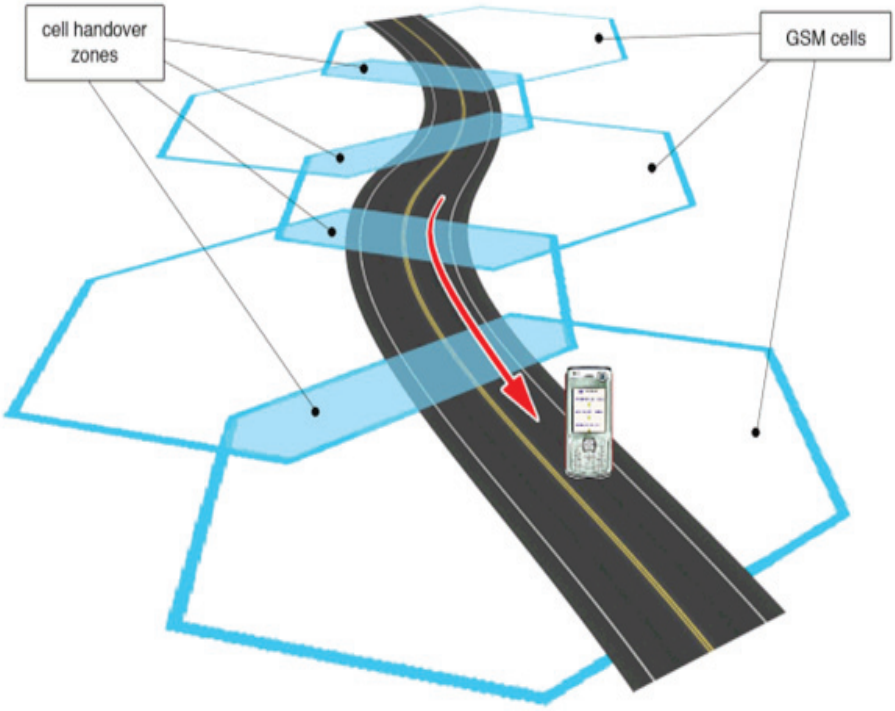

TECHNOLOGY • RESEARCH HIGHLIGHTS • VISIONS • SCIENCE
51

Floating mobile data pilot in the Helsinki Metropolitan Area

Validation of travel time data

Satu Innamaa | Esko Hätälä

VTT TECHNOLOGY 50

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Validation of travel time data

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FMD-matka-aikatieto-pilotti Helsingin seudulla – Matka-aika-aineiston validointi. **Satu Innamaa ja Esko Hätälä.** Espoo 2012. VTT Technology 51. 51 p. + app. 76 p.

Abstract

The floating mobile data (FMD) pilot aimed to provide anonymous travel time information from data provided by mobile phones. The main purpose of the pilot was to validate the quality of FMD by comparing it with camera-based travel time data. Additionally, the usability of data was assessed from a traffic management point of view and some principles were tested. A travel time camera system was used as a reference.

The main conclusion is that for traffic management operations, monitoring of cell handovers of active 2G phone calls does not produce a high enough number of observations. Consequently, it is recommended to select an FMD technology that is able to monitor a larger proportion of mobile phones per aggregation period per link. Independence of active phone calls would help to cover also night time traffic as well as smaller roads and main streets.

Another main conclusion is that the estimation of median travel time should be developed further. Although traffic-wise homogeneous links were targeted, obviously traffic on many links is dynamic in both space and time. Consequently, it is recommended that the estimation of traffic flow status be based on part-observations, and that the weight of different zones of the travel time link be balanced. If full observations on fluent parts of a link are allowed to dominate, the estimate will be biased.

The main implication related to ad hoc service is that the precision of ad hoc links was not high enough. The precision does not have to be as high as for static links, but nonetheless high enough to make validation of the data possible. Thus our recommendation is to improve it. Another recommendation is to increase the number of observations in ad hoc service to suffice for real time operations based on 5-minute medians.

Keywords FMD, floating mobile data, traffic monitoring, evaluation

FMD-matka-aikatieto-pilotti Helsingin seudulla
Matka-aika-aineiston validointi

Floating mobile data pilot in Helsinki Metropolitan Area – Validation of travel time data. **Satu Innamaa and Esko Hätälä.** Espoo 2012. VTT Technology 51. 51 s. + liitt. 76 s.

Tiivistelmä

FMD (floating mobile data) -pilotin tarkoituksena oli tuottaa anonyymiä matka-aikatietoa matkapuhelinten avulla. Pilotin päätavoite oli arvioida FMD-aineiston laatua vertaamalla sitä kamerapohjaiseen matka-aika-aineistoon. Lisäksi aineiston käytettävyyttä arvioitiin liikenteen hallinnan näkökulmasta ja joitain periaatteita testattiin. Matka-aikakamerajärjestelmää käytettiin pilotissa vertailujärjestelmänä.

Pilotin tärkein johtopäätös oli, että aktiivisten 2G-puheluiden soluvaihtojen seuranta ei tuota riittävän suurta määrää havaintoja liikenteen hallinnan tarkoituksiin. Sen takia suositellaan, että valitaan sellainen FMD-teknologia, joka mahdollistaa suuren matkapuhelimien osuuden seurannan kullakin aggregointijaksolla ja linkillä. Riippumattomuus aktiivisista puheluista helpottaisi liikenteen seurantaa yöaikaan sekä pienillä teillä että kaduilla.

Toinen pääjohtopäätös oli, että mediaanimatka-ajan estimointia pitäisi kehittää edelleen. On selvää, että vaikka tiejaksoista yritettiin tehdä liikenteellisesti homogeenisia, liikenne oli monella linkillä dynaamista sekä tilassa että ajassa. Tästä syystä suositellaan, että liikennetilanteen estimointi perustuisi osahavaintoihin (mittauksiin) ja linkin eri osien matka-aikojen osuus mediaanista tasapainottuisi. Jos linkin sujuvaan osaan painottuvien täyshavaintojen annetaan hallita, se vääristää estimaattia.

Tärkein ad hoc -palveluun liittyvä päätelmä oli, että ad hoc -linkkien tarkkuus ei ollut riittävä. Tarkkuuden ei tarvitse olla yhtä hyvä kuin staattisilla linkeillä mutta kuitenkin riittävä, jotta aineiston laadun arviointi on mahdollista. Tästä syystä suosituksena on parantaa ad hoc -linkkien tarkkuutta. Toinen suositus on kasvattaa havaintojen määrää ad hoc -palvelussa, jotta se riittäisi ajantasaiselle, viiden minuutin mediaaneihin perustuvalle liikenteen operoinnille.

Avainsanat FMD, floating mobile data, traffic monitoring, evaluation

Preface

The Finnish Transport Agency (FTA) developed the floating mobile data (FMD) collection method together with Nokia Siemens Networks (NSN), Telia Sonera and DNA as part of the FMD Sujuva project. FTA aimed to pilot the service from a traffic management point of view. VTT validated the field trial pilot data and supported development work from an end-user perspective.

The pilot group of the FMD Sujuva project included Esko Hätälä (FTA), Kari Hiltunen (FTA), Pasi Halttunen (Centre for Economic Development, Transport and the Environment), Zhi-Chun Honkasalo (NSN), Hunor Demeter (NSN), Esa Östring (Infotripla), Arto Luoma (Infotripla), Noora Salonen (Sito), Ilkka Tuominen (DNA), Satu Innamaa (VTT), and Jukka Viinikainen (TeliaSonera).

The steering group included Esko Hätälä (FTA), Kari Hiltunen (FTA), Pasi Halttunen (Centre for Economic Development, Transport and the Environment), Zhi-Chun Honkasalo (NSN), Markku Rauhamaa (NSN), Risto Tiainen (NSN), Ilkka Tuominen (DNA), and Jouni Sintonen (TeliaSonera).

Satu Innamaa (VTT) is fully responsible for the validation of travel time data and this report. Esko Hätälä was the FMD Sujuva project manager at FTA. Kari Hiltunen (FTA) and Pasi Halttunen (Centre for Economic Development, Transport and the Environment) lent their strong support to the development work. Zhi-Chun Honkasalo and Hunor Demeter were the key participants from NSN. Mikko Kallio (VTT) participated in making the reference measurements and processing raw data. The Budapest University of Technology and Economics (Dept. of Control for Transportation and Vehicle Systems, Dept. of Photogrammetry and Geoinformatics) also participated in the development of the theoretical and algorithmic results, as NSN subcontractors.

Contents

List of abbreviations

FTA	Finnish Transport Agency
FMD	Floating mobile data
OQI	Overall quality indicator
QWM	Quality weighted median

1. Introduction

The floating mobile data (FMD) pilot aimed to provide anonymous travel time information from data provided by mobile phones. Cellular source obtained from teleoperators was further processed by the FMD provider before input into FMD-DigiTraffic, the real-time data interface and time traffic flow status application of the Finnish Transport Agency (FTA). The links were predefined by FTA and divided from a traffic management point of view, i.e. aiming at links with homogenous traffic.

The main purpose of the pilot was to validate the quality of FMD by comparing it with camera-based travel time data. Also the usability of data was assessed from a traffic management point of view and some principles were tested. A current FTA travel time camera system was used as a reference system for pilot links that overlapped the current system. Measurements were complemented with a high quality camera and software developed for number plate recognition on links outside the current travel time system.

FMD was previously piloted in Finland in 2002 (Kummala 2002), with promising results for data based on location area updates.

2. Method

2.1 FMD method

2.1.1 Measurement

FMD measurement was based on at least two time stamps related to cell handover or location area update of mobile phones together with corresponding locations. The FMD measurement was the time-lapse between time stamps (travel time) linked to an estimate of the link length between them measured along the road (Figure 1).

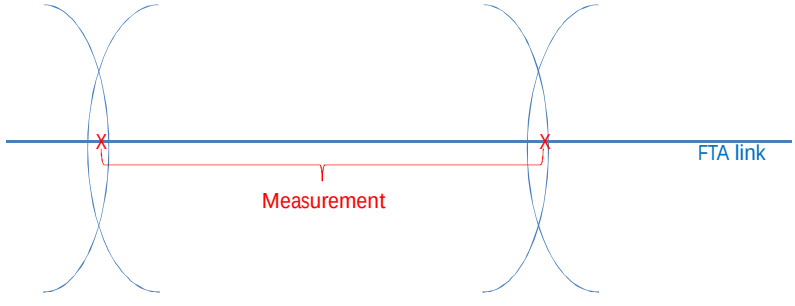


Figure 1. Measurement and FTA link.

In the pilot, 2G to 2G handovers of active phone calls from two teleoperators were included for all links. Over some links, location area updates of all phones from one teleoperator were used, too. Given that these two teleoperators account for roughly 60% of the mobile subscriber market share in Finland, and that a portion of mobile traffic is 3G, it is estimated that the pilot result represents roughly 20%–25% of overall available mobile phone data.

2.1.2 Observation

FMD observation is an estimate of the FTA link travel time based on one or several measurements of a single mobile phone made on the FTA link. A measurement or several measurements of a single mobile phone were generalised as one observation to represent the FTA link travel time based on relative measurement link lengths of free flow travel time (assumed to correspond to the speed limits) in different parts of the FTA link.

$$T_{observation} = T_{measurement} \cdot \frac{T_{FTA\ link\ in\ free\ flow}}{T_{measurement\ link\ in\ free\ flow}}$$

2.1.3 Quality indicator

(An overall) *quality indicator* (OQI) was determined for each observation to indicate the reliability of observation. Quality indicator value 100% was determined to indicate that measurements covered the whole physical road section, that the physical location of handovers or location area updates were known exactly, and that it was certain that the mobile phone had travelled the path in question without taking detours.

2.1.4 Median

The 5-minute median travel time of an FTA link was calculated for FMD based on the *quality weighted median* (QWM) of the observations. In practice, first the observations were sorted according to the order of magnitude of the FTA link travel time. Next, the observation for which the cumulative sum of OQIs of observations smaller than or equal to it (including the observation in question) was closest to 50% of the maximum of the cumulative sum of OQIs was equalled to the median.

The QWM of travel time was observation t_n of travel time observations sorted in order of magnitude where n was the sequence number for which the following expression as minimised:

$$\left| 50\% \cdot \sum_{all} q_i - \sum_{i=1}^{n} q_i \right|$$

where q_i is the overall quality of observation *i.* An example of the calculation is given in Figure 2.

Observation (min)	Overall quality of observation	Cumulative sum
10.1	57 %	57 %
10.1	67 %	124 %
10.1	92 %	216 %
10.3	75 %	291 %
10.3	27 %	318 %
10.6	84 %	402 %
10.7	65 %	467 %
10.8	65 %	532 %
10.8	48 %	580 %
11.5	13 %	593 %
11.5	39 %	632 %
12.1	33 %	665 %
12.5	11 %	676 %
12.8	2 %	678 %

← Quality weighted MEDIAN is the observation for which the cumulative sum is closest to 50% of its maximum

Figure 2. An example of how to select the quality weighted median for travel time for one link.

2.1.5 Ad hoc travel time

Static links of FMD service are located mostly on main roads and streets where traffic volume is high and continuous monitoring is needed. However, an event like a festival or exhibition may initiate traffic somewhere outside the monitored road network. In addition, if a road is closed due to a major traffic incident, congestion can occur in locations where traffic flow is normally always free-flowing. It is not economically profitable to cover all the roads for such rare occasions. However, to guarantee traffic management at all times, an *ad hoc FMD service* was set up.

An ad hoc FMD service produces travel times also around any given location. This service provides detailed travel time information in cases when a temporary urgent need cannot be met by a basic travel time service (i.e. due to scheduled events and random incidents). The main difference in determining the static link travel times and ad hoc travel times is that an ad hoc link is determined around the requested location based on cell handover locations. In principle, one handover location on both sides of the requested location would make the ad hoc link but, in practice, at least two handover locations of both operators were used for better performance.

2.2 Pilot area

The FMD system was piloted in the western part of Espoo in Finland (Figure 3, Table 1). The pilot consisted of 36 links (Appendix A) including main road links (Ring I, Ring II, Road 1, and Road 51), lower class roads and main streets (Road 110, Kalevalantie, Kokinkyläntie, Kuitinmäentie–Martinkyläntie, and Röyläntie), and turning links (ramps between ring roads and Road 1). Röyläntie and Kokinkyläntie had the lowest traffic volumes of the pilot links. On Road 51 there were links based on location area update in addition to links based on cell handover. All other links were based on cell handover.

Figure 3. Pilot links in Espoo, see Appendix A for individual link maps.

Table 1. Pilot link positions and lengths (metres).

ID	Link	Dir.	Endpoint1	Endpoint2	Length
4	Ring I link 1	1	101/2/733	101/3/352	3848
24	Ring I link 1	2	101/3/352	101/2/733	3848
3	Ring I link 2	1	101/3/352	101/4/2445	3181
23	Ring I link 2	2	101/4/2445	101/3/352	3181
5	Ring II	1	102/1/972	102/2/1762	2813
25	Ring II	2	102/2/1762	102/1/972	2813
9	Ring II turning Road 1 East	1	102/2/1762	1/4/712	3937*
11	Ring II turning Road 1 West	1	102/2/1762	1/5/732	1559*
2	Road 1 link 1	1	1/4/707	1/5/862	3545
22	Road 1 link 1	2	1/5/862	1/4/707	3545
1	Road 1 link 2	1	1/5/862	1/5/5949	5087
21	Road 1 link 2	2	1/5/5949	1/5/862	5087
8	Road 1 turning Ring I North	1	1/4/705	101/3/379	2622*
7	Road 1 turning Ring I South	1	1/4/709	101/2/727	3880*
10	Road 1 turning Ring II South	1	1/4/712	102/2/1762	4465*
12	Road 1 turning Ring II South	1	1/5/732	102/2/1762	2714*
15	Road 51 link 1	1	51/1/1913	51/2/3087	5516
15	Road 51 link 1	2	51/2/3087	51/1/1913	5516
16	Road 51 link 2	1	51/2/3087	51/5/1700	5671
16	Road 51 link 2	2	51/5/1700	51/2/3087	5671
20	Road 51 link 12	1	51/2/1013	51/4/2306	4406
20	Road 51 link 12	2	51/4/2306	51/2/1013	4406
6	Road 51 link 3	1	51/5/1700	51/6/2424	3501
26	Road 51 link 3	2	51/6/2424	51/5/1700	3501
30	Road 51 link 4	1	51/4/2306	51/7/2464	11633
30	Road 51 link 4	2	51/7/2464	51/4/2306	11633
17	Road 110	1	110/1/1816	110/3/412	3556
29	Road 110	2	110/3/412	110/1/1816	3556
13	Kalevalantie	1			925*
27	Kalevalantie	2			925*
18	Kokinkylantie	1			1588*
28	Kokinkylantie	2			1588*
14	Kuitinmäentie - Martinkyläntie	1			3488*
14	Kuitinmäentie - Martinkyläntie	2			3488*
19	Röyläntie	1	11365/1/619	11365/1/6213	5594
19	Röyläntie	2	11365/1/6213	11365/1/619	5594

*Shape file link length; other lengths from road register

2.3 Data

2.3.1 FMD pilot data

FMD pilot data were collected for quality assessment on the links given in Appendix A. Pilot data were collected during May 14–31, 2012, except for links on ramps and Röyläntie where data were valid from May 23.

Pilot data consisted of

- Individual FMD travel time measurements
- Individual FMD observations
- FMD medians
- Corresponding quality metrics.

2.3.2 Reference data

Reference data were collected with the current FTA travel time camera system or VTT travel time cameras. Correspondence of the links of both systems to FMD links is presented in Appendix A. The validation results of the VTT camera system are shown in Appendix B.

The FTA travel time camera system was used as reference data for links on Ring road I, Ring road II, Road 1 and Road 51. Individual travel time observations and median travel times were used from these pilot links. Reference data were from the same period as FMD pilot data collected 24 hours per day. Pilot links on Road 51 and Ring II did not match FTA camera travel time links, and for these links reference travel times were estimated linearly based on the proportion of free flow travel time on partial links (Appendix A).

The VTT travel time camera system consists of two high class Tappile Vega 2H licence plate cameras and software developed at VTT that automatically produces travel time observations. This system was used to measure reference data for Kalevalantie, Kokinkyläntie, Kuitinmäentie-Martinkyläntie, Turuntie-Pitäjänmäentie and Röyläntie. The dates on which reference data were collected are listed in Table 2. The weather was clear on all these dates and the cameras were functioning well. Data collection lasted one day per link per direction, starting around 6:30 a.m. and lasting approximately 11–12 hours. Only one direction was monitored per time. Monitoring covered one or two lanes per direction. This corresponded to all lanes except for Kalevalantie eastbound, where only the two lanes meeting Ring I East (North) were included. Cameras were located at each end of the FMD links.

Table 2. Monitored days with VTT camera system.

Link	Direction 1	Direction 2
Road 110	May 14, 2012	May 15, 2012
Kalevalantie	May 22, 2012	May 23, 2012
Kokinkyläntie	May 24, 2012	May 25, 2012
Kuitinmäentie/Martinkyläntie	May 16, 2012	May 21, 2012
Röyläntie	May 28, 2012	May 30, 2012

The number of detected vehicles at each camera point and the sample size of matched travel time observations are presented in Table 3. The weather was sunny during most of the pilot period. Times at which the sun reflected directly against a camera or a licence plate observations were few, but this is a common problem to all cameras so the data were considered valid.

Table 3. Number of observed vehicles at each camera point and sample size of matched travel time observations.

Link	Direction	Camera 1	Camera 2	Travel time observations
Road 110	West	5868	3163	497
	East	7524	4478	603
Kalevalantie	West	7638	6263	3747
	East	6606	5457	3167
Kokinkyläntie	South	1764	2203	770
	North	1719	1909	751
Kuitinmäentie- Martinkyläntie	West	5863	3244	708
	East	2187	3978	253
Röyläntie	South	975	1847	600
	North	3161	885	513

2.4 Indicators and analyses

The results were analysed for FMD quality and usability. In addition, the principles set for FMD were assessed.

The following indicators were calculated for the FMD quality analysis:

- Median travel time for 5-minute periods
- Number of observations per 5-minute period, for a 24 hour period and 7–21 hours
- Standard deviation of observations, in daytime traffic (10–14 hours)
- Deviation in mean travel time (difference between FMD median travel time and the median in reference data).

Data quality analysis included

- Scatter plots of medians and individual observations
- Comparisons of sample sizes
- Temporal coverage (proportion of time with median)
- Variation
- Error distribution (deviation in mean and median values, cumulative error curves)
- Confidence intervals
- Performance on ramps
- Performance in a snowstorm.

For the ad hoc service, data analysis included scatter plots of individual observations and comparisons of sample sizes between ad hoc data and static link data.

The usability study for the FMD system covered the user interface, user interaction with the system, and the suitability and usefulness of the system for user tasks. The usability of the user interface and suggestions on how to improve it are reported in a separate usability evaluation report (Penttinen et al. 2012). It includes the overall analysis of the system and detailed analysis of various functions, listing of the most critical issues, and a generic proposal for potential improvements and their priority.

The usability of FMD itself as a source of information was evaluated after four weeks of online piloting at the traffic management centre (TMC) of FTA. TMC manager Mika Jaatinen was interviewed after this trial period.

Some principles were also verified. This included the calculation method for the median and the performance of the quality indicator. In addition, the need to filter out observations from a parallel road or by multiple cell phones in a car or bus were assessed. Lastly, the required sample size was determined.

3. Results

3.1 Performance of FMD on static links

3.1.1 Correspondence of medians

The correspondence of 5-minute median travel times of FMD and the reference systems was studied by making scatter plots for all links (Appendix C). Plots were made for Tuesday 16 May, Wednesday 22 May and Thursday 31 May, 2012 for all links with FTA reference data. For links where reference data were measured with the VTT camera system, a plot was made for the measurement day.

Based on the plots the following observations were made:

1. FMD Median value on correct level (same as reference)
    - Road 51 link 12 East (16.5. and 31.5.)
    - Kokinkyläntie South and North
2. Strong variation in FMD median value, median on correct level
    - Ring II North and South
    - Road 1 link 2 West (22.5. and 31.5.)
    - Road 51 link 1 West and East
    - Road 51 link 2 West (22.5. and 31.5.) and East
    - Road 51 link 3 East
    - Road 51 link 4 West (22.5. and 31.5.)
3. FMD Free flow travel time on correct level, too short travel time for congestion
    - Ring I link 2 North (16.5.)
    - Road 1 link 1 West
    - Road 51 link 12 West (all days) and East (22.5.)
    - Kalevalantie East and West
4. Strong variation in FMD median value, median corresponded to too short travel time (even free-flow travel time) in congested conditions
    - Ring I link 1 North (16.5.)
    - Road 1 link 2 East
    - Road 51 link 2 West (16.5.)
    - Road 51 link 3 West

- Road 51 link 4 West (16.5.)

5. Strong variation in the FMD median value, the median corresponded to too short a travel time in free-flow conditions (and congested conditions)
   - Ring I link 1 North (22.5. and 31.5.)
   - Ring I link 2 North (22.5. and 31.5.)
   - Road 1 link 1 East
   - Road 1 link 2 West (16.5.)
   - Road 51 link 4 East
   - Road 110 West and East
   - Kuitinmäentie-Martinkyläntie West and East
6. Strong variation in the FMD median value corresponded to too long a travel time in free-flow conditions
   - Röyläntie North.

To summarize the observations: Strong fluctuations in median value were observed for most links (categories 2 and 4–6). For some links (category 1 and 2) the medians reflected the traffic situation well. However, there were links where the median value was clearly on a lower level (even down to free-flow travel time) in congested conditions than in the reference data (categories 3–5). For some links median value was clearly on a lower level than in the reference data (also) for free-flow conditions.

