trip, instead of traffic flow
  - **Link cost prediction**
    - Need trajectories or dense observations for input

→ They are not applicable for this problem setting

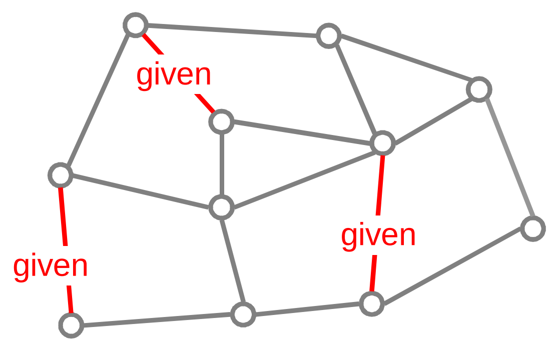


We formulate this problem as an inverse Markov chain problem

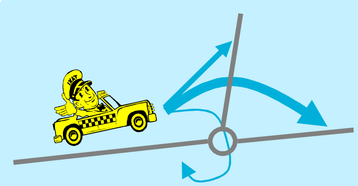
- **Overview: to approximate traffic system with Markov-chain model**
  – Traffic flow of every road is computed as a visiting probability of the road from the approximated Markov model
  – Define: inter-link transition probability matrix
    - Representing drivers' route selection probability at each intersection
  – Task: to determine the transition matrix
    - So that its stationary distribution is consistent to the observation
    - This is an **inverse problem of Markovian transition**

Input:

Traffic flow on a very limited link set



Analytical model

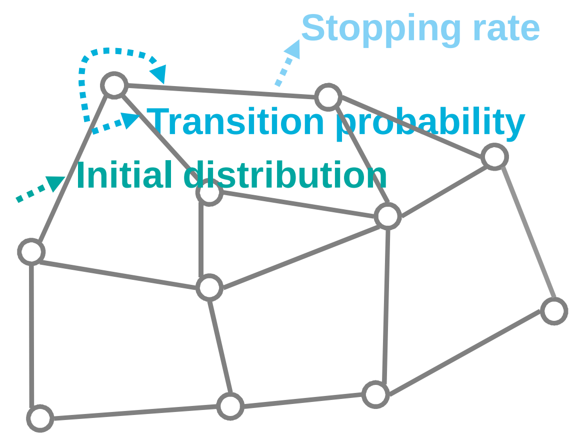


Estimate inter-link transition probabilities for all the intersections

Output:

- Traffic flow on all of the links

Solving the inverse problem of Markov chain



- Formulation: Traffic Markov process
  - Markovian driver model with three types of parameters
    - **Initial road distribution for a trip**
    - **Inter-road transition probability**
    - **Stopping rate for a trip**

- Learning the model to estimate traffic flows on **no-data links**
  - Objective is to make its stationary distribution *d*(*i*) be proportional to the observed traffic frequency f(i)

