TOWARDS COST EFFICIENT TRAFFIC DATA COLLECTION

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1. Motivation

The mobility demand of our society increased rapidly in the last decades. To ensure accessibility the traffic infrastructure needs to be used more efficiently. One way to achieve this is the introduction of dynamic traffic management (DTM).

DTM monitors the traffic situation and tries to optimize it by applying different control measures like speed limits, route guidance, lane closure, ramp metering, intersection control or others to the traffic network. In its ideal form it is a continuous cycle that gets evaluated by checking the effects of the taken measures to the traffic situation, although in practice the measures are often predefined and not tuned to the detailed actual traffic situation. Traffic models are used to support traffic engineers with the optimization task by predicting the effect of different measures before applying them to the real network.

Vital for the DTM cycle is traffic data collection to enable the feedback loop to traffic operations. Roadside detection is nowadays the most common way of traffic data collection, but probe vehicle data, GSM data and vehicle to infrastructure communication are getting more and more momentum. With the new variety in data collection methods, research on data fusion, to combine different data sources to better traffic state information increases.

This paper wants to look at this development from a different perspective. We are proposing a framework to develop a guideline for efficient traffic data collection in road networks. Important factors will be purchase and maintenance costs, incident detection, travel time estimation, traffic control and environmental impact. First, we are going to introduces briefly the source for data collection, then have a look at previous detector placement studies and have a look at actual traffic data and the general cost of it before getting into the proposed framework.

2. State of the Art Data Collection

State of the Art traffic data collection, used for online traffic management, relies on local real-time traffic information data to estimate the actual network-wide traffic situation in the network. Sources are: [1)]

▸ *Roadside detection*

- Infrared detectors, which detect passing vehicles when a beam of light is interrupted. Active infrared detectors are additional able to recognize temperature differences (engine heat, body warms). Usually gathered information: aggregated flows and aggregated speeds in one minute intervals.
- Radar detectors, which measure the presence and the speed of vehicles using the Doppler Effect. Usually gathered information: aggregated flows and aggregated speeds in one minute intervals. Further they can measure the height of the passing vehicle.
- Ultrasonic detectors, which transmit ultrasonic sound waves instead of electro-magnetic radar waves. Usually gathered information: aggregated flows in one minute intervals plus a record of vehicle types, distinguished by their height.
- Induction loop detectors, which detect vehicles entering a created electro-magnetic field by induction of Foucault currents. With two induction loops placed closely together (commonly 1 meter apart) not only the vehicle but also its speed can be detected. Usually gathered information: aggregated flows and aggregated speeds in one minute intervals. Vehicle types can be obtained by induction patterns and is experimentally in use.
- Video cameras, which detect vehicles when entering and exiting a road stretch. Usually gathered information: aggregated flows and aggregated speeds in one minute intervals plus individual travel time data if a license plate recognition is used.

▸ *Probe vehicle data*

- Probe vehicles, transmitting traffic messages containing location, speed, and others at regular time intervals.
- GSM data, which is recently used to gather travel time data of the road network.

▸ *Others*

- Vehicle to infrastructure communication, using beacons along the road to collect data from passing equipped vehicles.

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- Historical data, which gives a basic idea of the development of the traffic situation in previous times.
- Weather conditions, which have an influence on the traffic flow.

An additional input is the network description, including the network structure, road works and other information. Road authorities are using the gathered data for traffic operation to allow the traffic to flow as smoothly as possible and to detect and react on any abnormal situations.
In order to limit the detection point inside a network, only a few studies have been conducted, which will be introduced in the following.