3.1.2 Correspondence of observations

The correspondence of individual observations of FMD with reference data was studied by making scatter plots (Appendix D) in a similar way as for medians in the previous chapter. Links for which the median travel time was estimated based on shorter links (Ring II and Road 51) were not included, as there were no corresponding observations as reference.

Based on the plots, the following observations were made:

1. Satisfactory
   - Road 1 link 2 West (22.5. and 31.5.) and East
2. Observations missing from the most congested conditions, otherwise satisfactory
   - Road 1 link 2 West (16.5.)
3. Observations on correct level, outlier[1] observations existed only in the reference data
   - Road 1 link 1 West and East
   - Ring I link 1 North (22.5. and 31.5.)

[1] An outlier is an observation of a vehicle that had stopped on the way or did a small detour but returned back to the link resulting in longer travel times than other vehicles at that time.

    - Ring I link 2 North (22.5. and 31.5.)
    - Kokinkyläntie North and South
4. Observations on correct level, outlier observations existed only in the reference data, observations missing from the most congested conditions
    - Ring I link 1 North (16.5.)
    - Ring I link 2 North (16.5.)
    - Kalevalantie West and East
5. Outlier observations only in FMD
    - Röyläntie North
6. Too short travel times in FMD
    - Road 110 East and West
    - Kuitinmäentie-Martinkyläntie West and East

To summarize the observations: For most links the level of observations corresponded well to reference data. However, there were some links where observations represented too short travel times (category 6). The absence of observations of most congested conditions was observed in many plots (categories 2 and 4). There were also many links where the reference data included many outliers (single observations that did not match the free- flow travel time), but these were missing from the FMD observations (categories 3 and 4). There was only one link (category 6) where the situation was the reverse.

3.1.3 Number of observations

The average number of observations was calculated both for the full 24 hour period but also for the busier period of 7–21 hours. For all links, the 24 hour average varied between 0.8 and 4.5 observations per 5 minutes except for Road 51 link 12 where it was 15.9–19.3 (Table 4, more detailed results in Appendix E). That link was based on both 2G location area updates and 2G–2G handovers. The Road 51 link 4 result was based on location area updates only, but the result did not result in a sufficiently large number of observations. In the reference data, the number of observations per 5-minute periods varied between 6.3 and 30.1, being significantly higher. Nevertheless, both datasets represent only a fraction of the vehicles, as average 5-minute traffic volume exceeded 100 on all main road links except Road 51 link 4 where it was 53–56 vehicles per 5 minutes over 24 hours.

Table 4. Average number of observations used in calculation of the 5-minute median travel time for FMD and reference system (Ref.) and loop detector based 5-minute traffic volume (LAM) when available. Links based on location area update are in bold. Only 5-minute periods with at least one observation were included in the calculation of averages.

NSN Link	Link	24 h average			7–21 average		
		FMD	Ref.	LAM	FMD	Ref.	LAM
242	Ring I link 1 South	2.1	-	127	2.7	-	183
41	Ring I link 1 North	1.9	9.5	110	2.4	13.5	163
232	Ring I link 2 South	4.5	-	144	6.1	-	207
31	Ring I link 2 North	3.3	25.3	142	4.5	36.0	211
252	Ring II South	2.1	38.1	71/110	2.6	52.7	106/164
51	Ring II North	1.6	28.8	95/109	1.9	39.2	144/166
222	Road 1 link 1 East	2.6	24.2	136	3.4	32.7	198
21	Road 1 link 1 West	4.5	10.7	138	6.3	15.4	207
212	Road 1 link 2 East	1.8	15.3	119	2.2	19.2	170
11	Road 1 link 2 West	2.3	7.2	117	2.9	9.9	180
152	Road 51 link 1 East	3.6	21.2	129	4.9	31.0	194
151	Road 51 link 1 West	3.1	30.1	126	4.2	44.5	193
162	Road 51 link 2 East	2.3	9.5	-	3.0	14.0	-
161	Road 51 link 2 West	2.9	11.7	-	3.7	17.4	-
202	**Road 51 link 12 East**	**15.9**	**12.4**	129	**22.4**	**18.3**	194
201	**Road 51 link 12 West**	**19.3**	**19.4**	126	**28.1**	**28.3**	193
262	Road 51 link 3 Dir East	2.3	14.0	-	3.0	20.9	-
61	Road 51 link 3 Dir West	1.4	14.8	-	1.5	22.2	-
302	**Road 51 link 4 East**	**2.1**	**7.9**	**56**	**2.5**	**11.3**	**82**
301	**Road 51 link 4 West**	**3.7**	**6.3**	**53**	**4.9**	**8.8**	**82**
171	Road 110 East	1.3	-	-	1.6	4.6	-
292	Road 110 West	1.7	-	-	2.0	4.3	-
272	Kalevalantie East	0.8	-	-	1.1	23.4	-
131	Kalevalantie West	1.0	-	-	1.2	27.9	-
181	Kokinkyläntie East	0.9	-	-	1.1	5.6	-
182	Kokinkyläntie West	0.8	-	-	1.0	5.7	-
142	Kuitinmäentie-Martinkyläntie West	1.1	-	-	1.3	5.2	-
141	Kuitinmäentie-Martinkyläntie East	1.0	-	-	1.1	2.3	-
191	Röyläntie North	1.0	4.1	-	1.1	4.1	-

The 7–21 average was both relatively and absolutely even higher for the reference data than for FMD compared to the 24 hour average (Table 4, more detailed results in Appendix E). For all links the 7–21 hour average varied between 1.0 and 6.3 observations per 5 minutes, except for the location area update based Road 51 link 12 where it was 22.4–28.1. The number of observations per 5 minute periods varied between 2.3 and 44.5 in the reference data, being at least 8.8 on main roads (Ring roads, Road 1 and 51).

On Road 51 link 12, the proportion of medians based on at least 10 observations was 77% in westbound traffic and 71% in eastbound traffic during hours 5–

24. Corresponding proportions were 77% and 64% in the reference data. On other links, the proportion with such a high number of observations was very small in FMD.

Temporal coverage, i.e. the proportion of time when the 5-minute median was available, was calculated (Table 5, more detailed results in Appendix E). For FMD, the 24 hour proportion varied between 33% and 89% on main roads, and between 5% and 35% on smaller roads. For the corresponding reference data, the median was available 74–97% of the time over 24 hours on main roads. The only exception was Road 51 link 4 in the Eastbound direction, where this proportion was only 51% probably due to problems in data transfer. This was the only link where FMD exceeded the reference system in the 24 hour average.

Table 5. Proportion of time with median (%).

NSN Link	Link	24 h average		7–21 average	
		FMD	Reference	FMD	Reference
242	Ring I link 1 South	56	-	81	-
41	Ring I link 1 North	53	78	79	89
232	Ring I link 2 South	69	-	95	-
31	Ring I link 2 North	68	84	94	91
252	Ring II South	57	95	83	96
51	Ring II North	44	97	66	100
222	Road 1 link 1 East	66	87	92	95
21	Road 1 link 1 West	69	86	96	94
212	Road 1 link 2 East	54	85	79	93
11	Road 1 link 2 West	56	82	83	87
152	Road 51 link 1 East	64	88	93	90
151	Road 51 link 1 West	65	93	93	95
162	Road 51 link 2 East	60	84	88	99
161	Road 51 link 2 West	57	74	83	88
202	**Road 51 link 12 East**	**87**	**87**	**100**	**98**
201	**Road 51 link 12 West**	**89**	**94**	**99**	**100**
262	Road 51 link 3 East	59	84	87	99
61	Road 51 link 3 West	33	74	50	88
302	**Road 51 link 4 East**	**54**	**79**	**72**	**87**
301	**Road 51 link 4 West**	**69**	**51**	**91**	**51**
171	Road 110 East	35	-	53	95
292	Road 110 West	33	-	50	86
272	Kalevalantie East	7	-	11	100
131	Kalevalantie West	8	-	12	100
182	Kokinkyläntie West	5	-	7	99
181	Kokinkyläntie East	7	-	11	100
142	Kuitinmäentie-Martinkyläntie West	16	-	25	96
141	Kuitinmäentie-Martinkyläntie East	9	-	14	79
191	Röyläntie North	14	-	21	90

In the 7–21 hours traffic, the FMD median was available 50–100% of the time on main roads and 7–53% on smaller roads (Table 5, more detailed results in Appendix E). Corresponding proportions were 87–100% for the main roads (plus 51% for Road 51 link 4 West) and 79–100% for the smaller roads. FMD coverage was greater than the reference for five of the main road links; on the smaller roads it was significantly poorer.

3.1.4 Deviation in mean and median values in congested conditions

Deviation in mean and median (absolute) values (difference between FMD median travel time and the median in the reference data) in congested conditions was calculated per kilometre for all links. Traffic was considered congested if travel speed was less than 90% of free flow speed. Only time periods 7–9 hours and 15–18 hours were included as there was no real congestion outside of them, and thus outlier peaks of periods with little traffic could be excluded from influencing the results.

The results are presented for the links with recurrent congestion in Table 6. It should be noted that for Road 51 links the reference medians were estimated based on shorter, non-corresponding links. For Ring I, Road 1 link 1 and Road 51, the mean deviation from reference data was significantly higher than the median deviation, indicating some large deviations from the reference, and especially the mean deviation was high. For Road 110 and Road 1 link 2, median values were higher than mean values. The median deviation in congested conditions was less than 10 seconds per kilometre for Ring II, Road 1 link 2 West, Road 51 links 1, 12 and 3 East, and Road 51 link 4.

Table 6. Mean and median deviation from reference data (seconds) of travel time per kilometre in congested conditions (travel speed median in reference data less than 90% of free-flow speed during time periods 7–9 and 15–18).

NSN link	Link	Mean of deviation	Median of deviation	N	Free-flow travel time
41	Ring I link 1 North	-81	-47	1695	272
31	Ring I link 2 North	-87	-48	1254	185
51	Ring II North	-8	1	2954	126*
252	Ring II South	4	5	2964	126*
21	Road 1 link 1 West	-35	-19	1373	131
222	Road 1 link 1 East	-41	-21	25	131
11	Road 1 link 2 West	3	5	1092	190
212	Road 1 link 2 East	-30	-32	528	190
152	Road 51 link 1 East	-16	-9	129	248*
162	Road 51 link 2 East	-57	-27	128	246*
161	Road 51 link 2 West	-64	-39	685	244*
202	Road 51 link 12 East	-80	-1	174	230*
201	Road 51 link 12 West	-32	-14	208	230*
262	Road 51 link 3 East	-34	-4	103	140*
61	Road 51 link 3 West	-125	-26	639	134*
302	Road 51 link 4 East	-17	-7	1443	473*
301	Road 51 link 4 West	-7	-4	2036	467*
171	Road 110 East	-52	-70	151	276**
292	Road 110 West	-29	-46	140	283**

* Free-flow travel time calculated combining FTA statistics

** Free-flow travel time estimated visually from reference data

3.1.5 Standard deviation in daytime traffic

The standard deviation of all observations and medians was calculated for daytime traffic (10-14 hours) over all days. However, for links measured by the VTT camera system the standard deviation covered only one day.

On the main roads (Ring I and Road 1), the standard deviation of single travel time observations was significantly higher in the reference data than in FMD (Table 7). On smaller roads, the situation was vice versa. On these roads also the standard deviations of the median were higher in the reference data than in FMD except for Road 1 link 1 East. The same applied to the standard deviation of the median values on smaller roads, except for Kokinkyläntie North and Kuitinmäentie-Martinkyläntie East.

Table 7. Standard deviation of single travel time observations and single median travel time values in daytime traffic (10–14 hours).

NSN link	Link	FMD		Reference	
		Observations	Medians	Observations	Medians
31	Ring I link 2 North	44.3	20.5	299.3	93.6
41	Ring I link 1 North	94.4	57.6	286.0	135.0
51	Ring II North	84.2	69.7	-	4.9
252	Ring II South	54.3	48.8	-	257.8
222	Road 1 link 1 East	77.3	32.4	307.1	3.8
21	Road 1 link 1 West	39.6	23.5	328.1	79.1
212	Road 1 link 2 East	37.8	34.5	78.0	57.8
11	Road 1 link 2 West	39.5	30.6	199.7	143.6
151	Road 51 link 1 West	44.2	27.5	-	3.4
152	Road 51 link 1 East	38.0	31.7	-	16.0
161	Road 51 link 2 West	91.4	68.8	-	52.0
162	Road 51 link 2 East	76.8	37.9	-	10.8
201	Road 51 link 12 West	44.8	11.4	-	156.5
202	Road 51 link 12 East	54.0	14.9	-	27.2
262	Road 51 link 3 East	64.7	36.4	-	4.7
61	Road 51 link 3 West	26.9	27.1	-	4.1
302	Road 51 link 4 East	118.9	95.9	-	26.2
301	Road 51 link 4 West	118.0	77.9	-	114.4
171	Road 110 East	313.8	289.0	9.4	59.3
292	Road 110 West	379.5	203.4	7.5	85.4
272	Kalevalantie East	24.3	23.6	10.8	5.8
131	Kalevalantie West	19.0	19.3	10.0	10.5
181	Kokinkyläntie South	69.7	72.2	9.6	65.3
182	Kokinkyläntie North	34.7	35.1	9.7	83.8
141	Kuitinmäentie-Martinkyläntie East	139.5	117.7	12.6	231.6
142	Kuitinmäentie-Martinkyläntie West	195.4	167.3	10.3	97.1
191	Röyläntie North	701.7	648.5	6.7	31.9

3.1.6 Confidence intervals

A confidence interval represents an estimated range of values which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data. If normal distribution can be assumed, the confidence interval θ is calculated as

$$\theta = \overline{x} \pm z \cdot \frac{s}{\sqrt{n}}$$

Where $\overline{x}$ is the mean value, z is the upper (1 - C)/2 critical value for the standard normal distribution (i.e. 1.96 for 95% confidence level), s is the estimated standard deviation (standard error), and n is the number of samples.

Four well-performing links (satisfactory performance in congestion) were selected for the study of confidence intervals: Ring I link 2 North, Ring II North, Road 1 link 2 West and Road 51 link 12 East. Confidence intervals were calculated over all median values in the given time frames that had corresponding values in both data with a 95% confidence level.

The confidence intervals of any of these links did not overlap in FMD and reference data when calculated for 5–24 hours data (Table 8). For the peak periods (7–9 and 15–18 hours) data, the only link where the intervals overlapped was Road 51 link 12 East. However, on that link the confidence interval of FMD (227–249 seconds) was much wider than the confidence interval of the reference data (238–240 seconds).

Table 8. Confidence intervals calculated over all median values in the given time frames that had corresponding values in both data.

	Monday to Friday 7–9 and 15–18 hours		**All days 5–24 hours**	
	FMD	**Reference**	**FMD**	**Reference**
Ring I link 2 North	206–213	158–160	196–201	156–157
Ring II North	184–191	191–197	146–149	179–182
Road 1 link 2 West	214–223	228–234	193–196	190–192
Road 51 link 12 East	227–249	238–240	216–223	224–224

3.1.7 Cumulative error curves

Cumulative curves of the absolute value of relative error (deviation from reference data) were determined for the same best performing links selected for the confidence interval study: Ring I link 2 North, Ring II North, Road 1 link 2 West and Road 51 link 12 East. In addition, FMD-FTA median plots were made for all links. All graphs were made both for peak hours (Monday to Friday 7–9 and 15–18 hours) and for 5–24 hours traffic on all days (Appendix F). The missing median value in FMD was regarded as a 100% deviation.

Median plots (Appendix F) show that on Ring I link 2 North and Road 51 link 12 East, congested conditions were detected most poorly by FMD. On Road 1 link 2 West, some median values corresponding to congested conditions were approximately correct in FMD but not all. On Ring II North, the deviation seemed random or at least not dependent on congestion level.

Other links than Road 51 link 12 East suffered from having a significant amount of time with no median value available (seen as a vertical line at the 100% level on the cumulative curves of Appendix F). On Road 1 link 2 West, the proportion of missing medians was rather small during peak hours but significant for 5–24 hours traffic.

The tables below show indicators describing cumulative error curves (at most 10% error means errors smaller than or equal to ±10%). Based on these, Ring II North performed worse than the others, while Road 51 link 12 East and Road 1 link 2 West were the best ones during peak hours (Table 9). In full 5–24 hours traffic, Road 51 link 12 East was clearly the best (Table 10).

Table 9. Indicators describing the cumulative error curve during peak hour traffic (Monday to Friday 7–9 and 15–18), in parentheses the same proportions excluding the effect of missing median values in FMD.

	Ring I link 2 North	**Ring II North**	**Road 1 link 2 West**	**Road 51 link 12 East**
% of medians with at most 10% error	30% (42%)	14% (20%)	46% (51%)	43% (43%)
% of medians with at most 20% error	56% (77%)	31% (44%)	68% (76%)	86% (86%)
% of medians with at most 40% error	67% (92%)	56% (80%)	82% (92%)	95% (95%)
Maximum absolute value of error in the best 95% of medians	100% (53%)	100% (79%)	100% (50%)	40% (37%)

Table 10. Indicators describing the cumulative error curve in 5–24 hours traffic (all days), in parentheses the same proportions excluding the effect of missing median values in FMD.

	Ring I link 2 North	**Ring II North**	**Road 1 link 2 West**	**Road 51 link 12 East**
% of medians with at most 10% error	30% (40%)	8% (17%)	35% (56%)	61% (62%)
% of medians with at most 20% error	58% (78%)	19% (40%)	52% (83%)	90% (92%)
% of medians with at most 40% error	70% (93%)	36% (78%)	59% (95%)	96% (98%)
Maximum absolute value of error in the best 95% of medians	100% (48%)	100% (132%)	100% (40%)	33% (24%)

3.1.8 Performance on ramps

There were four links in the pilot area representing traffic merging from one main road to another via level-separated intersections. The lengths of ramp links were determined to match the existing FTA camera system. However, links that covered only a short section before or after the ramp were not suitable for the FMD system, as there should have been at least one but preferably a few cell handover zones on both main roads within the link to be able to measure the movement of vehicles (mobile phones) merging from one main road to another. Even a combination of observations from either of the main roads only would not be representative, as merging delay would be excluded. In an urban environment, 1.0–2.0 kilometres in both directions from the ramp would be a good length for turning links.

3.1.9 Performance in snowstorms

The performance of FMD during snowstorms was also studied. Data from two massive snowstorms (February 28 and March 19, 2012) was plotted for links Ring I link 2 North and Road 1 link 2 West.

On February 28, there were clearly less observations in the reference data around noon and during the evening traffic peak hour than normally (Figure 4). However, FMD produced observations as in normal weather conditions. On March 19 there was a total absence of observations in the reference data in the morning on Road 1 (Figure 5), after noon and in the evening on Ring I (Figure 6), while the FMD system produced observations normally.

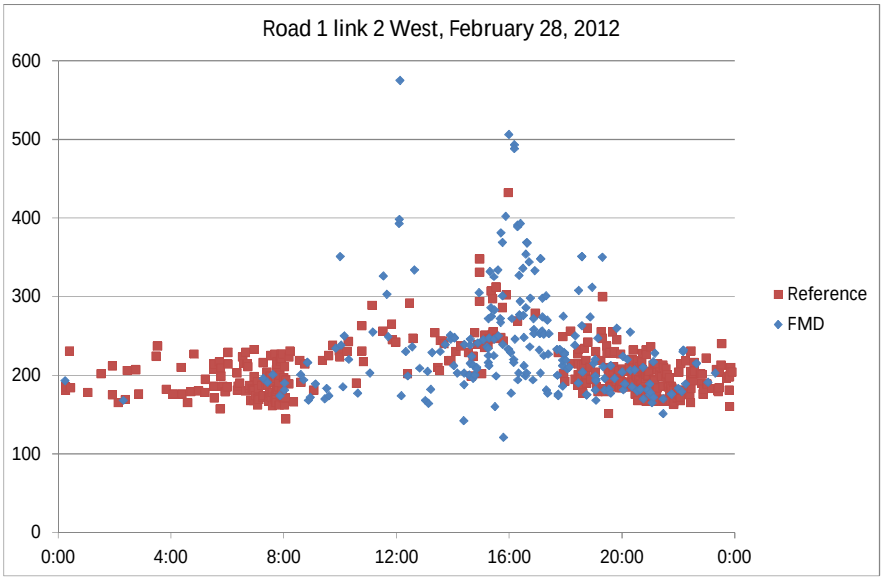


Figure 4. Individual travel time observations (seconds) of FMD and the reference system on Road 1 link 2 West on February 28, 2012 during heavy snowfall.

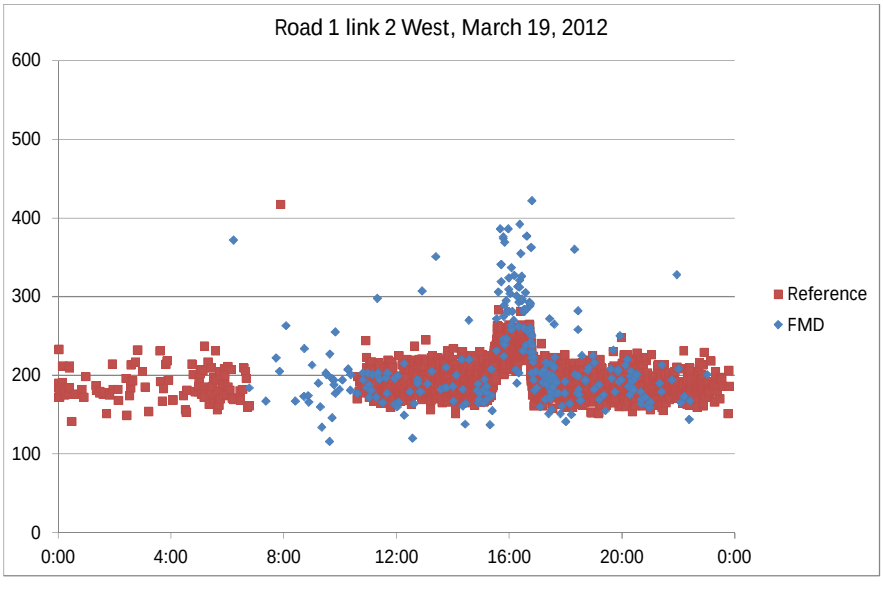


Figure 5. Individual travel time observations (seconds) of FMD and the reference system on Road 1 link 2 West on March 19, 2012 during heavy snowfall.

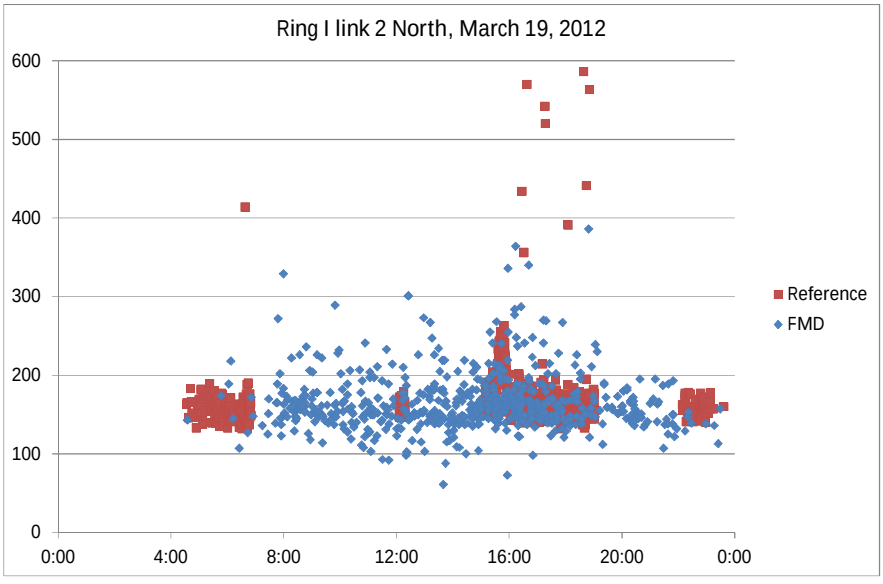


Figure 6. Individual travel time observations (seconds) of FMD and the reference system on Ring I link 2 North on March 19, 2012 during heavy snowfall.