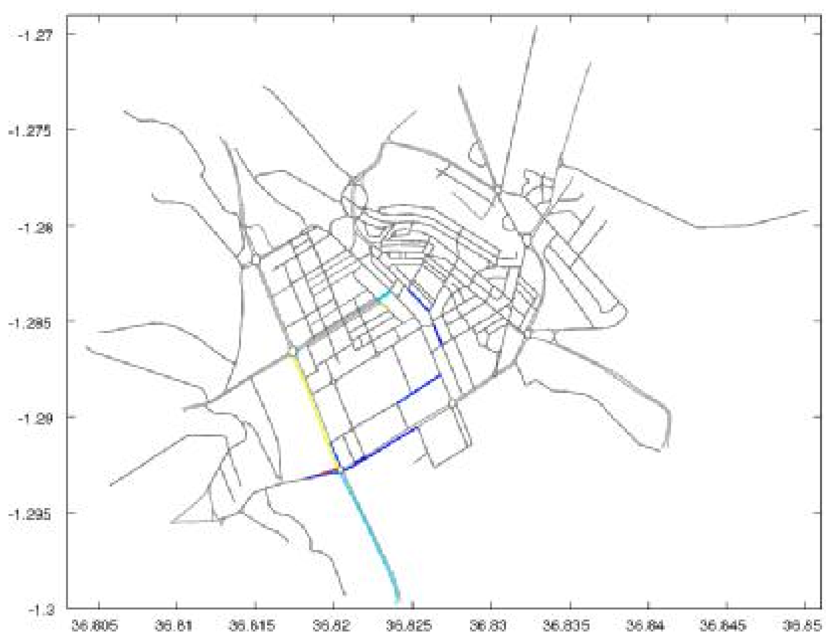
$$d(i) \propto f(i)$$

  - Introduce **regularization terms** for some restrictions based on prior knowledge
    - Penalize right and left turns
    - Penalize inter-link transitions between different road types, e.g. from a highway to a side road
  - Solve this learning problem using a gradient descent method

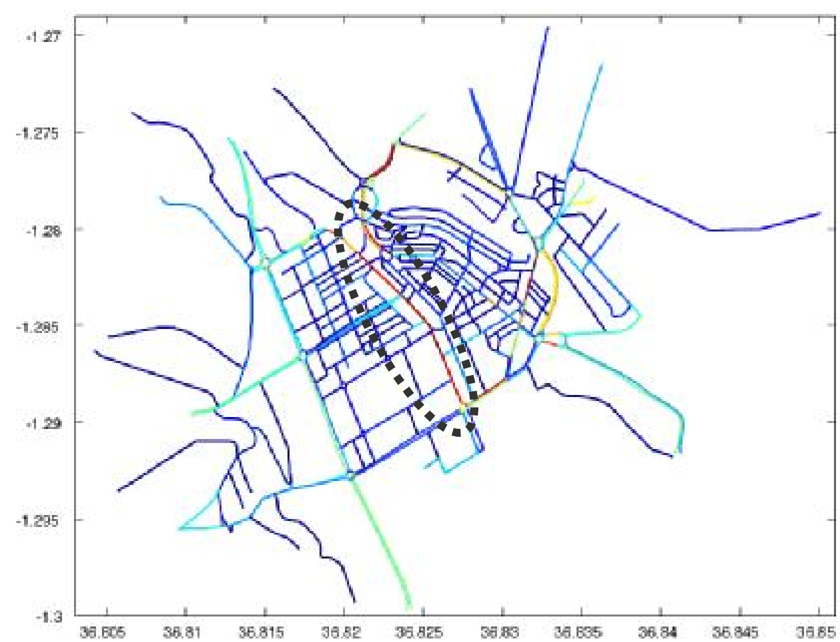
Evaluation of traffic flow using real data in Nairobi Central Business District (1/2)

- Good agreement at the Web-cam links
- Heavy congestion is indicated in the central area
  - Highlighted by the dotted circle
  - Notice that the heaviest congestion road has no Web cameras