3. Detector Placement Studies

The detector placement problem is a less explored research topic in transportation. Relevant research includes the work done in transportation planning for obtaining accurate origin-destination trip matrices [5]. Some researchers have conducted simulation based research to identify the relationship between detector location and travel characteristics on arterial roads [6)7)8)]. Very limited research to date has been focused on the detector placement problem for freeways with respect to travel time estimation. [9)]
A Virginia Transportation Research council report [9)] found that the placement of detectors for the development of accurate travel time estimates will vary by location based on specific conditions. Arbitrary, evenly spaced detectors do not necessarily result in accurate travel time estimates. With carefully placed detectors that are well maintained, travel time estimates can be derived with an acceptable level of accuracy from point detection, under incident-free travel conditions. The methods developed in this research effort including the GPS data collection and the mathematical tool are effective in determining preferred detector locations when the objective is to minimize travel time estimate error. There is evidence that VDOT can reduce the number of detectors that are currently maintained by TMCs and can deploy far fewer than the 1/2 mile spacing guidelines, resulting in significant cost saving in both capital and operations and maintenance costs.
Based on the findings of these studies, we will have a look at real traffic data from the United States, the Netherlands and Japan to investigate the information gathered from inductive loop detectors only.

4. Induction Loop Detector Observations

Figure 1 shows data from San Francisco and shows that neighbored detectors, when installed closely to each other, hold no extra information in no incident cases. However, an incident at station 2 on January 4th was not fully detected by the neighbored stations, which would have let to insufficient input to online traffic operations.

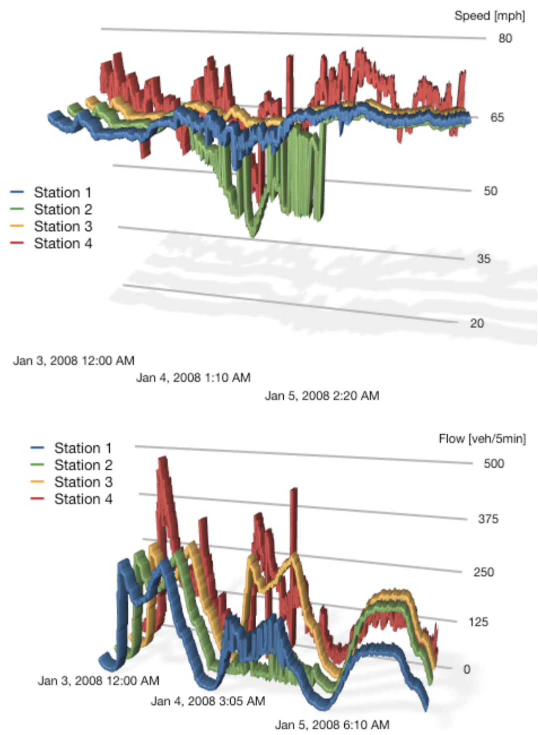

Figure 1: Speed and flow measurements in San Francisco at four different stations, where station 1-3 are neighbor stations and station 4 is further upstream.

Data from the Tokyo Metropolitan Expressways (see Figure 2) shows an additional important issue - reliability of detectors.

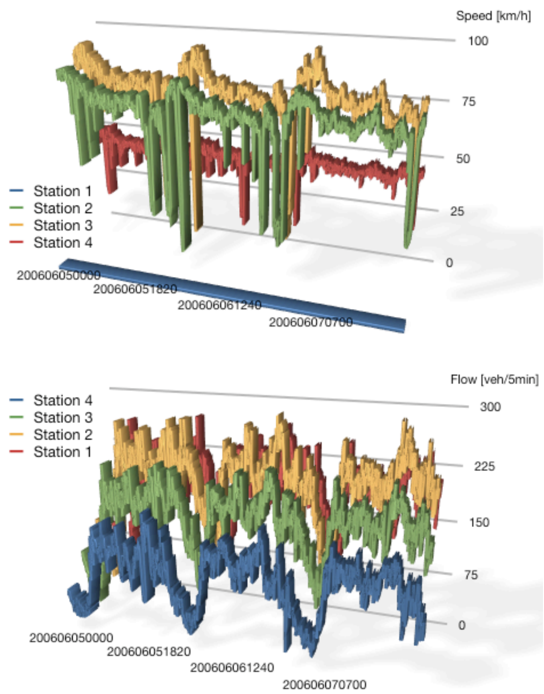

Figure 2: Speed and flow measurements on Tokyo Metropolitan Expressway at four different stations, where station 1-3 are neighbor stations and station 4 is further upstream.