3.1.10 Usability

TMC manager Mika Jaatinen was interviewed after the trial period. This chapter summarizes the interview.

It would be optimal to get at least 20 observations per 5-minute period for the calculation of the median travel time for each link. Ten observations is a minimum threshold to get reliable information that can be a base for traffic management decisions. If the median is based on fewer observations, traffic management operations cannot be undertaken due to too much uncertainty in the information. At the moment, FMD produces too few observations for most pilot links.

At night (0–5 hours) there is little traffic, and traffic flow status information is not requested by many. However, between 05:00 a.m. and 24:00 p.m. there is traffic on main roads like Ring I; therefore the traffic flow status is important for that period of time for each day – meaning that FMD should cover that time period almost 100% of time. At night time, there would be no strict minimum limits for the coverage of the FMD in general but it should be available for the most important roads also then. At the moment, FMD observations start to accumulate after 6:00 a.m. – a little earlier on some links – but the data covers well the time period until midnight. Between midnight and 6:00 a.m. there are few observations on all links.

In the capital area, on the main corridors entering the capital area and in other larger city regions, the geographic coverage of FMD at one moment in time should be at least 90% of all links, and 80% elsewhere. During the most important holiday

seasons (Christmas, Midsummer, etc.) FMD should be available and reliable at all times.

Only with sufficient geographical coverage and reliable travel time information is real-time traffic management possible in the capital area. In the future, also the operation of public transport will be part of traffic management. It would be very important and beneficial to get FMD coverage for the whole capital area (including the major street network), later also for the Tampere region. In the capital area there are many special events, like official state visits, that regularly require exceptional traffic management operations such as closing off streets, adjusting traffic light functions etc. FMD could help the operation of the traffic network. In addition to TMC, also police and public transport operators could use it. Police would actually need the information already now when manually operating traffic lights.

The best additional value of FMD could be achieved in the capital area where traffic lights, public transport, variable message signs, etc. provide means to actively manage traffic. Consequently, the benefit to capital area of expanding the system would be substantial.

3.2 Performance of ad hoc service

Ad hoc service was piloted on Road 1 on a 9 km link overlapping static links. Several ad hoc requests were sent during June 21 and 25 from different running meters (location of ad hoc service request). An ad hoc link was determined around the requested point based on calculated handover zones, not field measured ones like in the basic service with static links. Consequently, the preciseness of the ad hoc link length was not as accurate as for the basic service.

In eastbound traffic, the static link travel speeds contained many more outliers than in westbound traffic. Ad hoc travel speeds exceeded the static link travel speeds most of the time. Especially in westbound traffic there were numerous ad hoc travel speed observations that exceeded 200 km/h, which is not realistic.

The number of ad hoc observations was smaller than in the static link data – temporal coverage was not high enough for 5-minute medians in the service. However, there were enough observations to get an overview of the traffic situation over a longer time period.

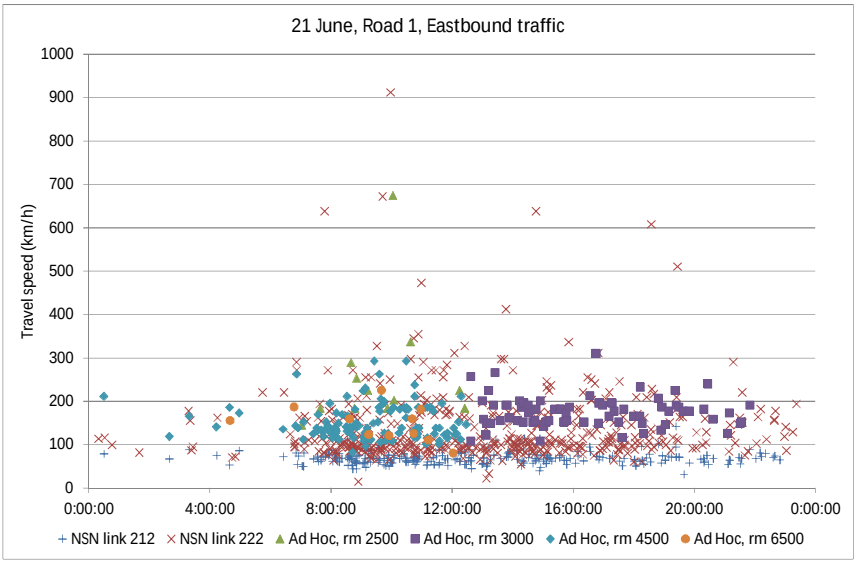


Figure 7. Individual travel speeds calculated from FMD travel time observations on static travel time links and from ad hoc travel times on Road 1, eastbound traffic, June 21.

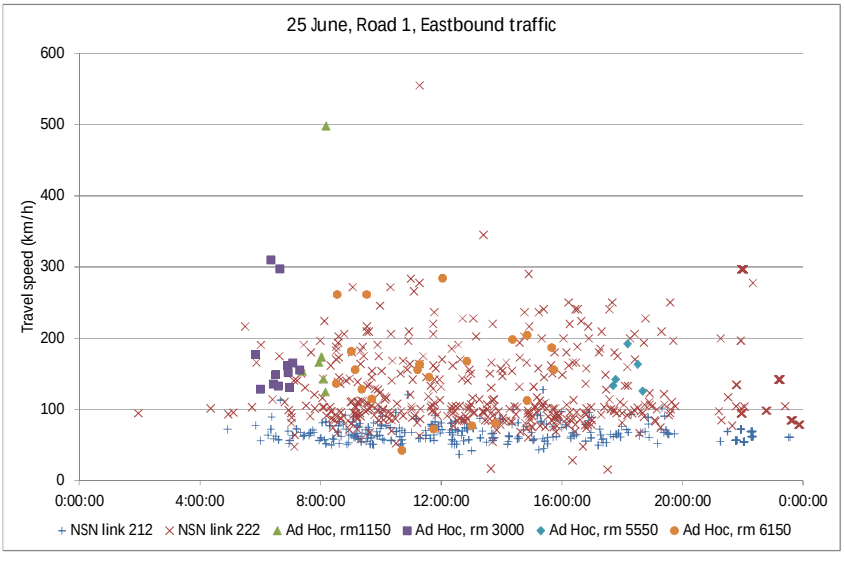


Figure 8. Individual travel speeds calculated from FMD travel time observations on static travel time links and from ad hoc travel times on Road 1, eastbound traffic, June 25.

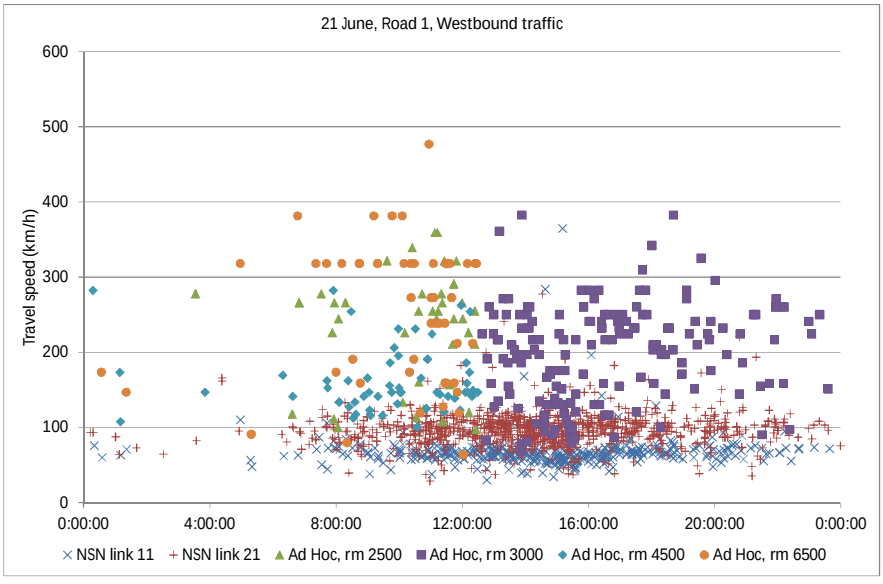


Figure 9. Individual travel speeds calculated from FMD travel time observations on static travel time links and from ad hoc travel times on Road 1, westbound traffic, June 21.

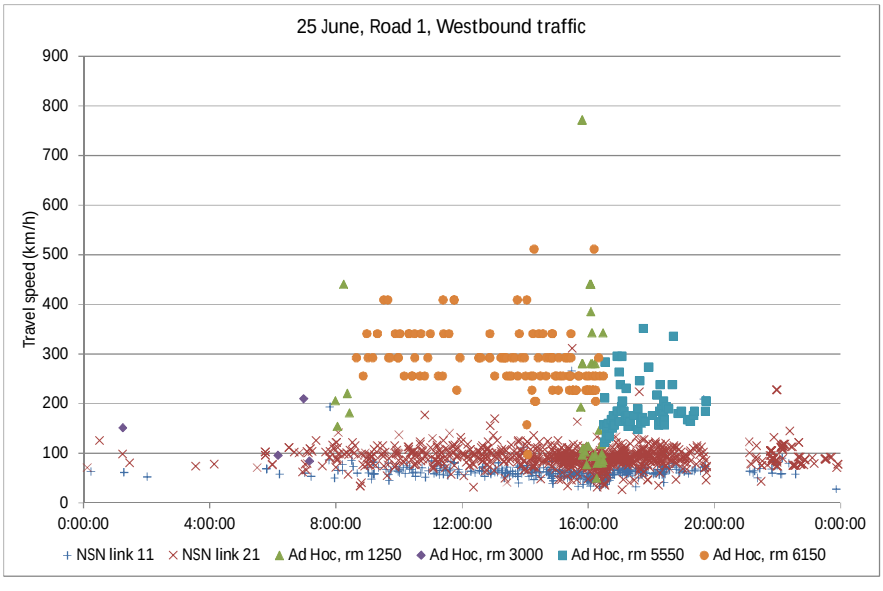


Figure 10. Individual travel speeds calculated from FMD travel time observations on static travel time links and from ad hoc travel times on Road 1, westbound traffic, June 25.

3.3 Verification of principles

3.3.1 Calculation of the median

The use of a quality-weighed median was assessed using westbound traffic data from the Road 1 link between Ring I and Ring II on May 4, 2012 (Figure 11). The quality (OQI) weighted median and regular median were calculated for a 5 minute aggregation period with 1 minute update interval with both methods (Figure 12). The result shows that the quality-weighted median had higher outlier peaks than the regular median and thus worked better.

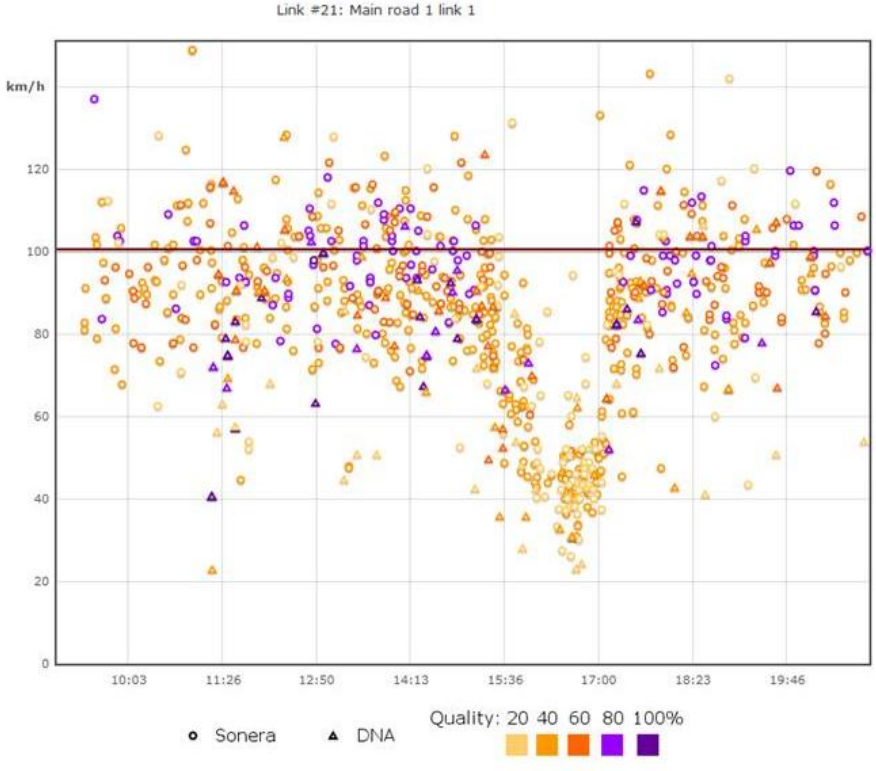


Figure 11. Individual FMD travel time observations by TeliaSonera and DNA on the westbound Road 1 link between Ring I and II, 4.5.2012. The colour code reflects the overall quality of the observation.

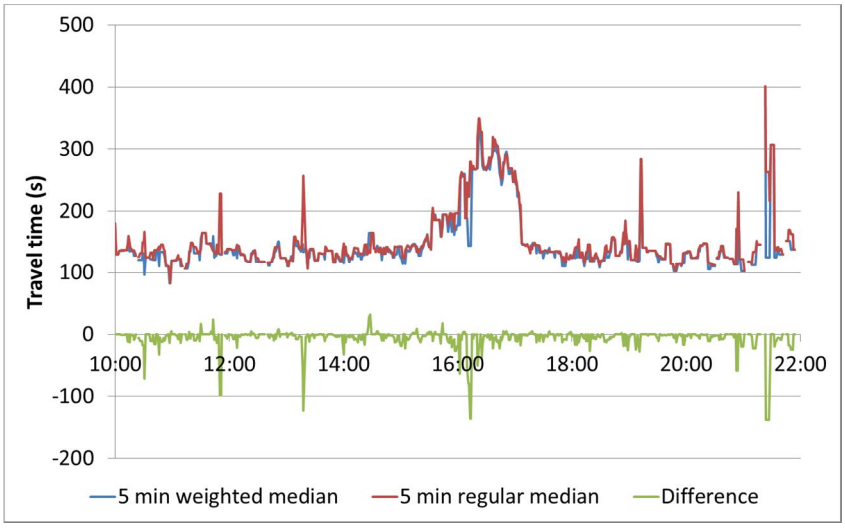


Figure 12. Quality-weighted median and regular median of FMD travel time.

The impact of filtering the lowest quality observations on the quality-weighted median value was assessed (Figure 13). The median of best quality observations only was more stable than the median of all observations. However, as the quality of observations was low during congested periods the filtered median would not be available during those most interesting hours. In addition, filtering had little impact on fluctuation of the median. Consequently, it was better to use all observations in the calculation of the median.

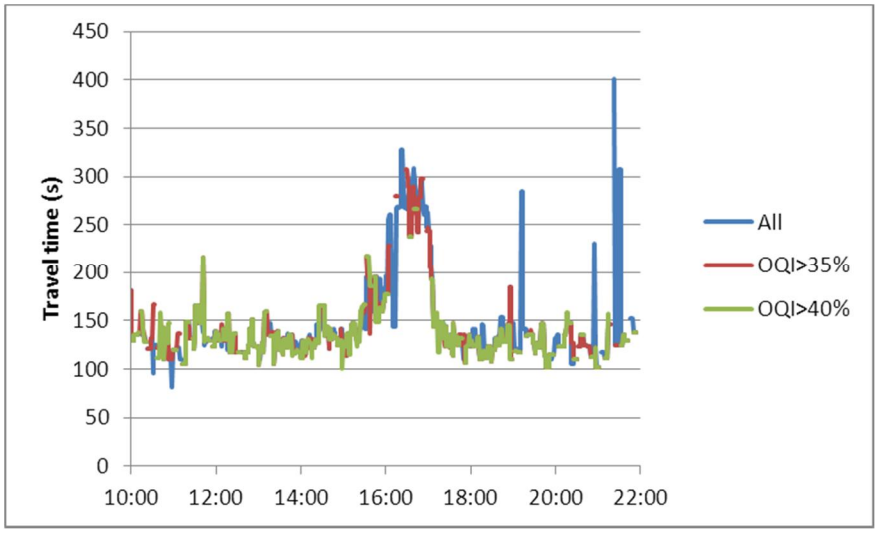


Figure 13. 5-min quality-weighted median of FMD travel time for all observations and when filtering those with OQI less than 35% or 40%

The impact of aggregation period length was studied by calculating medians for 5-minute, 10-minute and 15-minute periods with an update frequency of 1 minute (Figure 14). The result showed that 10-minute and 15-minute medians fluctuated significantly less than the 5-minute median. As the difference between the 10-minute and 15-minute median was relatively small and the 10-minute median reacted faster to changes in traffic situation, it could be considered most appropriate for this data.

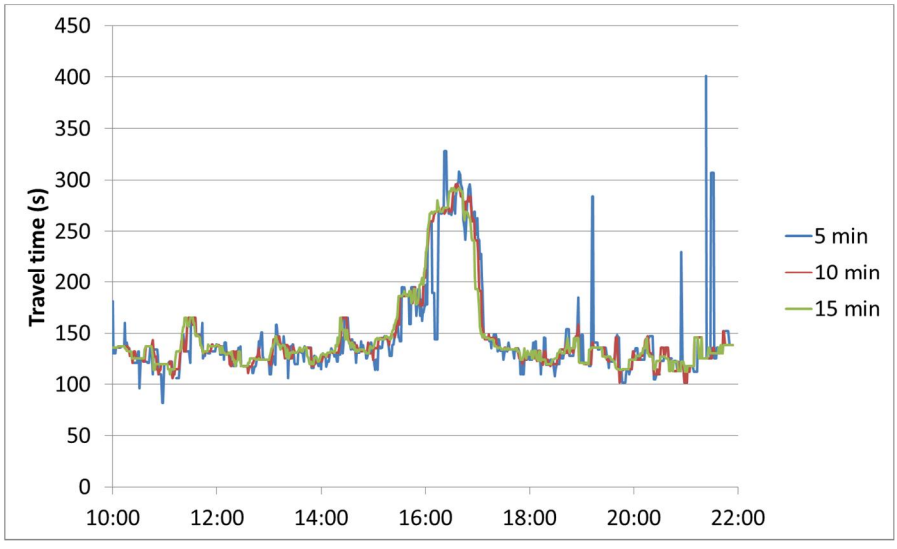


Figure 14. FMD travel time median with different aggregation period lengths.

3.3.2 Quality indicator

The service provider was asked to set a quality indicator value for travel time observations and medians. The ability of this set value to describe the reliability of the observation was studied for four well-performing links which had satisfactory performance during congestion: Ring I link 2 North, Ring II North, Road 1 link 2 West and Road 51 link 12 East.

On Ring I the distribution of quality indicator values was fairly equal (Figure 15). On other roads (Figure 16, Figure 17 and Figure 18), the most common class was 40–60. This is because the travel time link - handover zone relation was not one to one (e.g. some links were not covered 100% because of a lacking handover zone).

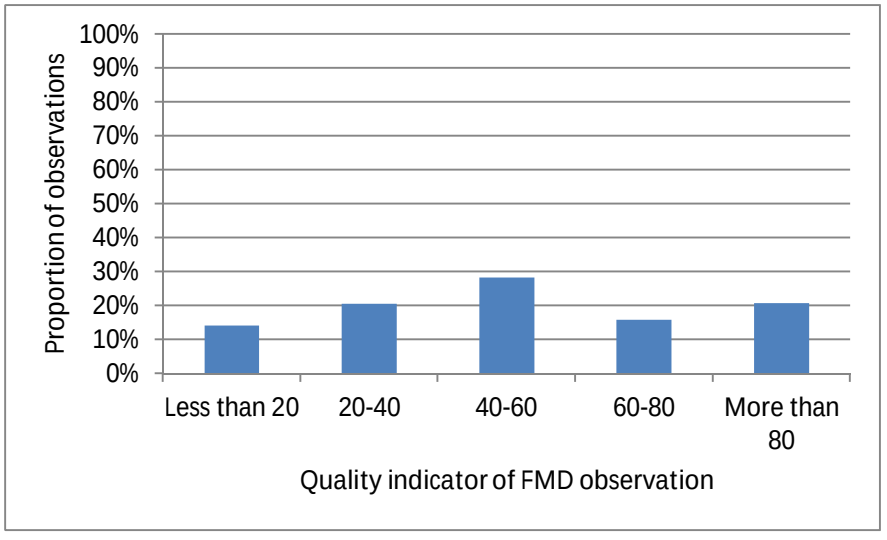


Figure 15. Distribution of quality indicator values of FMD observations on Ring I link 2 North.

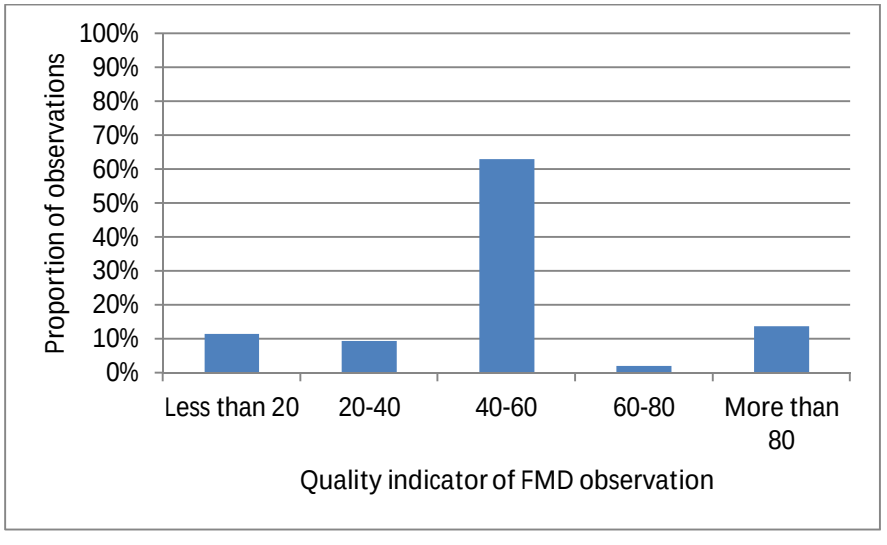


Figure 16. Distribution of quality indicator values of FMD observations on link Ring II East.

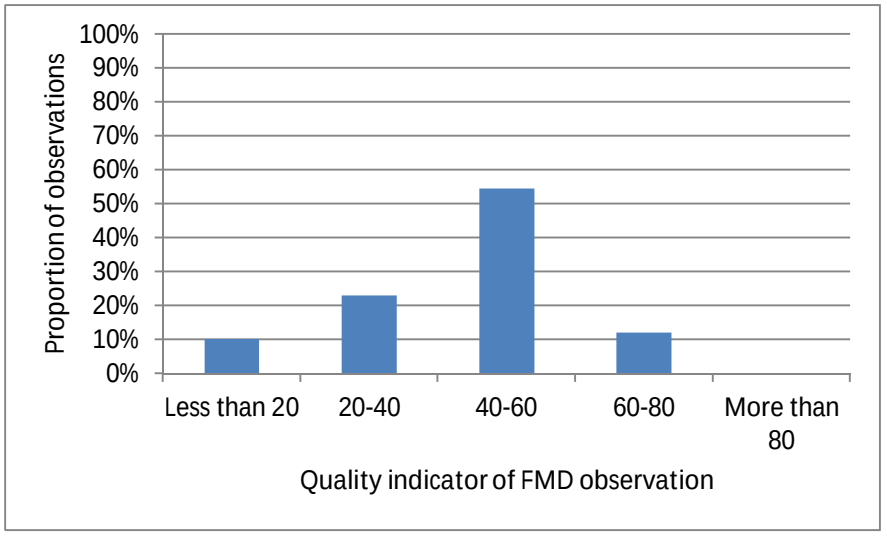


Figure 17. Distribution of quality indicator values of FMD observations on Road 1 link 2 West.