Web-cam observation

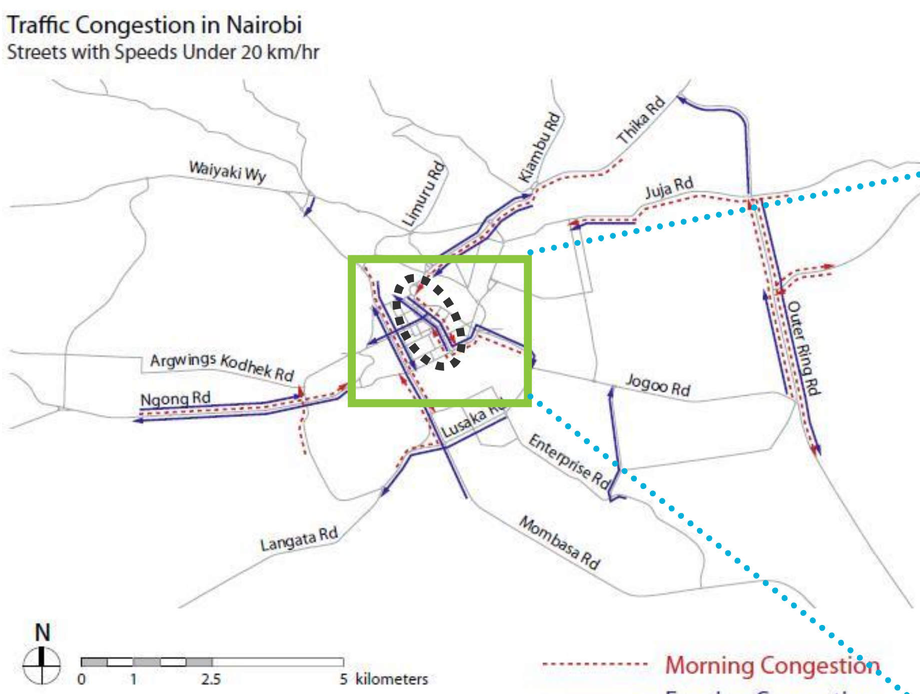


Estimated traffic flow



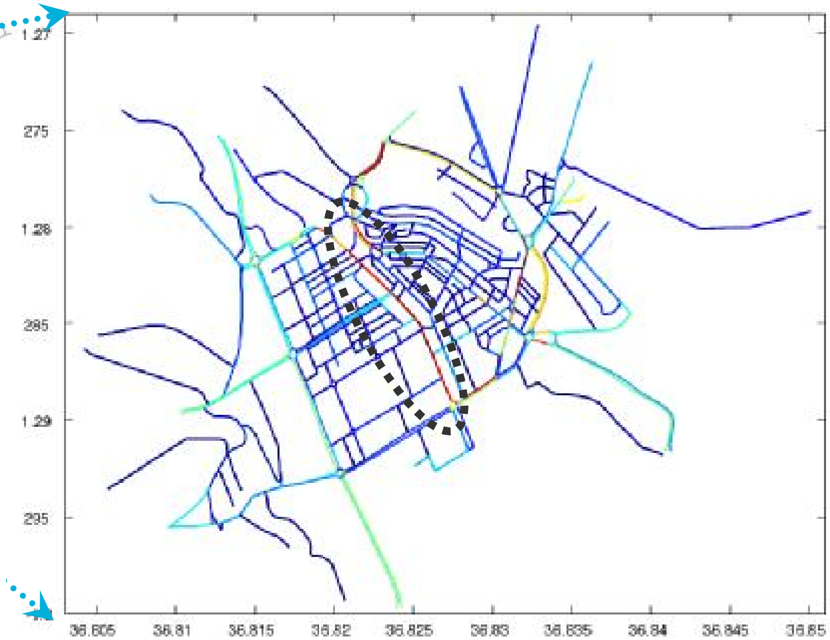
Evaluation of traffic flow using real data in Nairobi Central Business District (2/2)

- The predicted congestion is actually confirmed by a traffic survey report
  - i.e. Our algorithm successfully predicted unseen traffic !



Multimodal Transport modeling for Nairobi, Kenya: Insights and Recommendations with an Evidence-Based Model (2009)

Estimated traffic flow



CONCLUSION

- We have proposed a new approach to ITS.
  - Web-camera-based traffic monitoring
  - Network flow estimation from partial observation
- Using real Web cameras deployed in Nairobi, Kenya, we assessed the accuracy of our approach
- To the best of authors' knowledge, this is the first practical framework for monitoring an entire city's traffic without special and expensive infrastructure and time-consuming data calibrations.

Details of individual technology

- [Visual analytics]
  - Takayuki Katsuki, Tetsuro Morimura, Tsuyoshi Idé, "Bayesian Unsupervised Vehicle Counting," Technical Report RT0951, IBM Research - Tokyo, 2013.

- [Network analytics]
  - Tetsuro Morimura, Takayuki Osogami, Tsuyoshi Idé, "Solving inverse problem of Markov chain with partial observations," to appear in Neural Information Processing Systems (NIPS 2013).
    - Published also as Technical Report RT0952, IBM Research - Tokyo, 2013.