Station 1 is not working properly and no information is recorded from the detector. Without the neighboring detectors, no information would be available for this part of the network and traffic control would be impossible.

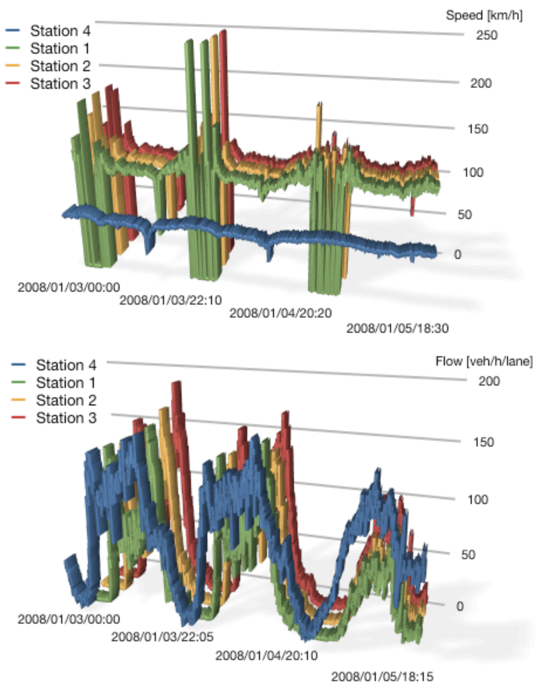

Figure 3: Speed and flow measurements on Dutch highway 13 at four different stations, where station 1-3 are neighbor stations and station 4 is further upstream.

Last but not least, data from the Netherlands, shown in Figure 3, shows that this problem is the same across continents and not a local issue.
All collected data shows that detectors with a wider spacing show different characteristics while closely placed detectors only deliver additional information for incident detection.
These facts in mind, one would say that more information leads to better operation, but one should also consider the costs for such data collection. In the following we will give a brief insight on these costs.

5. Purchase and Maintenance Costs

The purchase cost of sensor for traffic measurements are varying from a few hundred to several thousand US dollars (see Table 1).

Table 1: Cost of commercially available sensors [2)]

Sensor	Communication Bandwidth	Purchase Cost
Inductive loop detector	low to moderate	\$500 - \$800
Magnetometer	low	\$900 - \$6300
Magnetic	low	\$385 - \$2000
Microwave Radar	moderate	\$700 - \$1200
Active infrared	low to moderate	\$6500 - \$14000
Passive infrared	low to moderate	\$700 - \$1200
Ultrasonic	low	\$600 - \$1900
Acoustic array	low to moderate	\$3100 - \$8100
Video image processor	low to high	\$5000 - \$26000

Prices do not only vary by sensor type, but also by manufacturer and sensor capabilities. However, the purchase itself is not sufficient, the sensors have to be installed and maintained which includes other costs. Table 2 shows and example from a study of the Federal Highway Administration which has annualized the costs for instrumenting a six lane freeway station with different sensor types.

Table 2: Annualized per-lane sensor cost comparison to instrument a six-lane freeway sensor station [3)]

Sensor	Number required for 6 lanes	Expected life [years]	Annualized cost [\$]
Inductive loop detector	12	10	746
Video image processor	2 cameras 1 processor	10	580
Multi-detection zone micro-wave presence detecting radar	1	7	314
Acoustic array	6	5	486

The information above shows clearly that data collection should always be a trade off between the information and the pice paid for it. To support decision makers in this process we attempt to develop a guideline for cost efficient traffic data collection. This will be done inside the following proposed framework.

6. Proposed Framework

To analyze the detection efficiency of a network or to develop guidelines for detection placement planning, several aspects have to be taken into account (see Figure 4). As mentioned in section 5, the costs of the detection equipment is vital, and should include not only the purchase costs, but also the maintenance costs and equipment life-cycle.
With the budget for detection equipment installation and maintenance being usually the limiting factor, an evaluation should indicate an area specific level of detection (LOD) that is possible inside this budget. The

LOD is representing the overall coverage of the network, but especially the area wide data availability for reliable incident detection, travel time estimation, traffic control and traveler information systems.