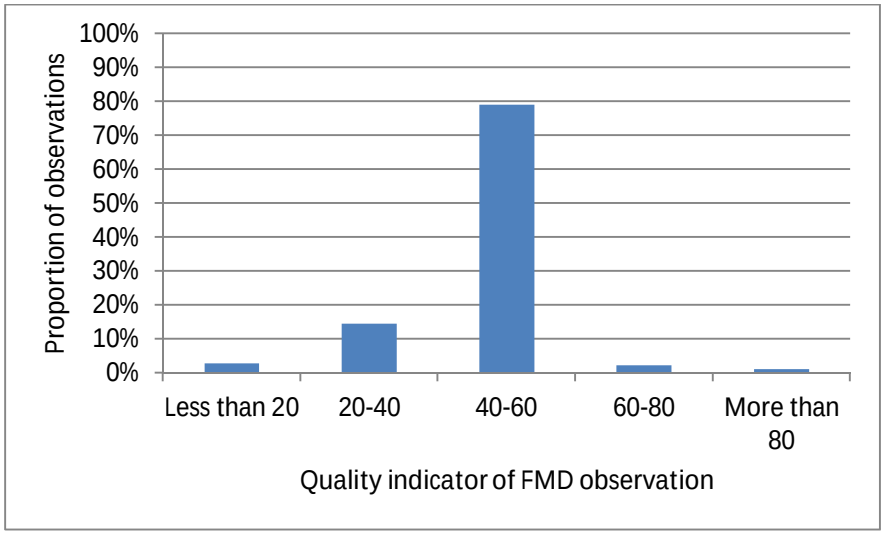


Figure 18. Distribution of quality indicator values of FMD observations on Road 51 link 12 East.

The relative difference of a single observation from the reference data median was plotted with a quality indicator value. Observations with a reference data median value over 600 seconds outside peak hours were excluded. Based on these four

links, the quality indicator seemed to work well in that the greatest differences from the median (deviation from reference data) were related to observations with the lowest quality indicator values (Figure 19–Figure 22). However, relatively large deviations (50–100%) exist also among the best quality observations.

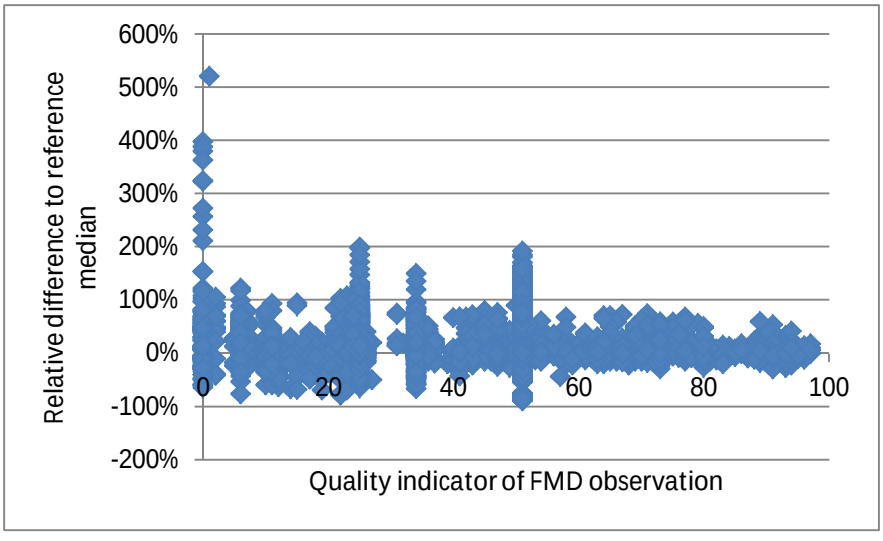


Figure 19. Relative difference of single observations from the reference median as a function of quality indicator value, Road 51 link 12 East.

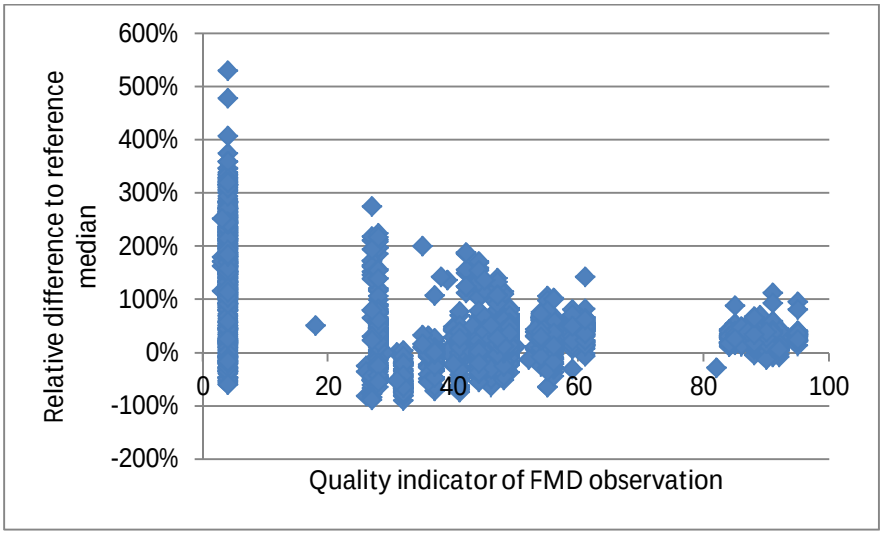


Figure 20. Relative difference of single observations from the reference median as a function of quality indicator value, link Ring II North.

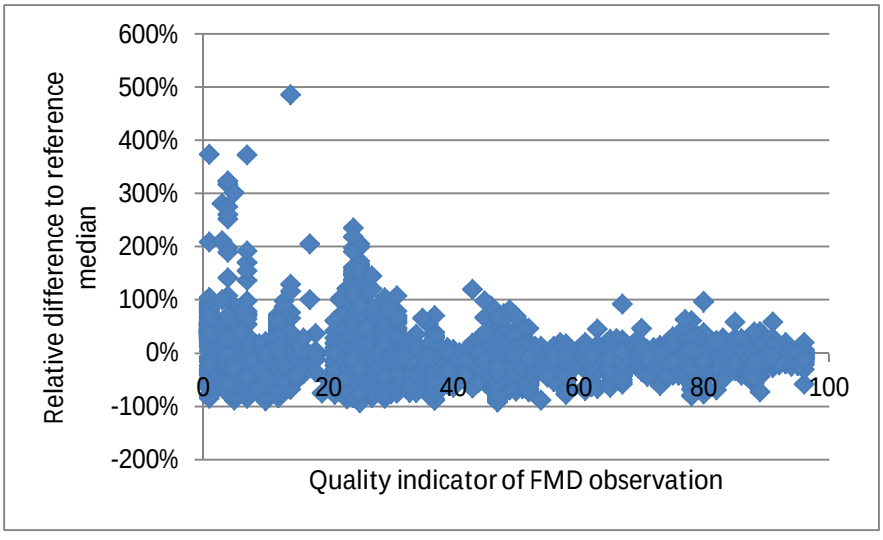


Figure 21. Relative difference of single observations from the reference median as a function of quality indicator value, Ring I link 2 North.

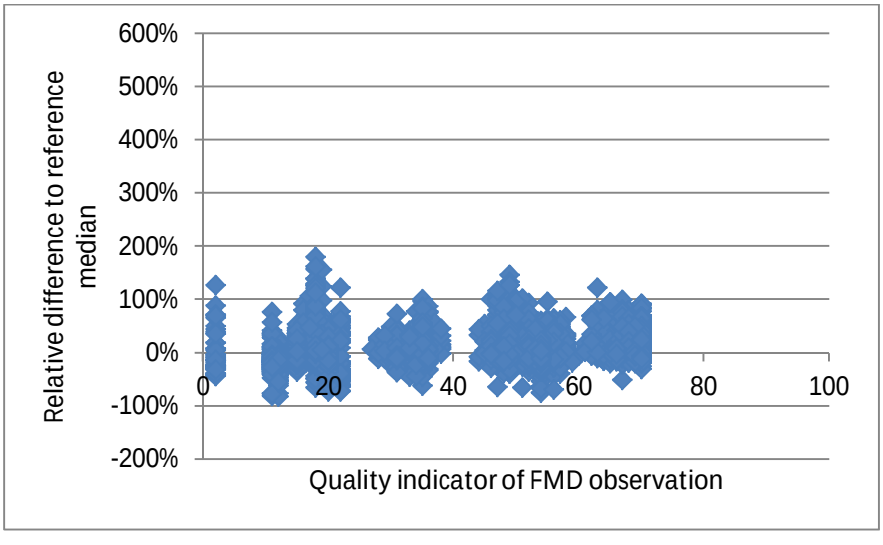


Figure 22. Relative difference of single observations from the reference median as a function of quality indicator value, Road 1 link 2 West.

3.3.3 Parallel roads

A parallel road problem exists when the primary road is located within the same mobile network cell as a secondary road or railway. Secondary road users bias the measurements on the primary road, mainly adding events which should not be registered and which bias the calculated median travel time.

The problem of parallel roads may be solved by utilising intermediate measurements within the travel time link or measurements in its surroundings. However, where the parallel road or railway does not differ in cells within the travel time link or its near surroundings, the only way to distinguish between these two traffic flows is by speed profile. Notably, two parallel roads located in the same cells and with very similar speed profiles cannot be separated.

In this pilot area, link 3 on Road 51 had a parallel road which was also part of the pilot links (Kuitinmäentie-Martinkyläntie). Single FMD observations of the Road 51 link were plotted alongside the reference data for the same day on the parallel road (Figure 23 and Figure 24). However, hardly any FMD observations from Road 51 were on the same travel time level as the reference observations from the parallel road. In addition, none of the other links (Appendix D) showed any indication of observations falling into both categories either. Consequently, it seems that although some roads are located parallel to each other, the piloted system was capable of distinguishing between them.

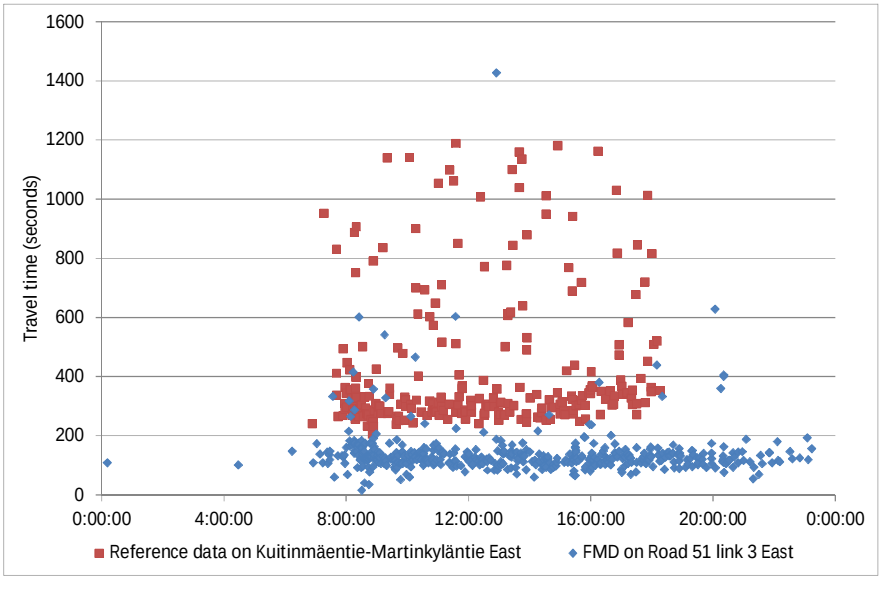


Figure 23. Travel times on Road 51 link 3 East (blue) and its parallel road (red) on May 21, 2012.

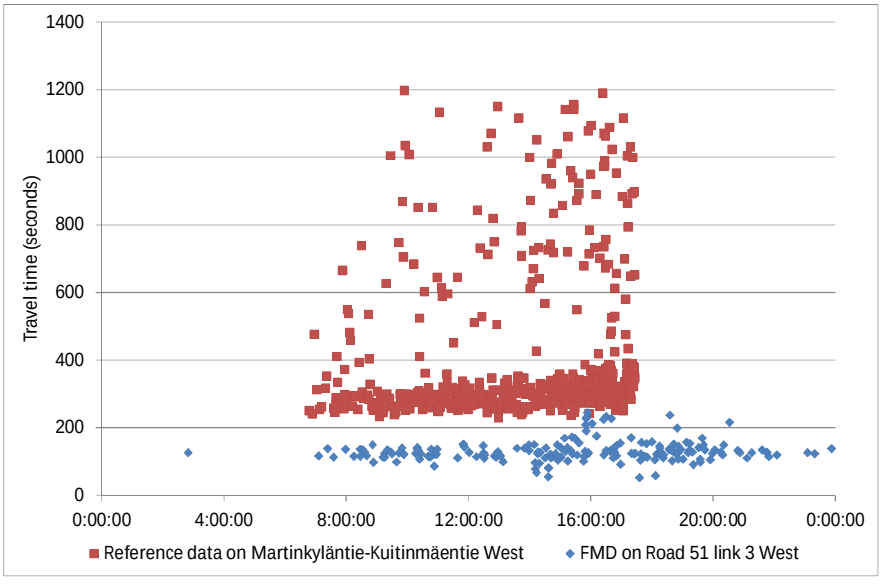


Figure 24. Travel times on Road 51 link 3 West (blue) and its parallel road (red) on May 16, 2012.

3.3.4 Multiple cell phones in a car or a bus

Multiple observations of a single car or bus (caused by several mobile phones in the vehicle) should be excluded. Only one phone per vehicle should contribute to the median travel time value. In practice, if observations come from multiple operators it is very difficult to detect them as the handover zones are in different locations. If the data comes from one operator and the physical location of handovers or location area updates is small, it may be possible to filter multiple observations.

However, if the physical location of handovers or location area updates take place over a larger area (longer stretch of road), it is difficult (or impossible) to distinguish between multiple observations from one vehicle (multiple phones) and observations from vehicles in a queue. This is consequent to the fact that a significant proportion of vehicles drive in queues with a headway of even less than 1 second; thus the time order of handovers (or location area updates) may differ from the order in which the phones pass the physical cross-section of the road.

Nevertheless, if handovers (or location area updates) occur for the same phones consecutively within a very short time frame (e.g. 1 second) in the same physical handover (or location area update) zones, it can be assumed that they are both travelling in the same vehicle – especially when the traffic flow is not congested.

3.3.5 Sample size

The required sample size was calculated for a 95% confidence level and 10% error based on the definition of confidence interval and standard deviation of FMD data in daytime (10–14 hours) traffic. On the best performing links with 16% or 20% relative standard deviation, the sample size for the 5-minute median should be 10 or 15. However, the standard deviation is larger for most of the links, and consequently the required sample size is large. If the standard deviation can be reduced by filtering out the poorest quality observations, the required sample size can be reduced as well.

Table 11. Sample size required for 95% confidence level and 10% error.

NSN link	Link	Standard deviation		Sample size required
		(Seconds)	(%)	
31	Ring I link 2 North	44.3	27 %	29
41	Ring I link 1 North	94.4	44 %	74
51	Ring II North	84.2	45 %	78
252	Ring II South	54.3	33 %	42
222	Road 1 link 1 East	77.3	72 %	200
21	Road 1 link 1 West	39.6	29 %	31
212	Road 1 link 2 East	37.8	21 %	16
11	Road 1 link 2 West	39.5	21 %	16
151	Road 51 link 1 West	44.2	20 %	15
152	Road 51 link 1 East	38.0	16 %	10
161	Road 51 link 2 West	91.4	34 %	45
162	Road 51 link 2 East	76.8	32 %	38
201	Road 51 link 12 West	44.8	20 %	15
202	Road 51 link 12 East	54.0	22 %	19
262	Road 51 link 3 East	64.7	47 %	87
61	Road 51 link 3 West	26.9	22 %	18
302	Road 51 link 4 East	118.9	24 %	22
301	Road 51 link 4 West	118.0	23 %	20

4. Discussion

The FMD pilot aimed to provide anonymous travel time information with data provided by mobile phones. The main purpose of the pilot was to validate the quality of FMD by comparing it with camera-based travel time data. Also the usability of data was assessed from a traffic management point of view and some principles were tested.

4.1 Validation of travel time data

The main result of the validation was that the number of observations is small if FMD is based on cell handover active 2G phone calls. Specifically, the average number of observations per 5-minute period was 1.0–6.3 in 7–21 hours traffic on links based on cell handovers, compared with 2.3–28.1 in the reference which was at least 8.8 on main road links. At night, the number of FMD observations on all links was very small, which is natural as few people make phone calls then.

Road 51 link 12 was based on location area update and all TeliaSonera phones using 2G could be detected. On those links (eastbound and westbound traffic), the number of observations was as high as or even little higher than in the reference data. However, also Road 51 link 4 was based on location area update, but there the sample size was as low as on the cell handover based links. It should be noted that this link was the longest (11.6 km), covering most of Road 51 in Espoo.

The temporal coverage, i.e. the proportion of time for which the 5-minute median value was available, was in 7–21 hours traffic approximately at the same level for FMD and reference data on the main roads. However, on smaller roads FMD was clearly worse. The lack of FMD observations at night made the 24-hour average smaller than in the reference data also for the main roads.

Another key result was that FMD showed too short travel times in congested traffic. For some links on Road 51 the travel time median of congested traffic was almost down to the level of free flowing traffic. Systematically too low values in congestion were seen clearly in mean and median deviations from reference data calculated for traffic peak hours for many links and in confidence intervals calculated for both datasets. One reason for the underestimation of congestion was that observations were estimated based on measurements that in most cases covered

only part of the road link. When a traffic situation is dynamic in space, it is easier to get at least two handovers (minimum requirement for making a measurement) for a mobile phone travelling on a fluent part of the link than for mobile phones making equally long phone calls on the congested part. Another reason for the underestimation on some links can be an over-representative proportion of mobile phone users in public transport on a free-flowing bus lane.

Furthermore, it was shown that FMD observations included more variation than travel times measured by a camera-based method due to inhomogeneous traffic flow status being unequally represented in the measurements. A small number of observations caused strong fluctuations in median travel time on many links even on main roads with high traffic volume. On some links, the fluctuation was balanced in such a way that mean and median deviations were nonetheless small. However, on several links large (negative) mean and median deviations showed regular underestimation of travel time in FMD.

The opposite was also found, however, as observations of the reference data included outliers, i.e. observations of vehicles that had stopped on the way or made a small detour but returned to the link, resulting in longer travel times than other vehicles at that time, which were totally missing from the FMD. If a detour from the travel time link is long enough, it is possible that some of these outliers have been filtered by the cell pattern. Although outliers are not wanted or needed, it is important not to filter out longer travel times based solely on the travel time itself as in real-time operation. To be able to detect when congestion is starting to build up is one of the most important issues travel time data is used for. If observations longer than free-flow travel time are filtered out, it is likely that also the first signs of congestion are lost. In this pilot, filtering was not applied by speed level.

Overall reliability of FMD was studied with cumulative error curves. For some links like Ring I link 2 North, there was not much difference between curves determined for 5–24 hours traffic and peak hours (7–9 and 15–18) traffic. However, for most links the peak hour traffic curve gave clearly worse values than the 5–24 hour curve, indicating a poor ability to estimate congestion. If a 10% error is exceeded for more than 50% of time in congested conditions, clearly there is room for improvement.

Based on this pilot it was shown that ramp links should be determined based on the location of handover zones. If too short links are applied and a handover zone is missing from one of the connecting roads, the travel time of turning vehicles (mobile phones) cannot be monitored.

The results also showed that weather conditions did not affect the reliability of FMD. The examples measured during 2 days of snowstorms indicated that bad weather preventing the camera system from detecting licence plates did not affect cell handover or location area update measurements.

4.2 Usability

Based on the TMC interview on usability, it was clear that pilot FMD does not yet meet the standards of traffic management. As a rule of thumb, TMC uses a minimum requirement of 10 observations per aggregation period (in this case 5 minutes) for reliable information. This minimum requirement was achieved on the best performing link (Road 51 link 12 West) 77% of the time during hours 5–24. On other links this requirement was seldom met. Power analysis using standard deviation of travel time resulted mostly in a larger sample size requirement than the 10 required as a minimum by TMC.

For TMC operation, the detection of congestion is important. FMD was able to detect congestion most of the time but the level of congestion was not estimated correctly.

If active phone calls are needed to produce data, it seems that there are very few observations between midnight and 6:00 a.m. The TMC requirement on getting traffic flow status information between 5 and 24 hours is, consequently, almost achieved.

TMC would like to cover the biggest city areas with FMD. To get sufficient geographic coverage, also smaller roads and main streets should be included. However, FMD did not perform well in this pilot in such environments despite rather high traffic volumes. The pilot also left in doubt the ability of FMD to monitor traffic in the countryside due to large cells and a small amount of traffic.

4.3 Performance of ad hoc service

The main result related to ad hoc data showed that the precision of ad hoc links was not high enough. This resulted in observations that corresponded to travel speeds over 200 km/h. Thus the reported ad hoc link start and end locations were closer to each other than they must have been in the field. Small errors partly average out over longer road sections but they are clear on such short links.

If similar 5-minute median travel times are targeted for ad hoc links as for static links, the number of observations is not high enough in the ad hoc data. Consequently, the temporal coverage would be poor. However, there were enough observations to give an idea of the traffic flow status over longer time periods. Nonetheless it is not enough for the real-time operating needs of TMCs.

In principle, travel speeds and precise ad hoc link end locations are not needed, but the difference of travel time in relation to free-flow travel time would be enough to reveal a delay in the area. However, TMC should be convinced that the quality of ad hoc travel time observations is high enough to serve as a basis for their work. It is hard to verify if the given ad hoc link is far from true and the observation frequency is low.

4.4 Verification of principles

The principles of how to determine the median value for travel time were tested. The results showed that a quality-weighted median performed better than a regular median. With the small number of observations in FMD, a 10-minute median worked better than a 5-minute or 15-minute median.

A quality indicator was targeted to indicate the reliability of data. Most commonly the OQI was around 40–60%. The reason for not getting higher quality observations was the mismatch between traffic-wise determined travel time link and handover locations of the mobile network. The quality indicator seemed to work well in that the highest differences from the median (deviations from reference data) were related to observations with the lowest values of the quality indicator. However, relatively large deviations (50–100%) existed also among the best quality (OQI 80-100%) observations.

Observations from parallel roads and railways should be excluded from the data based on cell patterns rather than speed level. The data showed no evidence of mixing data from parallel roads. Consequently, it seems that the piloted system was able to distinguish between them.

Also multiple observations (multiple mobile phones) representing the same vehicle should be excluded. However, in practice, multiple observations from two operators are impossible to observe. Also multiple observations of a single operator can be difficult to detect from vehicles travelling in queues. The sequence of handovers that occur for the same phones within a very short time frame (e.g. 1 second) in the same physical handover zones can be assumed to originate from a single vehicle when the traffic flow is not congested.

A theoretical sample size requirement was studied for the pilot links. On the best performing links with 16% or 20% relative standard deviation, the sample size for the 5-minute median should be 10 or 15. However, the standard deviation is larger for most of the links and consequently the required sample size is large. This theoretical sample size requirement is in line with the rule of thumb set by TMC requiring at least 10 but preferably 20 observations per median.

5. Conclusions and recommendations

The main conclusion was that for traffic management operations, monitoring of cell handovers of active 2G phone calls alone does not produce a high enough number of observations. Consequently, it is recommended that the selected FMD technology should be such that it is able to monitor a larger proportion of mobile phones per aggregation period per link. Independence of active phone calls would help to cover also night time traffic as well as smaller roads and main streets. The rule of thumb verified by the theoretical sample size requirement is to have at least 10 observations per aggregation period, preferably 20.

Another main conclusion was that the estimation of median travel time (or any other aggregated value for the whole link) should be developed further. Obviously, although traffic-wise homogeneous links were targeted, traffic on many links is dynamic in both space and time. Consequently, it is recommended that the traffic flow status estimate be based on part-observations, and that the weight of different zones of a travel time link be balanced rather than letting full observations emphasized on a fluent part of the link bias the estimate. Hence, part-observations on the congested section of the travel time link would get more weight in the observations.

The use of a location area update border increased the sample size and, consequently, reduced the error of the aggregated travel time estimate. The implication was therefore that use of technologies able to monitor a large proportion of mobile phones should be favoured. Unfortunately, the use of location areas is not feasible everywhere due to their large size.

All links must cover at least two but preferably more handover zones to produce data. Balancing the number of these zones in all parts of link is important – especially in locations with large cells. This was seen with ramp links where merging traffic could not be monitored if handover zones on the link covered only one of the intersecting main roads. Although the links should be determined to represent homogeneous traffic flow, a recommendation is to fine-tune the link division to guarantee balanced measurements also from the point of view of the cellular network(s).

The main implication related to ad hoc service was that the precision of ad hoc links was not high enough. It does not have to be as high as for static links but high enough to make validation of the data possible. Thus the recommendation is

to improve it. Another recommendation is to increase the number of observations in ad hoc service to suffice for real time operations based on 5-minute medians.

Although the quality indicator somewhat reflected the reliability of observation, it was not reliable enough to really pinpoint the highest quality observations. The recommendation is to proceed in developing the indicator.

References

Kummala, J. (2002). Matkapuhelimia hyödyntävä matka-aikapalvelu: Järjestelmän arviointi – Tulokset [Travel time service using mobile phones]. FinnRA Reports 55/2002, Finnish National Road Administration, Helsinki. 67 s. liitt. 13 p.

Penttinen, M., Pilli-Sihvola, E., Innamaa, S. (2012). Digitrafficin nykyisen käyttöliittymän arviointi ja tärkeimmät kehitysehdotukset. Muistio, VTT. 26 p.

Appendix A: Links

The following first table shows how different system links were matched. As the reference data links on main road 51 and Ring road II (orange fill in the first table) did not totally match the FMD links, the reference travel time of those NSN links were estimated based on free-flow travel time of the road sections. The equations are shown below in the second table.

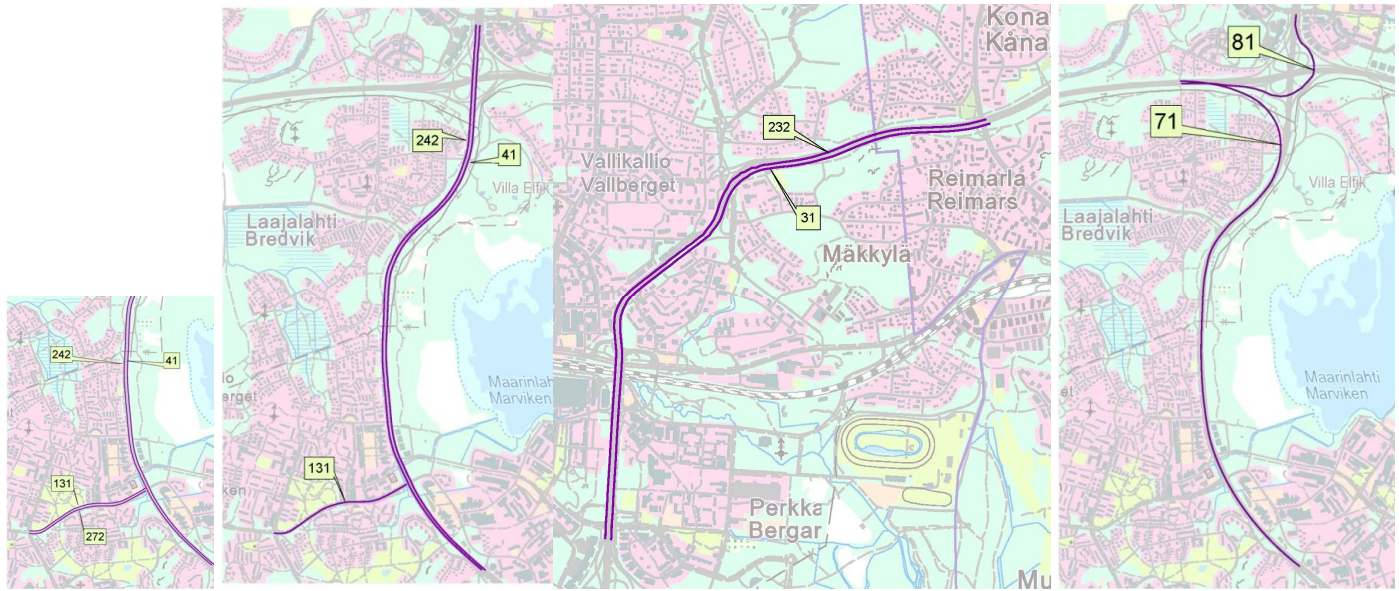
FTA				NSN		
Road	Link		Length (m)	Link		Length (m)
Ring I	24	Otaniemi -> Perkkaa	3926	41	Ring I link 1 North	3848
Ring I	25	Perkkaa -> Otaniemi	3900	242	Ring I link 1 South	3848
Ring I	26	Perkkaa -> Konala	3078	31	Ring I link 2 North	3181
Ring I	27	Konala -> Perkkaa	3329	232	Ring I link 2 South	3181
Ring II	10210101	Olari -> Mankkaa	2463	51	Ring II North	2813
Ring II	10210102	Mankkaa -> Olari	2463	252	Ring II South	2813
Road 1	80	Kehä I -> Stensintie	3523	21	Road 1 link 1 West	3545
Road 1	81	Stensintie -> Kehä I	3523	222	Road 1 link 1 East	3545
Road 1	82	Stensintie -> Kehä III	5114	11	Road 1 link 2 West	5087
Road 1	83	Kehä III -> Stensintie	5114	212	Road 1 link 2 East	5087
Road 51	5110101	Lemissaari -> Katajaharju	1732	151	Main road 51 link 1 West	5516
Road 51	5110102	Katajaharju -> Lemissaari	1732	152	Main road 51 link 1 East	5516
Road 51	5110201	Katajaharju -> Westend	2734	201	Main road 51 link 12 West	4406
Road 51	5110202	Westend -> Katajaharju	2734	202	Main road 51 link 12 East	4406

FTA				NSN		
Road	Link		Length (m)	Link		Length (m)
Road 51	5110301	Westend -> Matinkylä	3056	161	Main road 51 link 2 West	5671
Road 51	5110302	Matinkylä -> Westend	3056	162	Main road 51 link 2 East	5671
Road 51	5110401	Matinkylä -> Espoonlahti	5067	61	Main road 51 link 3 West	3501
Road 51	5110402	Espoonlahti -> Matinkylä	5067	262	Main road 51 link 3 East	3501
Road 51	5110501	Espoonlahti -> Sundsberg	6024	301	Main road 51 link 4 West	11633
Road 51	5110502	Sundsberg -> Espoonlahti	6024	302	Main road 51 link 4 East	11633
Road 110		Pitäjänmäki->Leppävaara		292	Road 110 West	3556
Road 110		Leppävaara->Pitäjänmäki		171	Road 110 East	3556
Kuitinmäentie-Martinkyläntie		Kuitinmäki->Espoonlahti		142	Kuitinmäentie-Martinkyläntie West	3488
Kuitinmäentie-Martinkyläntie		Espoonlahti->Kuitinmäki		141	Kuitinmäentie-Martinkyläntie East	3488
Kalevalantie		Kehä I->Pohjois Tapiola		131	Kalevalantie West	925
Kalevalantie		Pohjois Tapiola->Kehä I		272	Kalevalantie East	925
Röyläntie		Matalajärventie->Röylä		191	Röyläntie North	5594
Röyläntie		Röylä->Matalajärventie		192	Röyläntie South	5594
Kokinkyläntie		Mankaa->Olarinluoma		182	Kokinkyläntie West	1588
Kokinkyläntie		Olarinluoma->Mankaa		181	Kokinkyläntie East	1588

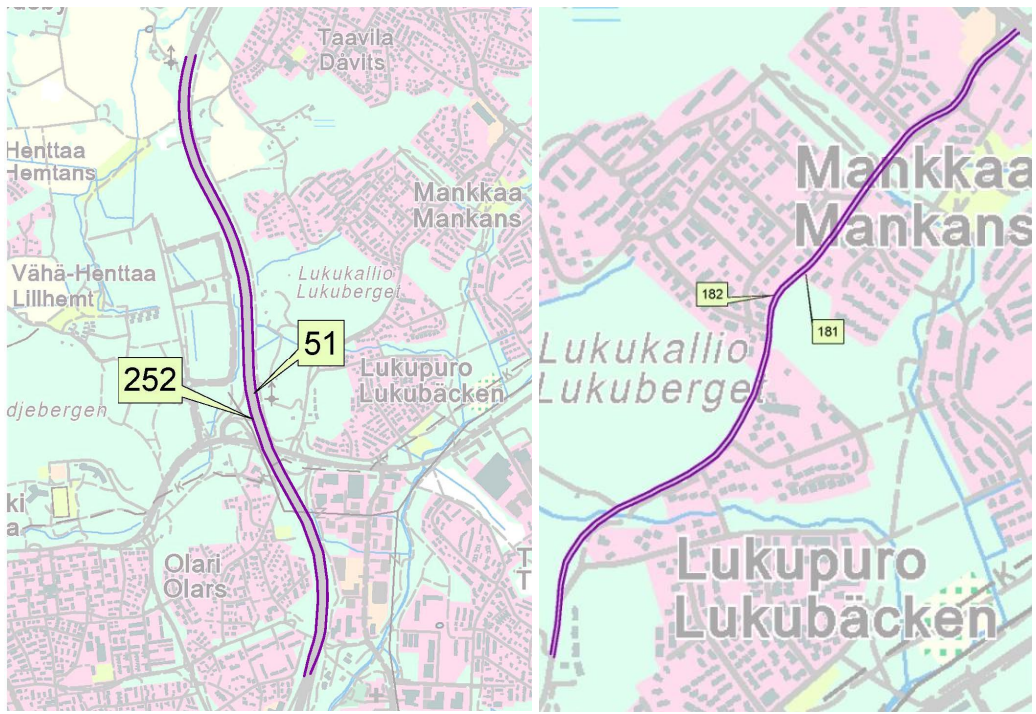
NSN Link		Length (m)	Equation for travel time from FTA links (= 7 digit numbers)
51	Ring II North		114%/10210101 (FTA link point at Mankkaa appr. 450m south of NSN link point)
252	Ring II South		114%/10210102
302	Road 51 link 4 East	11633	5110502+5110402+18.7%/5110302
262	Road 51 link 3 East	3501	69.1%/5110402
162	Road 51 link 2 East	5671	30.9%/5110402+5110302+37.5%/5110202
202	Road 51 link 12 East	4406	79.3%/5110302+5110202
152	Road 51 link 1 East	5516	62.5%/5110202+220%/5110102 (NSN link until Salmisaarenkatu, FTA link until Lemissaari)
301	Road 51 link 4 West	11633	5110501+5110401+18.7%/5110301
61	Road 51 link 3 West	3501	69.1%/5110401
161	Road 51 link 2 West	5671	30.9%/5110401+5110301+37.5%/5110201
201	Road 51 link 12 West	4406	79.3%/5110301+5110201
151	Road 51 link 1 West	5516	62.5%/5110201+220%/5110101

Individual links on map with NSN link numbers

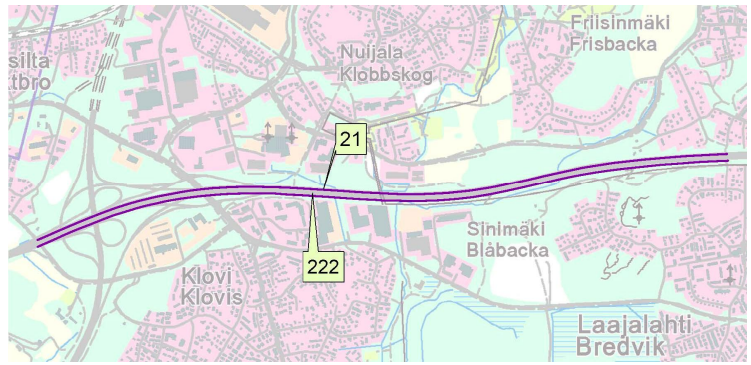
Links on Ring I and Kalevalantie



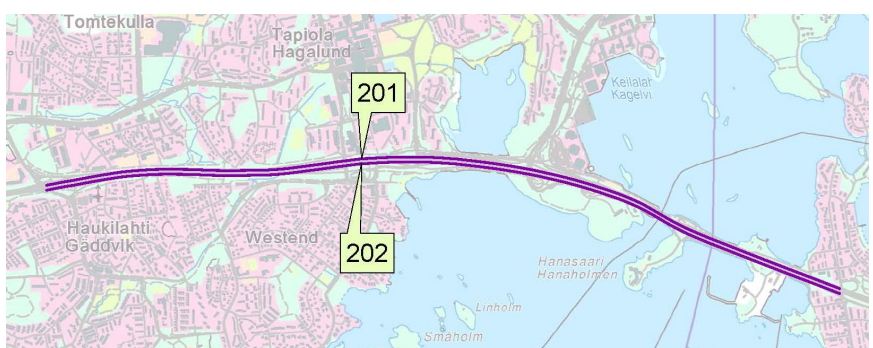
Links on Ring II and Kokinkyläntie

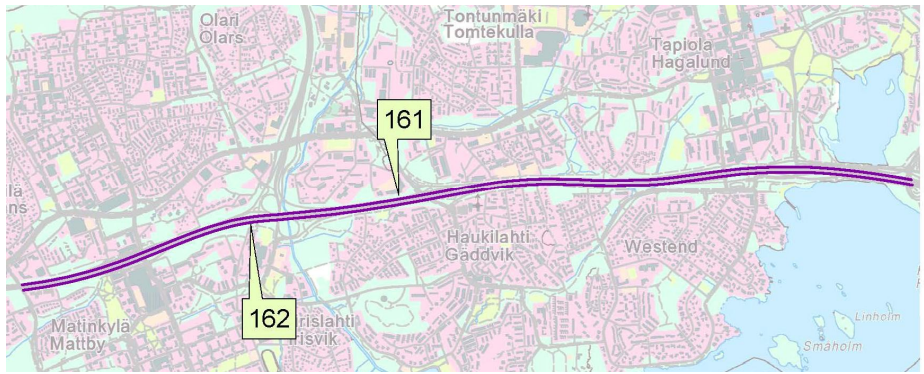


Links on Road 1



Links on Road 51 and Kuitinmäentie–Martinkyläntie

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Olars
Tontunmäki
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Westend
162
Matinkylä
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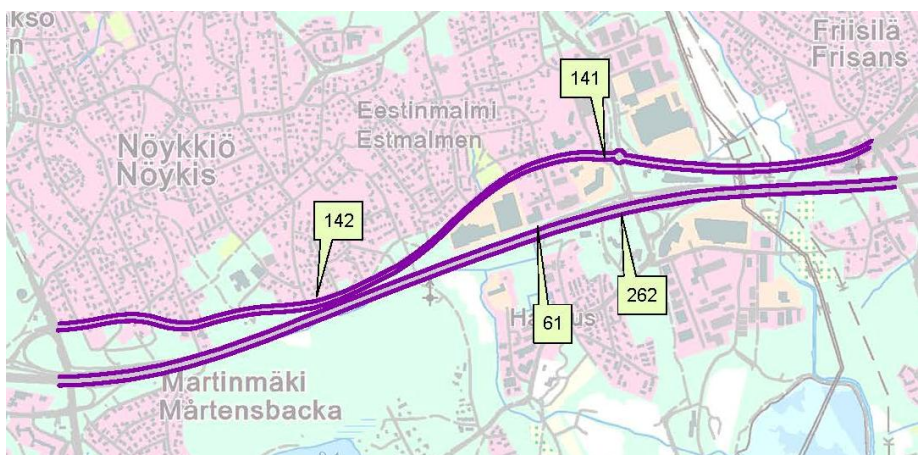
Linholm
Smaholm


Friisilä
Frisans
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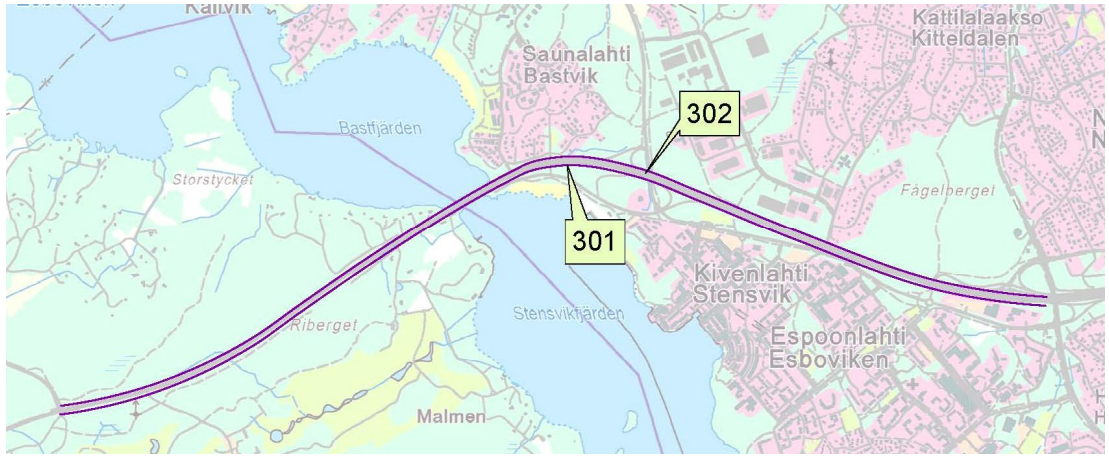
Eestinmalmi
Estmalmen
Nöykkiö
Nöykis
142
262
61
Martinmäki
Mårtensbacka

A8


Kattilalaakso
Kitteldalen
Saunalahti
Bastvik
302
Bastfjärden
Storstycket
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301
Kivenlahti
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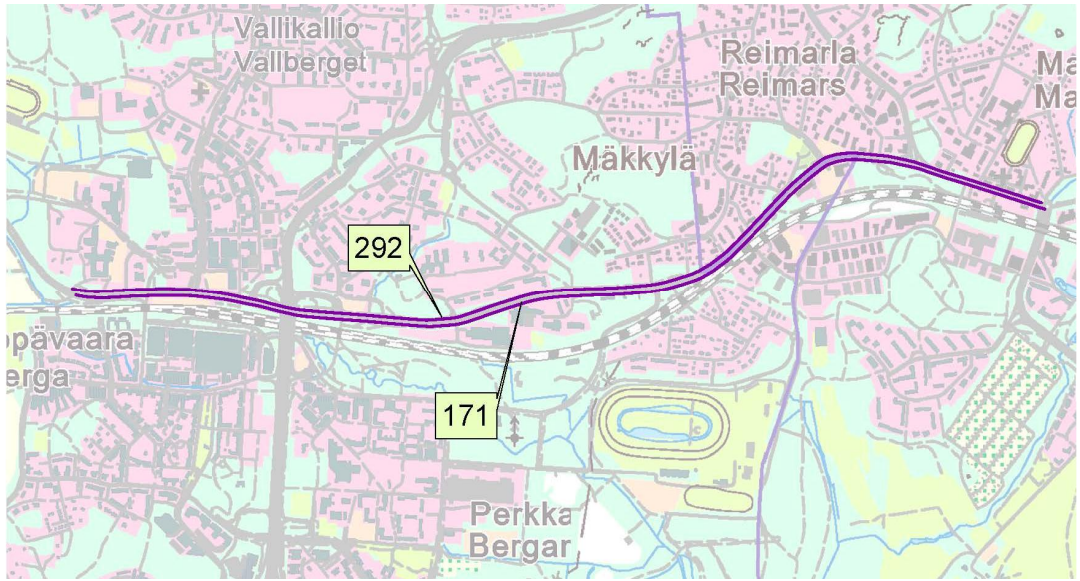
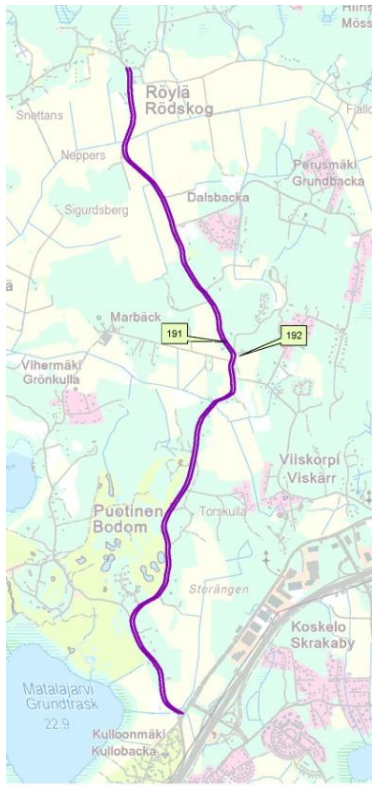
Riberget
Stensvikfjärden
Espoonlahti
Esboviken
Malmen

Links on Road 110



Links on Röyläntie



Appendix B: Validation of VTT travel time data

The proportion of vehicles detected by the VTT travel time camera system was assessed in Lusi in another travel time study in 2010. The proportion of detected vehicles (successfully read licence plate) was above 90% in the morning for both dates but the proportion was reduced around noon due to sunshine down to 74% for the first day (Table B1). The average detection rate was 85% and 87%. The vehicle needs to be detected by both cameras in order for the travel time to be measured. The average proportion of travel time measurements compared to DSL traffic volume was 75% and 78% (Table B2).

Table B1. Number of vehicle observations by the VTT travel time camera system and proportion compared to traffic volume measured by DSL.

21.4.2010

Hour	DSL	Camera 1	Camera 2	Proportion 1	Proportion 2
8	170	166	163	98%	96%
9	183	180	159	98%	87%
10	197	192	177	97%	90%
11	163	155	140	95%	86%
12	173	154	133	89%	77%
13	197	172	145	87%	74%
14	196	181	167	92%	85%
15	220	196	179	89%	81%
16	219	206	193	94%	88%
17	213	203	188	95%	88%
Total	**1931**	**1805**	**1644**	**93%**	**85%**

13.9.2010

Hour	DSL	Camera 1	Camera 2	Proportion 1	Proportion 2
9	212	187	192	88%	91%
10	209	196	194	94%	93%
11	208	184	187	88%	90%
12	191	151	164	79%	86%
13	162	145	139	90%	86%
14	200	190	175	95%	88%
15	197	173	175	88%	89%
16	194	167	168	86%	87%
17	183	158	142	86%	78%
Total	**1756**	**1551**	**1536**	**88%**	**87%**

Table B2. Number of travel time observations measured by the VTT travel time camera system and proportion compared to traffic volume measured by DSL.