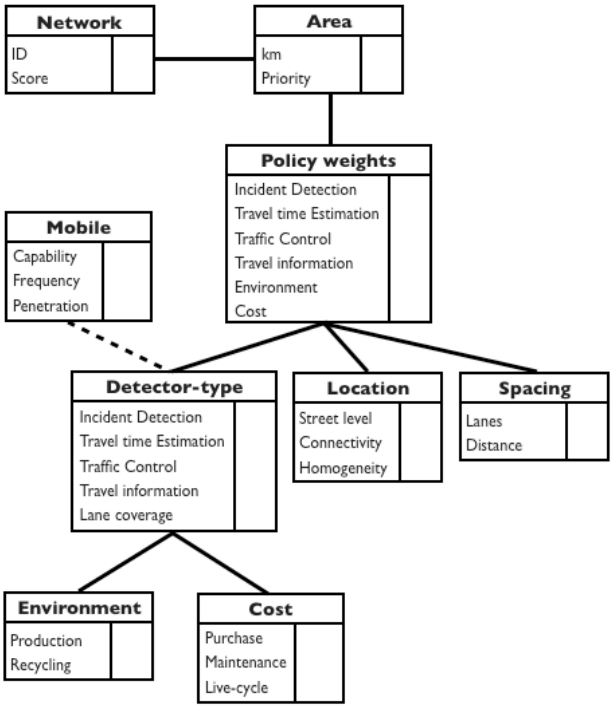

Figure 4: Framework elements to determine efficiency of traffic data collection scheme in a network

Such data availability and also reliability depends on the detection equipment. This is why the first step needed to implement this framework, is to determine parameters for the data availability and reliability of each detection equipment for each task or combination of tasks. In case of probe vehicle data and vehicle to infrastructure data collection, the parameters will be dependent on on-board equipment capabilities, transmission frequencies and penetration rates.

This information, together with the spacing of the detection points will allow to determine the data coverage of an network area. However, to determine the LOD of the area, location specifics should be added, since detector placement is, as mentioned before, strongly dependent on location.

This leads to a second major task for implementing such a framework. It needs information on the correlation of incidents and location. For obvious reasons, weaving areas, intersections and ramps are locations which require a denser detection than mid-block part of the network - in an incident free traffic state.

Having the detection equipment, spacing and location needed determined, policy weights will be used to find the mot suitable detection plan for a network under the limitation of the available budget.

Applying such a framework would lead to efficient detection plans, but there is the risk of a high data redundancy given a large enough budget. One of course could argue that this states no problem, since the more data is available, the more precise will be any estimation and forecast used for traffic operations. However, one more and more important aspect should be taken into account as an additional limitation - environmental impact. The environmental impact should not be forgotten. With research projects going on to limit and reduce the carbon footprint of transportation with intelligent transportation systems (ITS) and efficient road management strategies, it should be ensured that the installation and usage of the necessary equipment for such efforts will not backfire in terms of the impact to our environment.

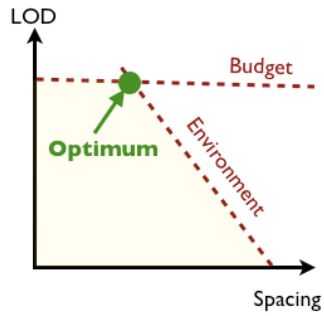

Figure 5: Scheme of the optimal detection density considering the available budget and environmental concerns

Therefore we propose a bilevel optimization that optimizes the LOD within a given budget, taken into account the environmental impact (schematic shown in Figure 5).

7. Conclusions and Future Work

In this paper we have stated the motivation to develop guidelines for efficient data collection, incorporating new detection and data collection methods in existing networks, to achieve an optimal level of detection within a given budget and environmental friendly. We have proposed the elements of a framework to perform the task, based on previous studies and own observations.

In the next step we are going to determine parameter-sets for different detector types, which will be combined with location, spacing and environmental sets to determine the LOD for first highway and then any type of network.

8. Acknowledgment

All traffic measurement data for this study was provided by the International Traffic Database (ITDb). Data available to the public can be accessed through www.trafficdata.info.

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