21.4.2010

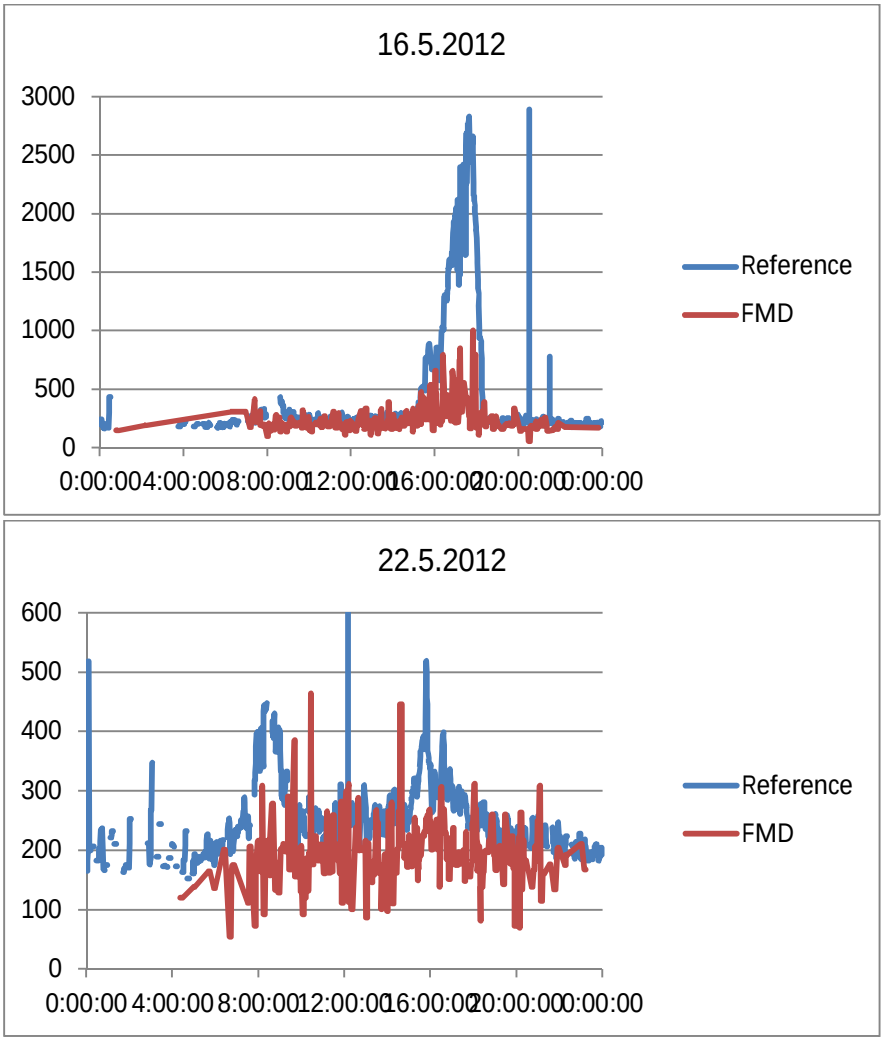
Hour	Travel time observations	DSL	Proportion
8	151	170	89%
9	156	183	85%
10	163	197	83%
11	122	163	75%
12	127	173	73%
13	128	197	65%
14	153	196	78%
15	168	220	76%
16	177	219	81%
17	170	213	80%
Total	**1515**	**1931**	**78%**

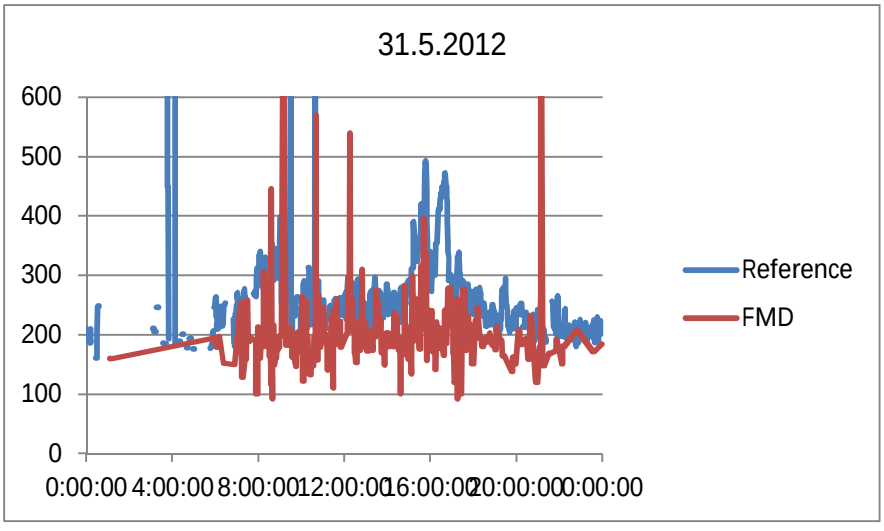
13.9.2010

Hour	Travel time observations	DSL	Proportion
9	168	212	79%
10	175	209	84%
11	159	208	76%
12	133	191	70%
13	123	162	76%
14	156	200	78%
15	148	197	75%
16	139	194	72%
17	122	183	67%
Total	**1323**	**1756**	**75%**

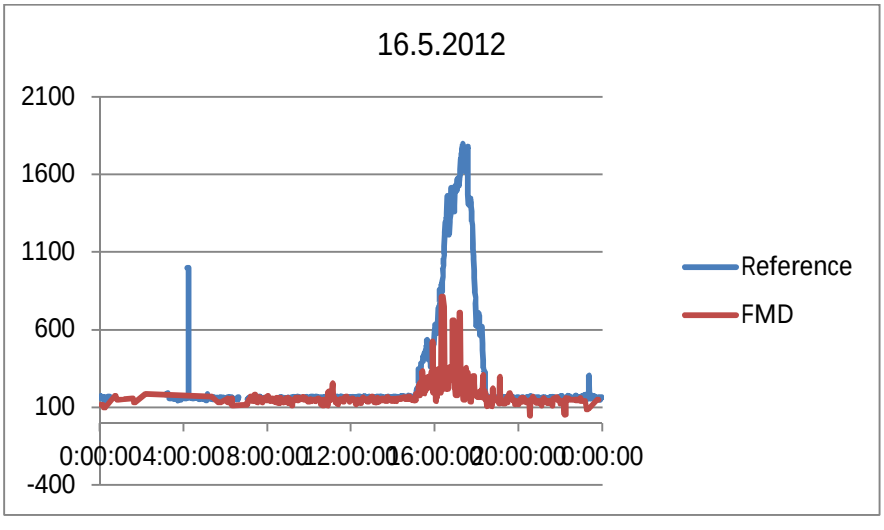
Appendix C: Travel time medians of FMD and reference data

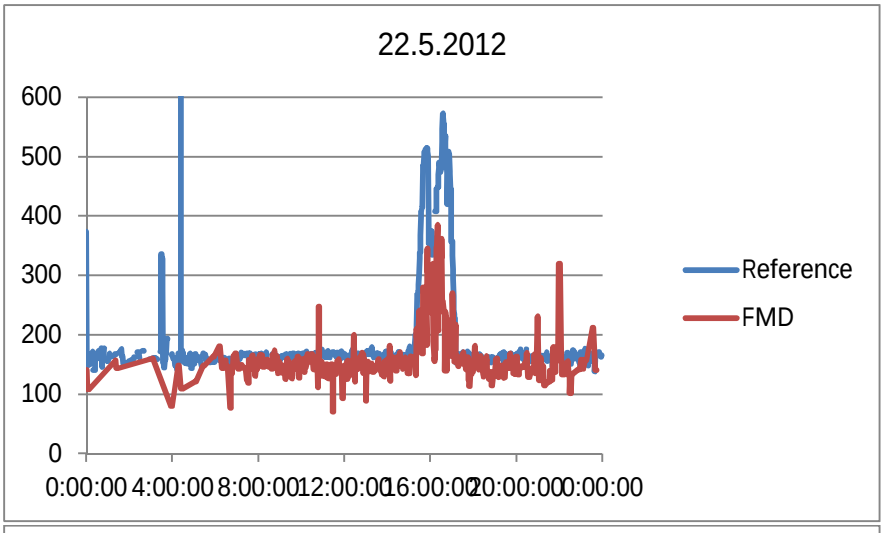
Travel time medians (seconds) on Ring I link 1 North (NSN link 41)





Travel time medians (seconds) on Ring I link 2 North (NSN link 31)

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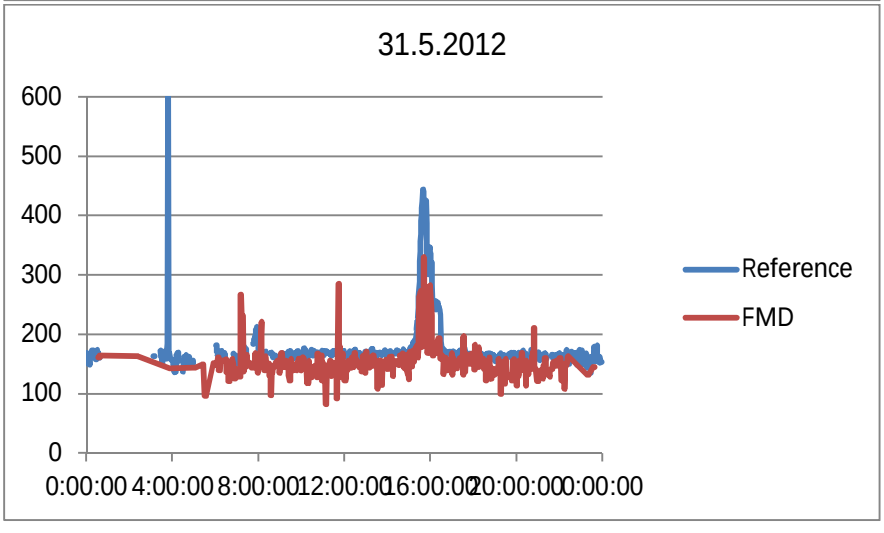
Reference
FMD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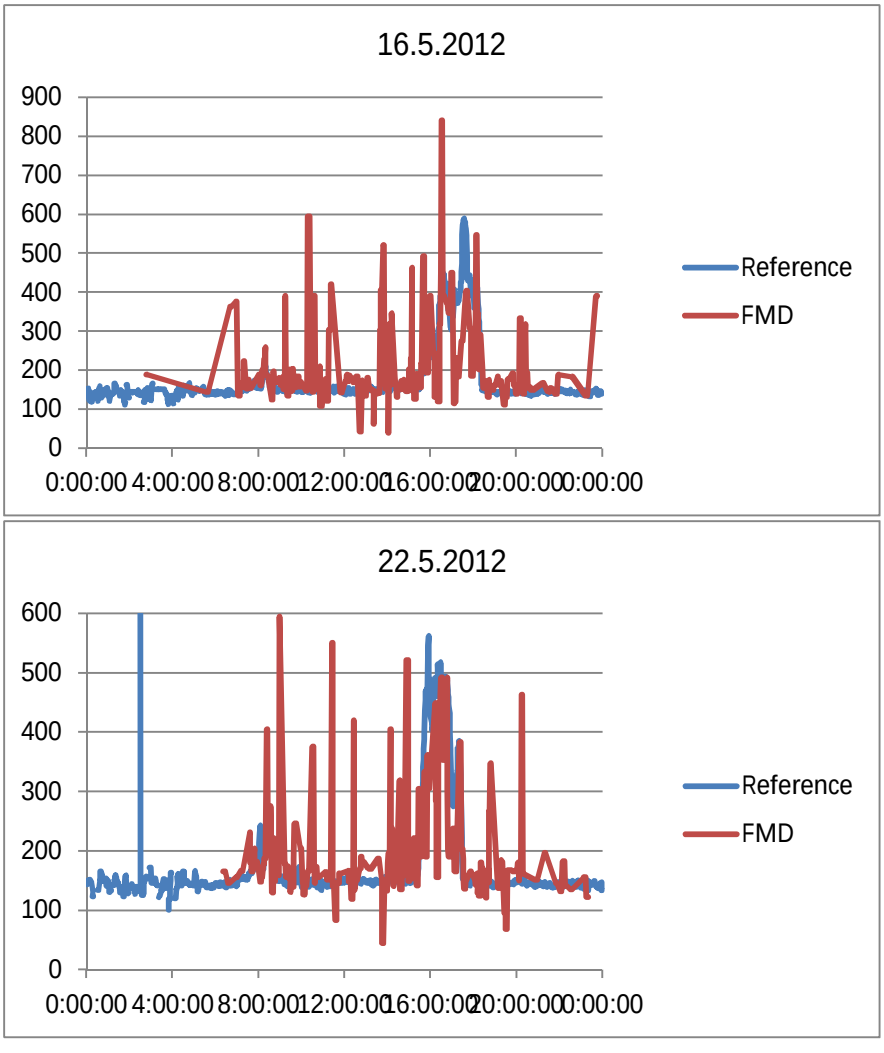
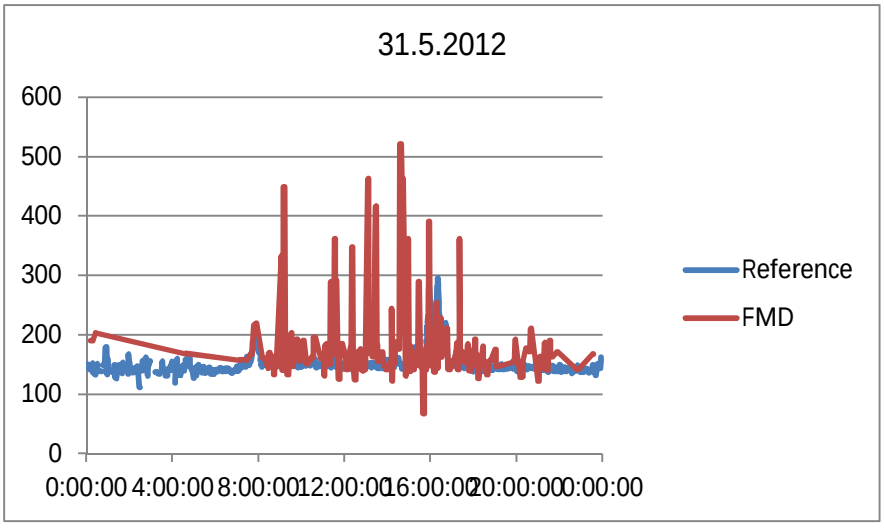
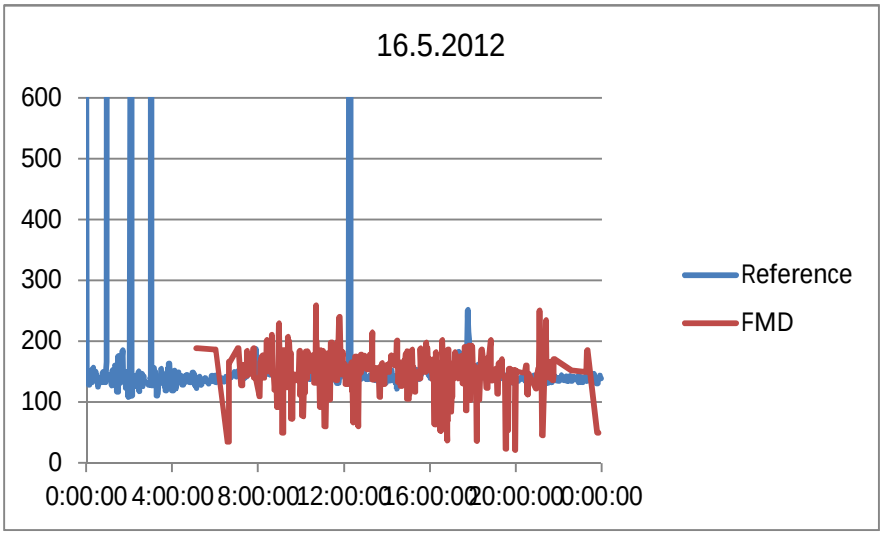
Reference
FMD

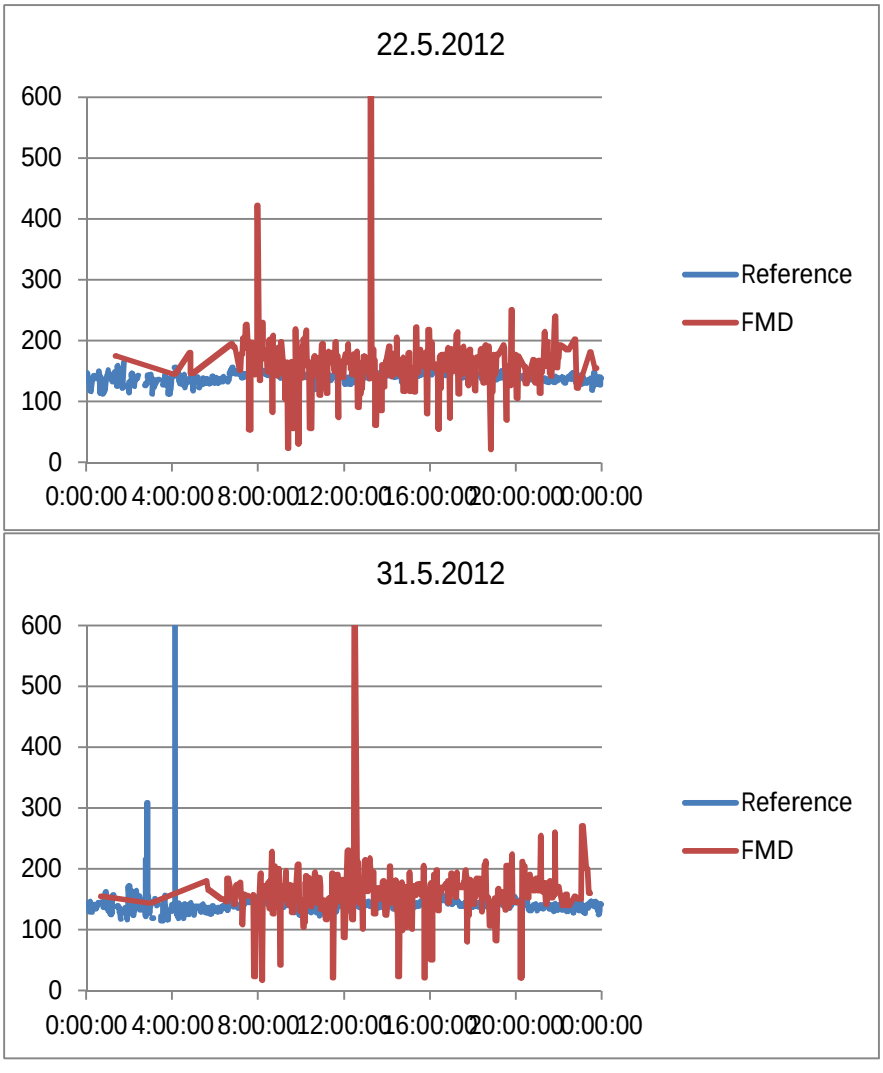
Travel time medians (seconds) on Ring II North (NSN link 51)





Travel time medians (seconds) on Ring II South (NSN link 252)

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Reference
FMD
31.5.2012
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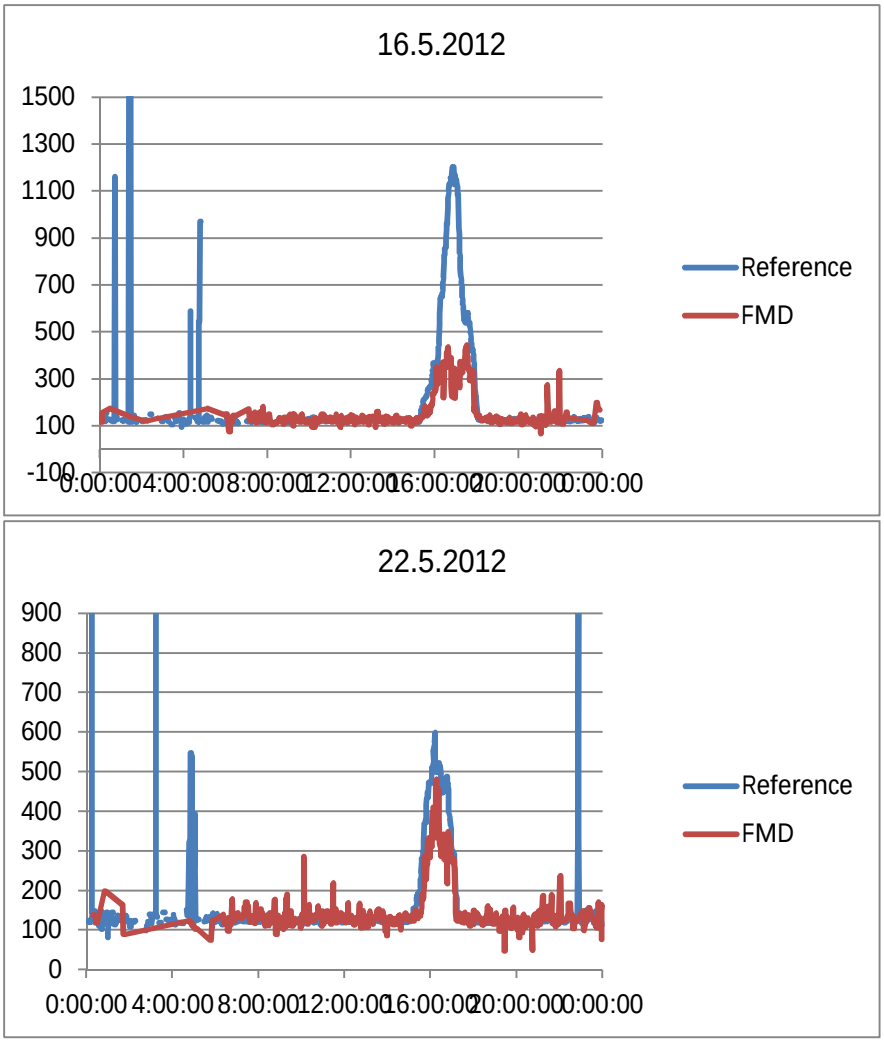
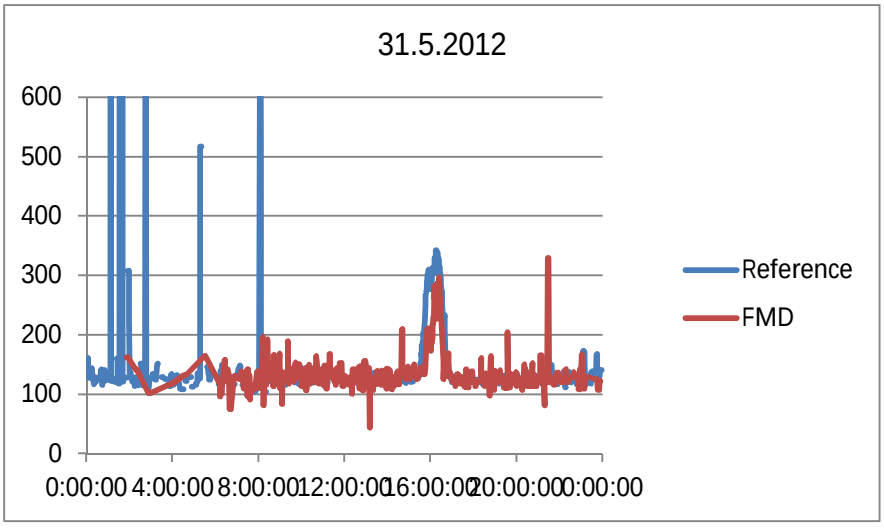
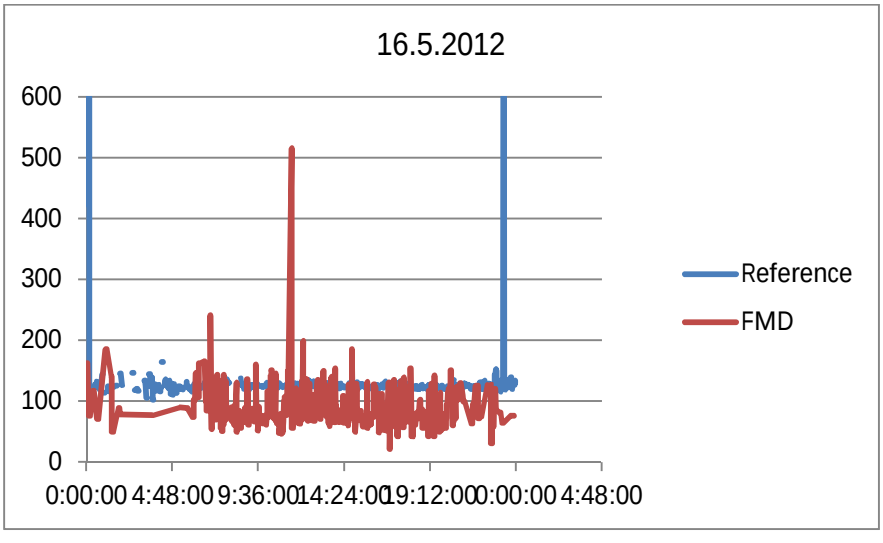
Reference
FMD

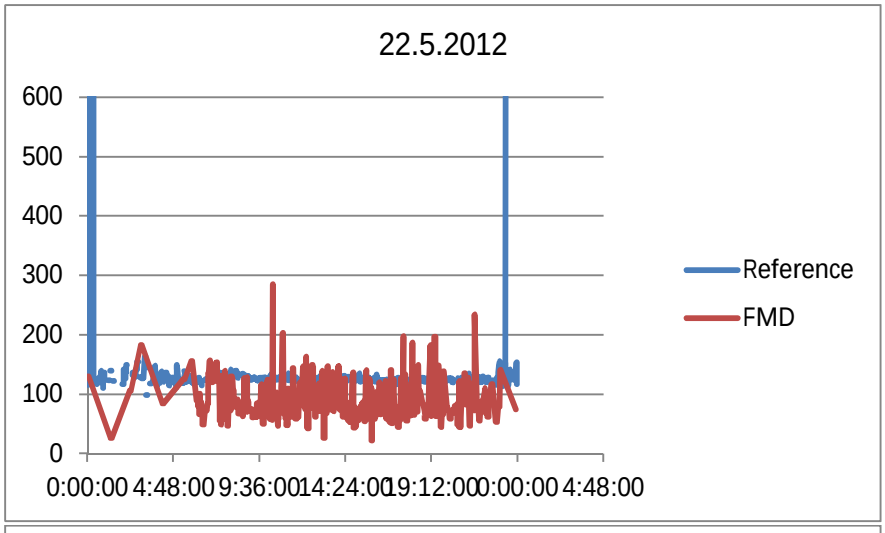
Travel time medians (seconds) on Road 1 link 1 West (NSN link 21)





Travel time medians (seconds) on Road 1 link 1 East (NSN link 222)

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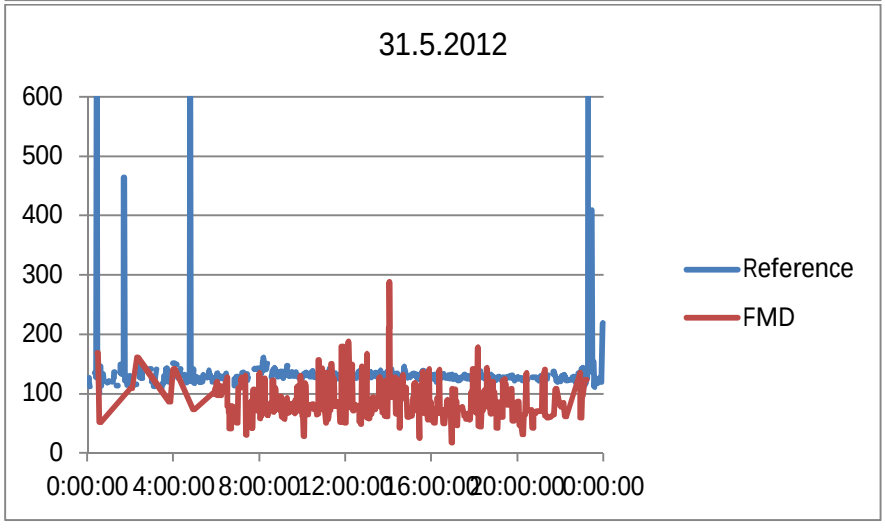
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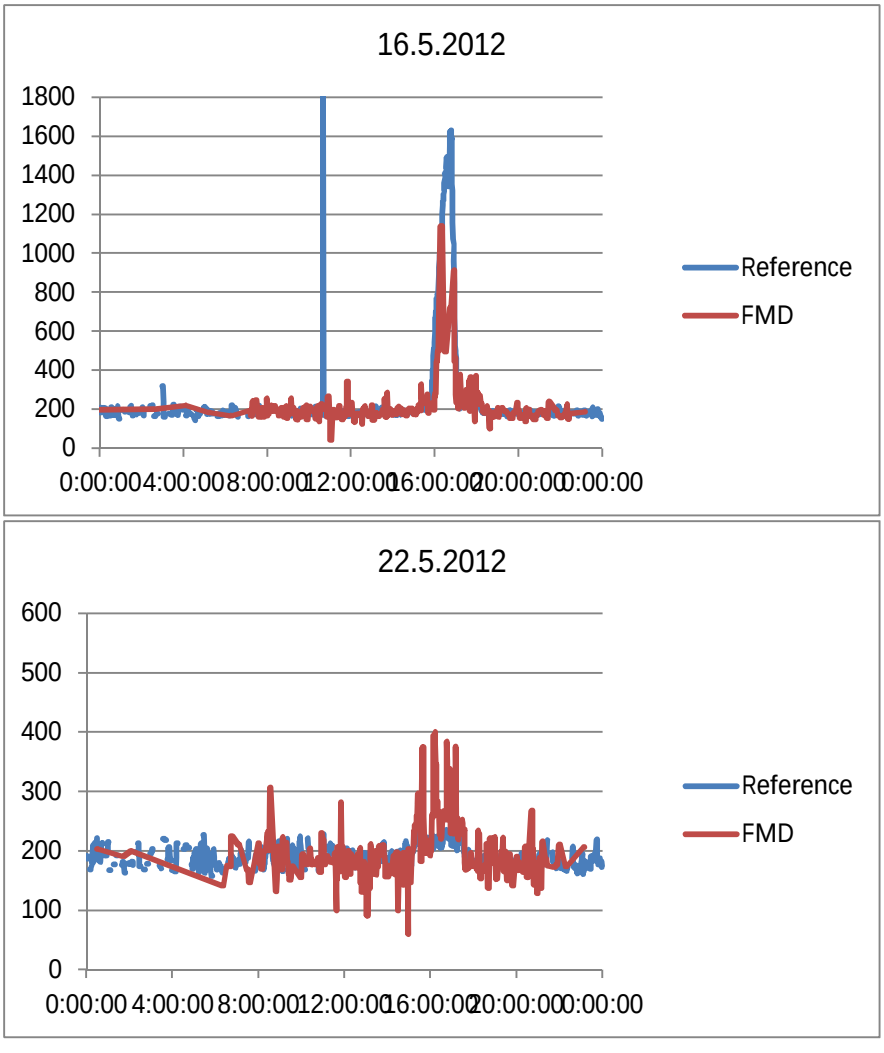
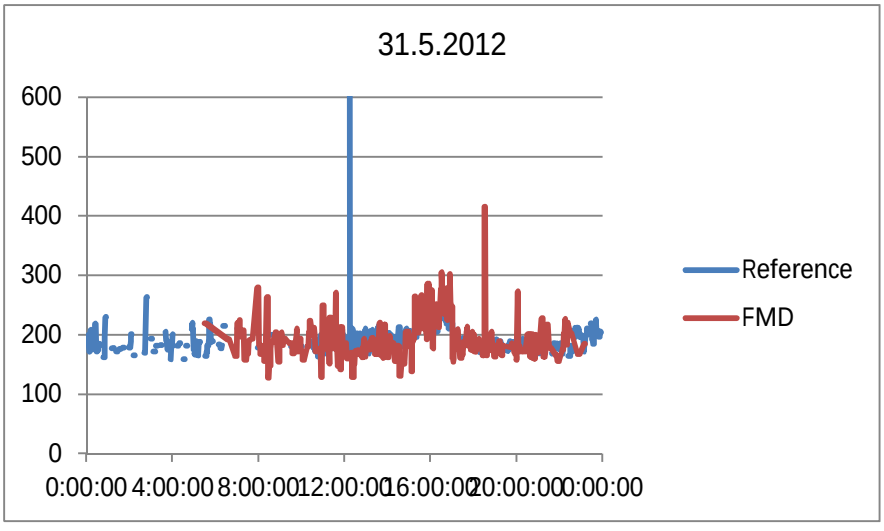
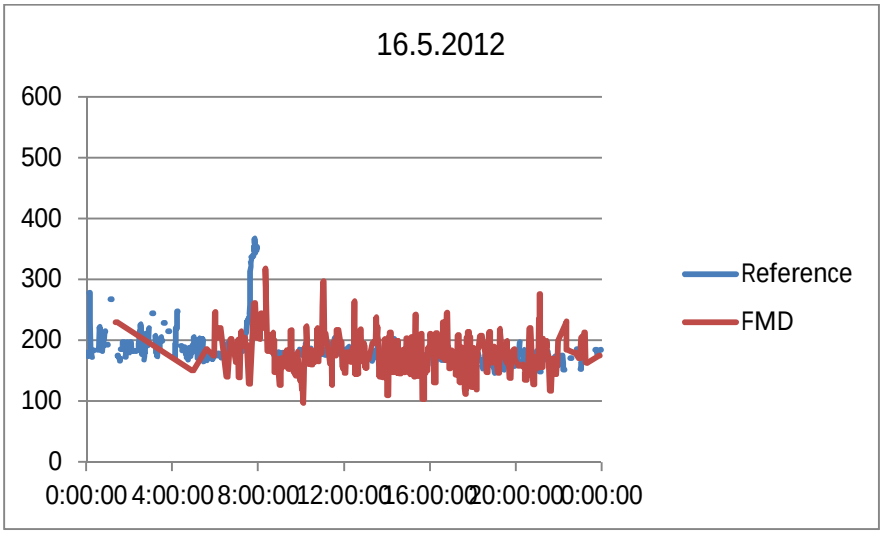
Reference
FMD

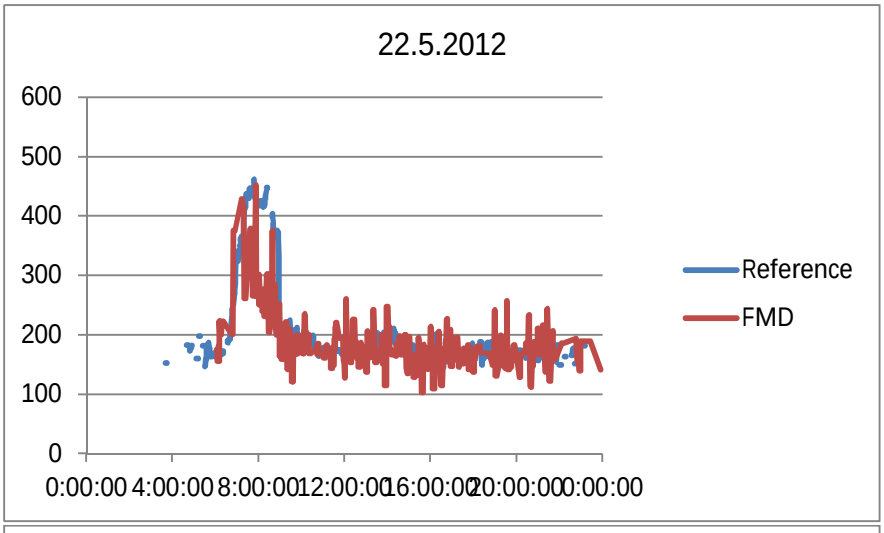
Travel time medians (seconds) on Road 1 link 2 West (NSN link 11)





Travel time medians (seconds) on Road 1 link 2 East (NSN link 212)

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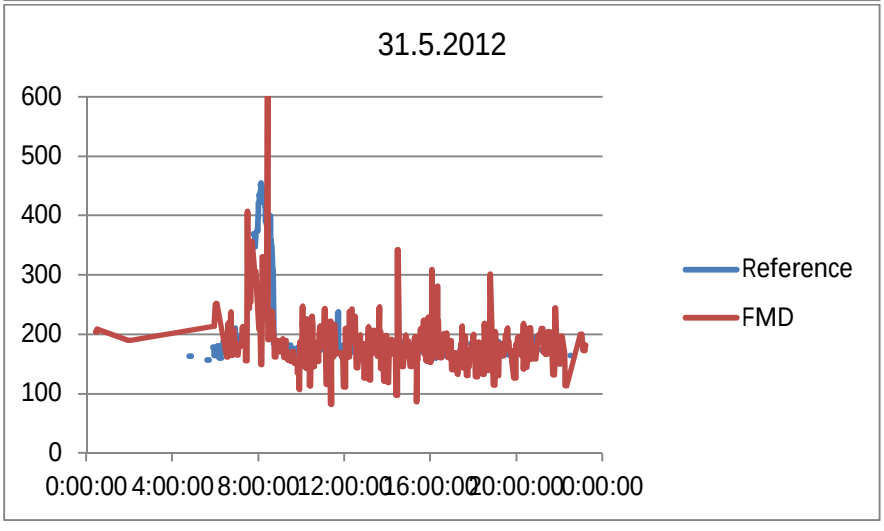
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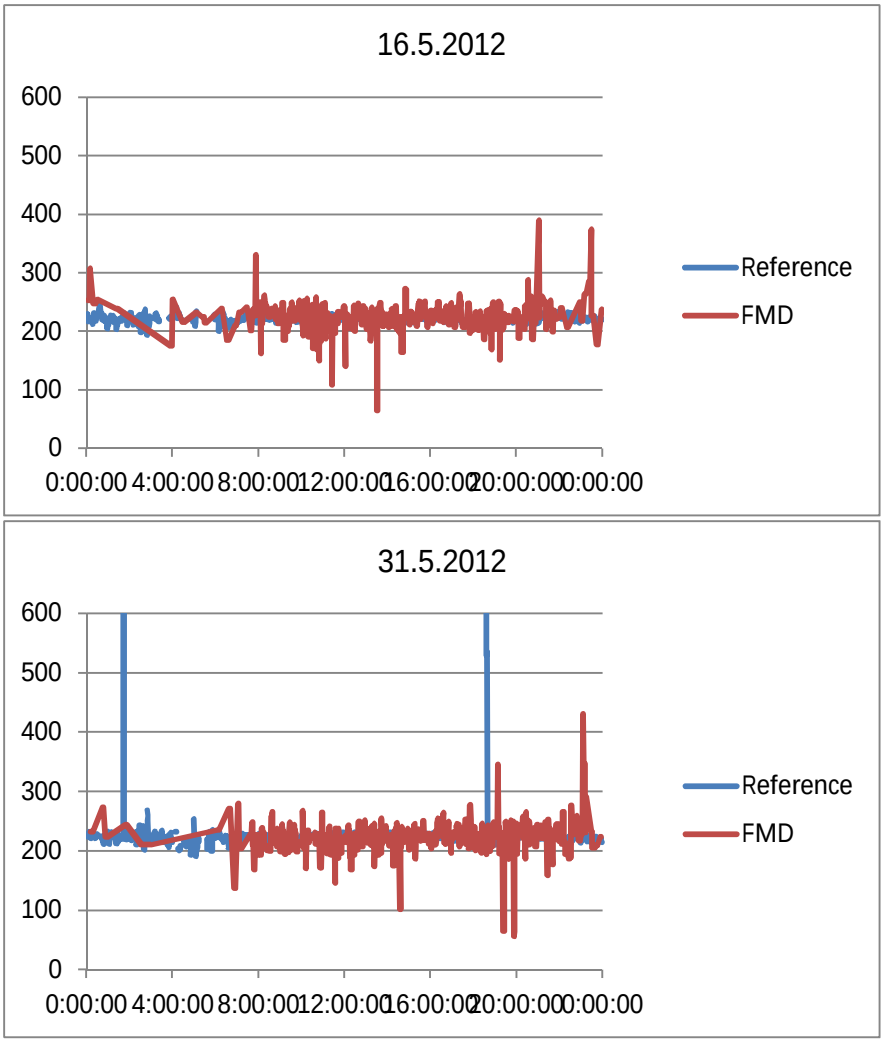
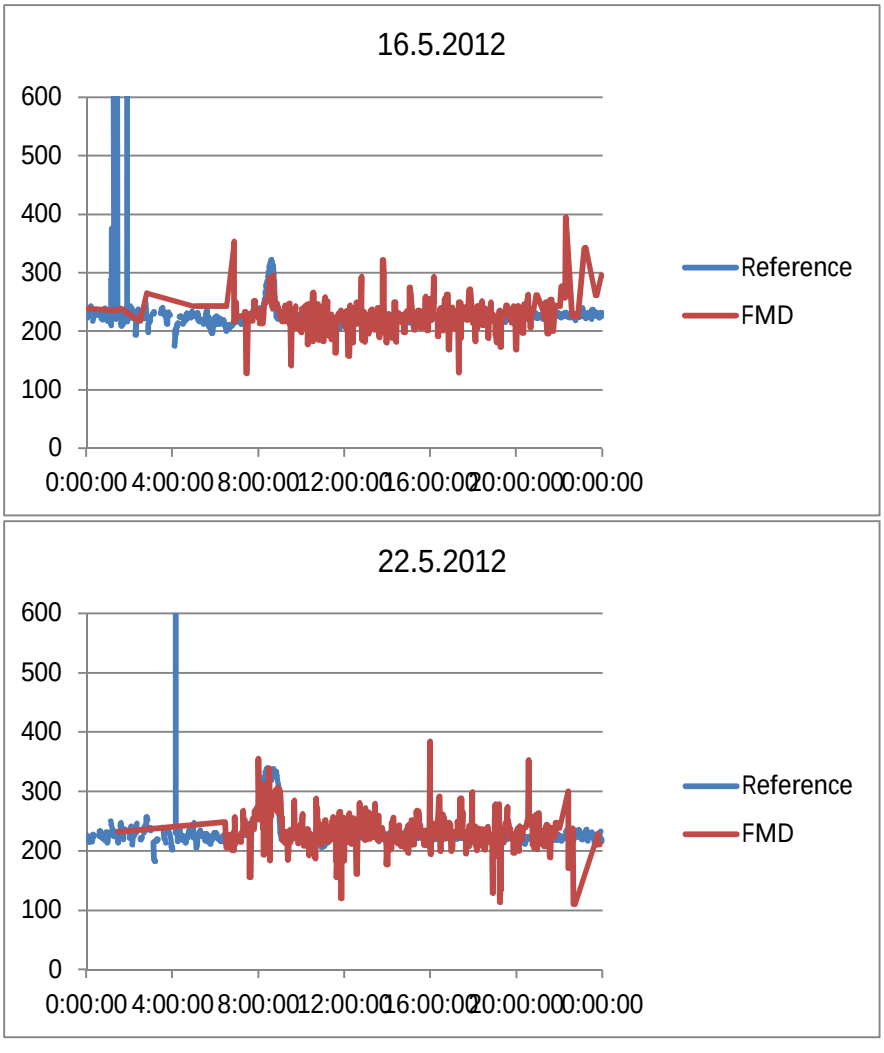
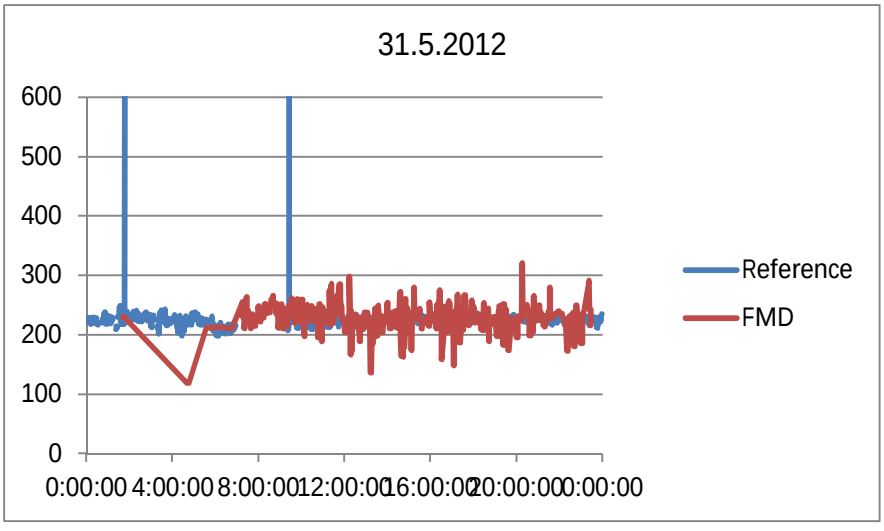
Reference
FMD

Travel time medians (seconds) on Road 51 link 1 West (NSN link 151)

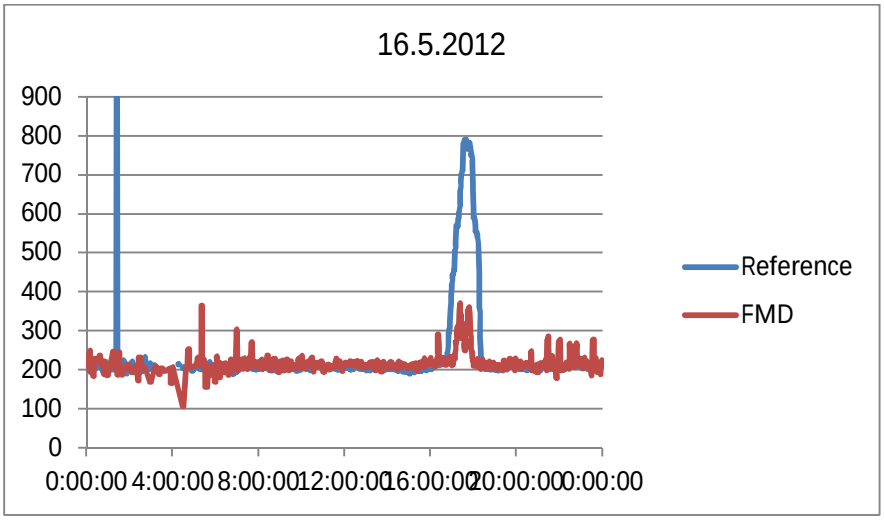


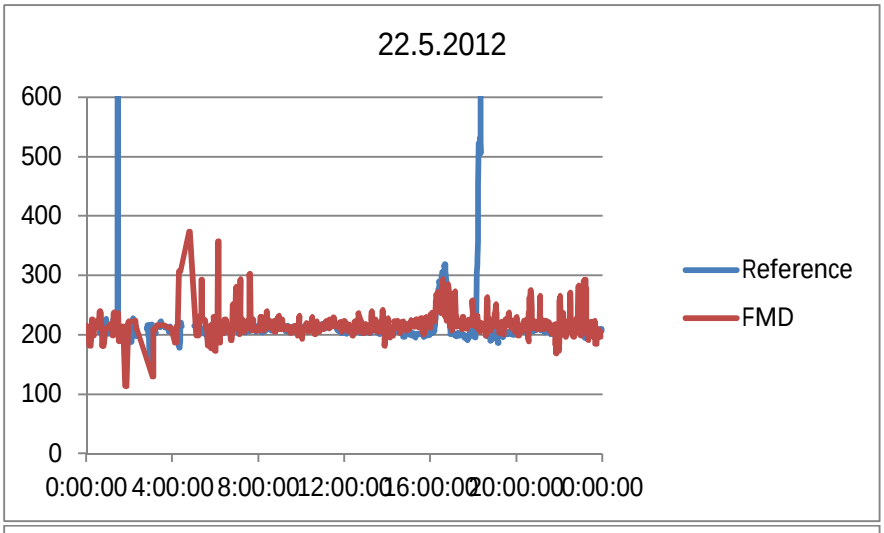
Travel time medians (seconds) on Road 51 link 1 East (NSN link 152)





Travel time medians (seconds) on Road 51 link 12 West (NSN link 201)

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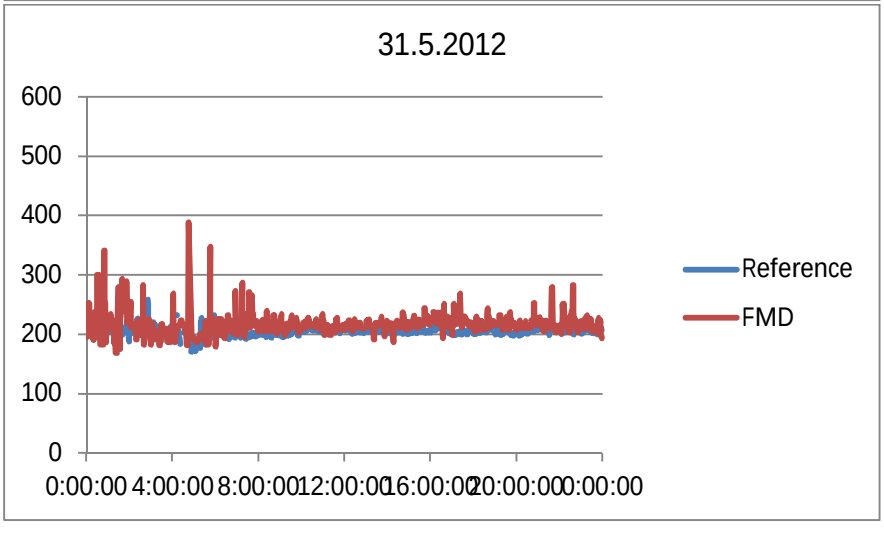
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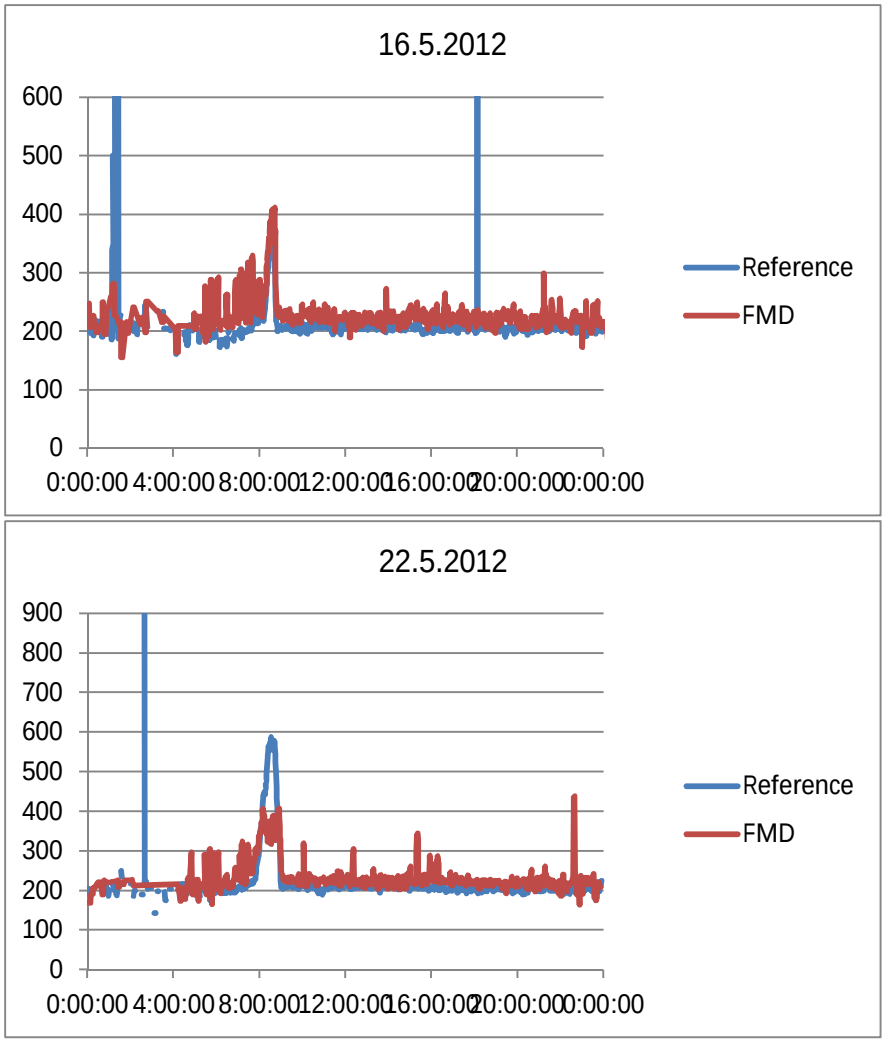
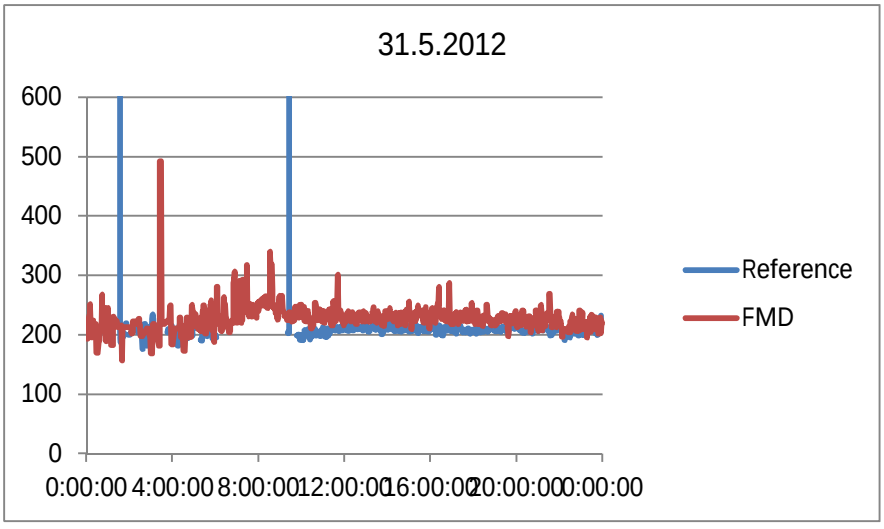
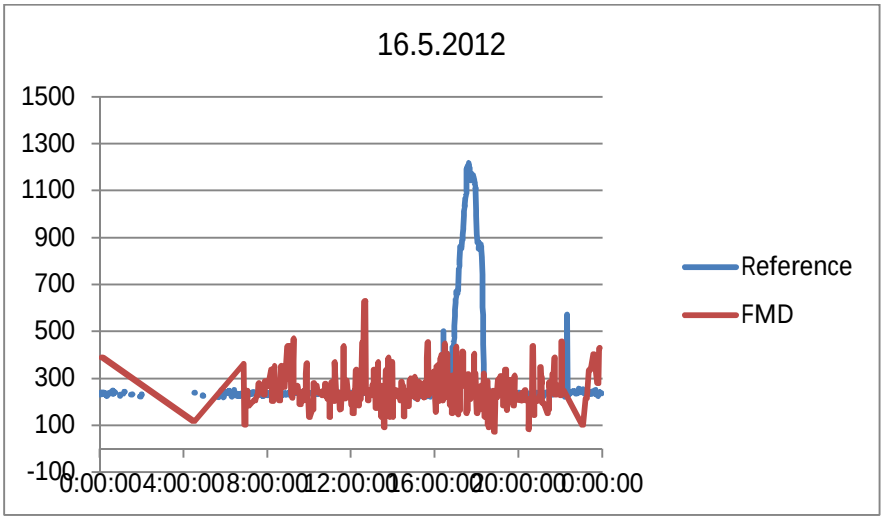
Reference
FMD

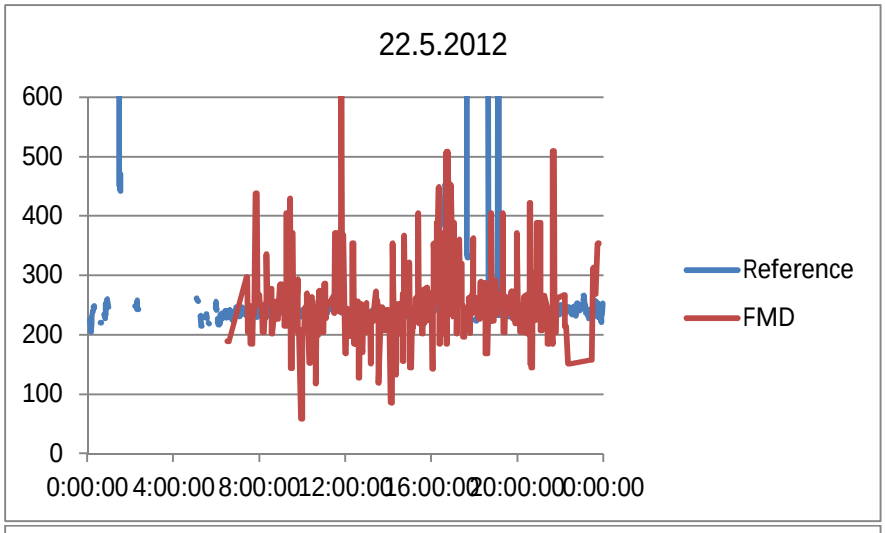
Travel time medians (seconds) on Road 51 link 12 East (NSN link 202)





Travel time medians (seconds) on Road 51 link 2 West (NSN link 161)

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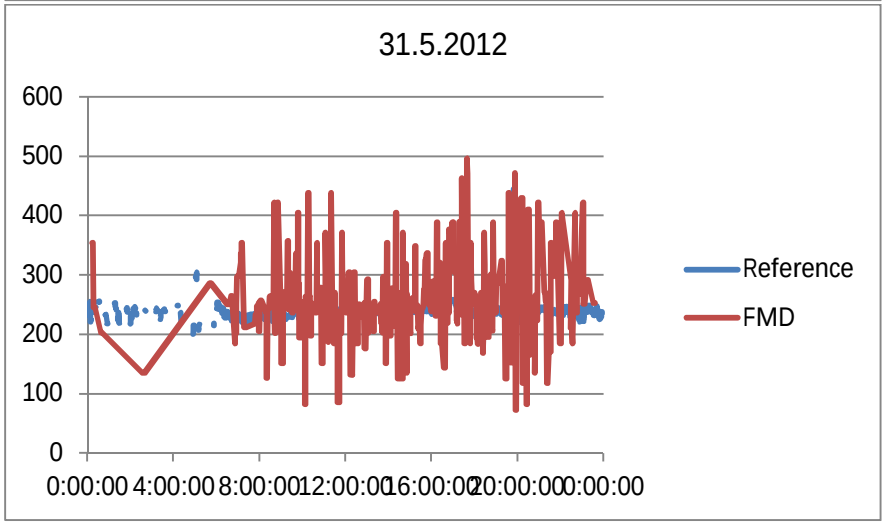
FMD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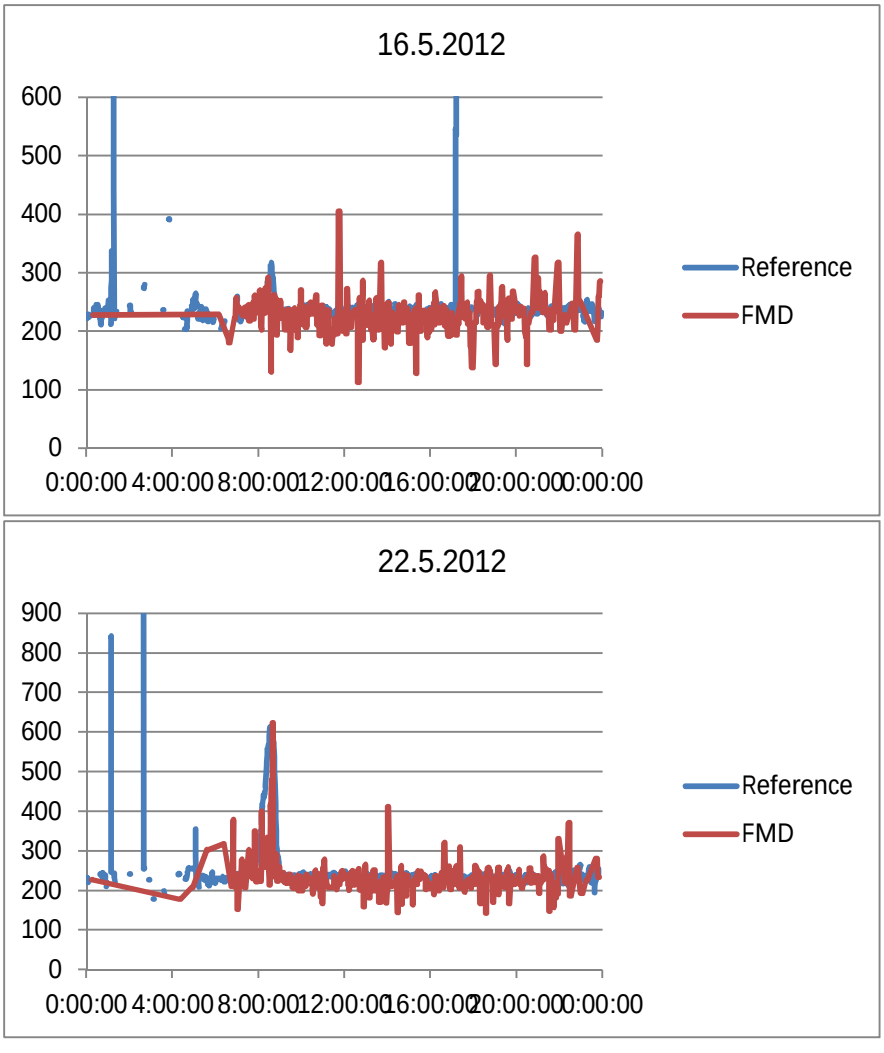
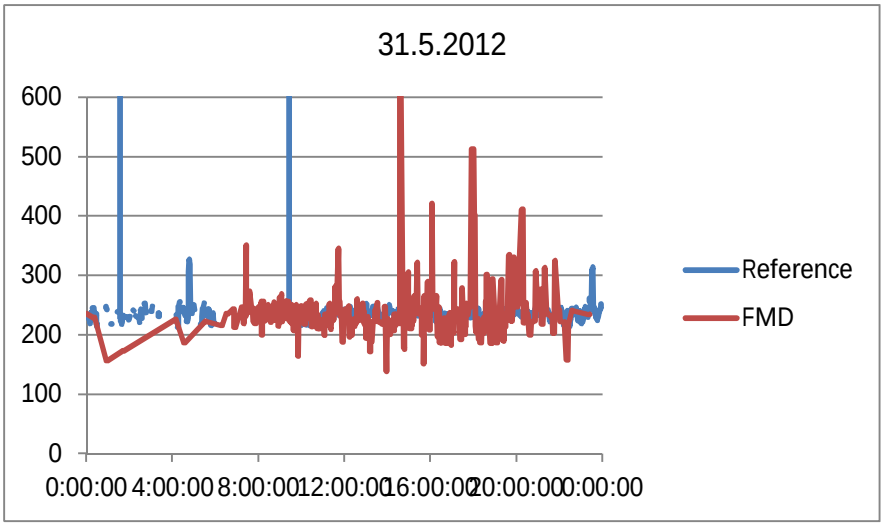
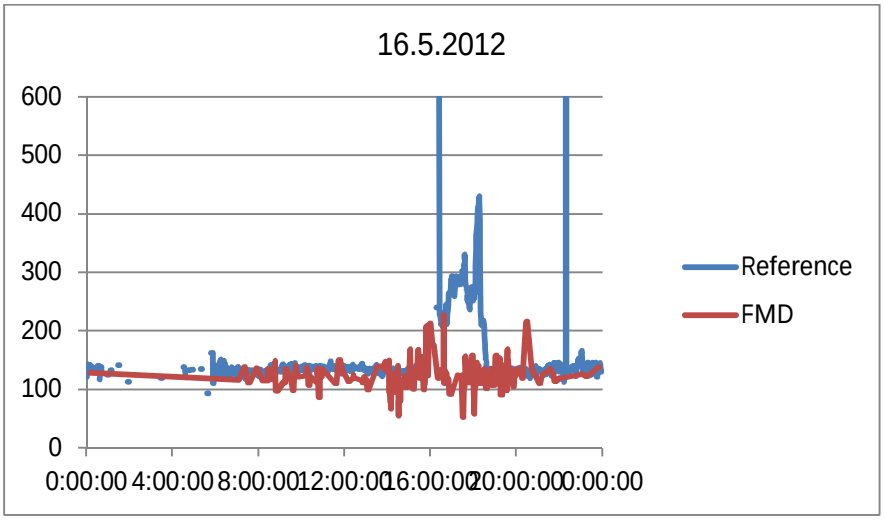
Reference
FMD

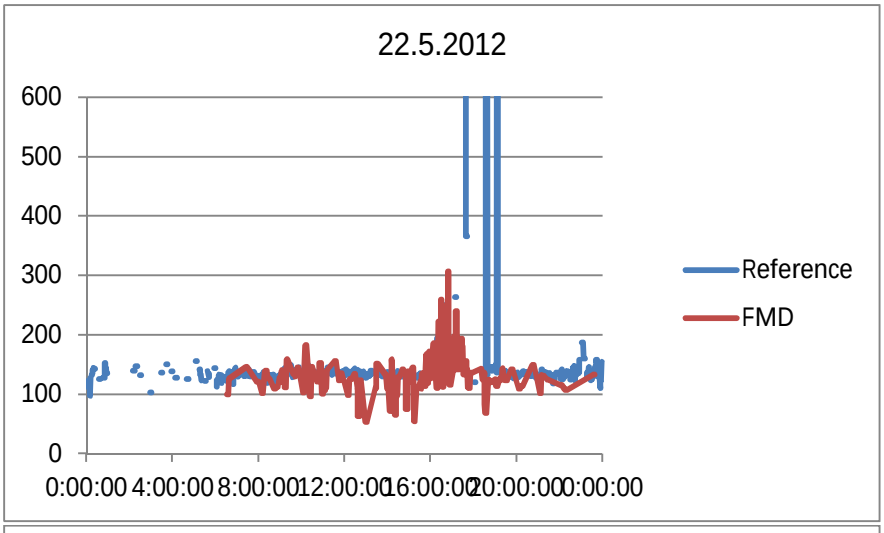
Travel time medians (seconds) on Road 51 link 2 East (NSN link 162)





Travel time medians (seconds) on Road 51 link 3 West (NSN link 61)

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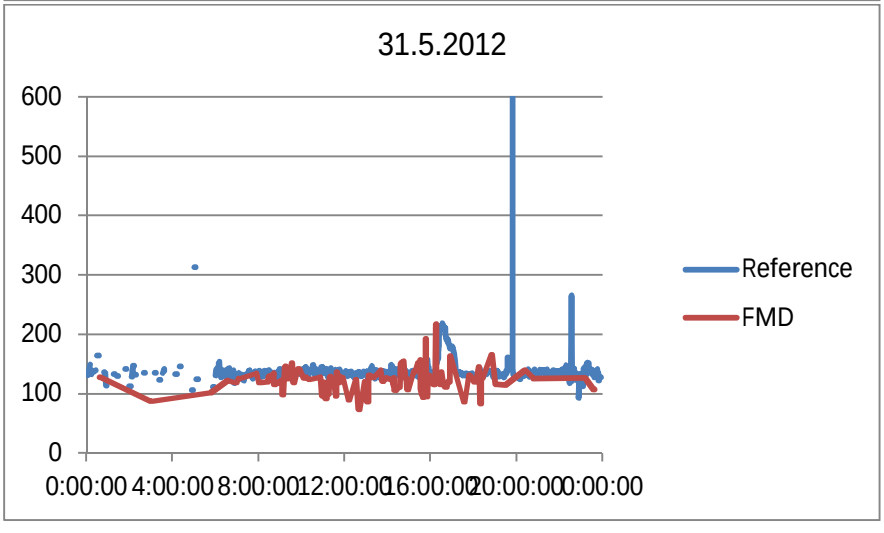
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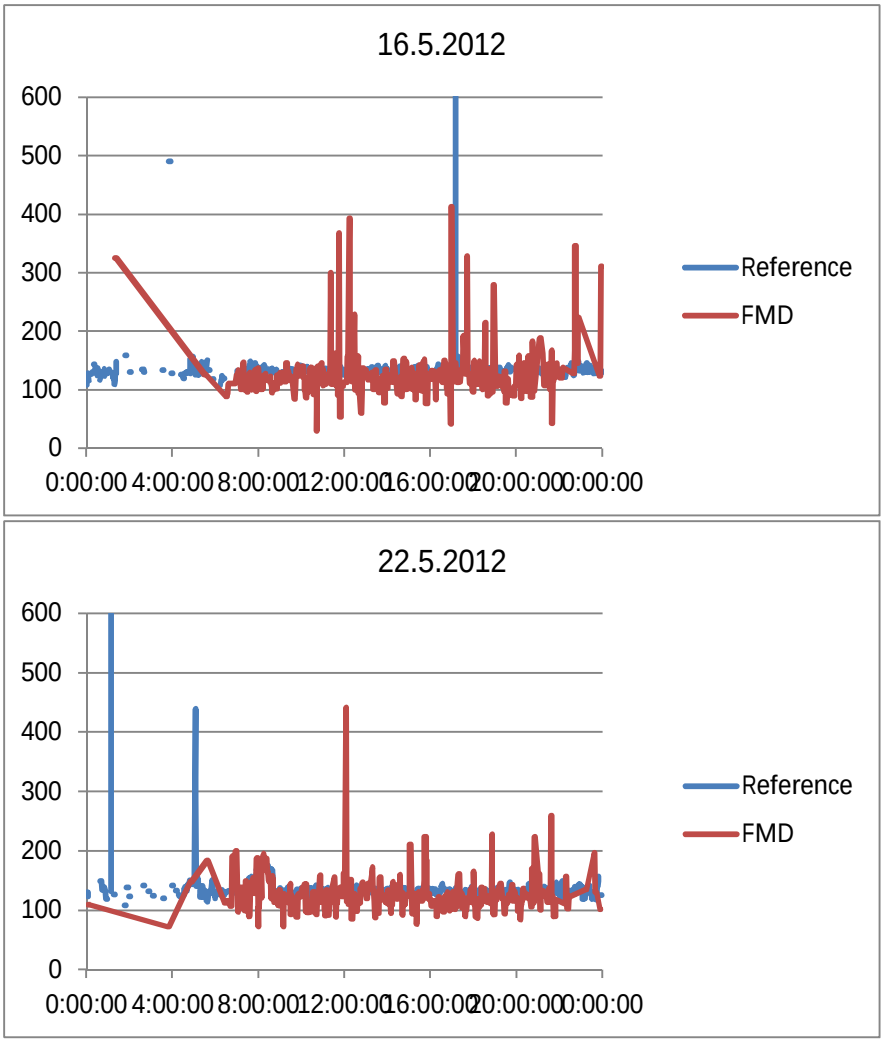
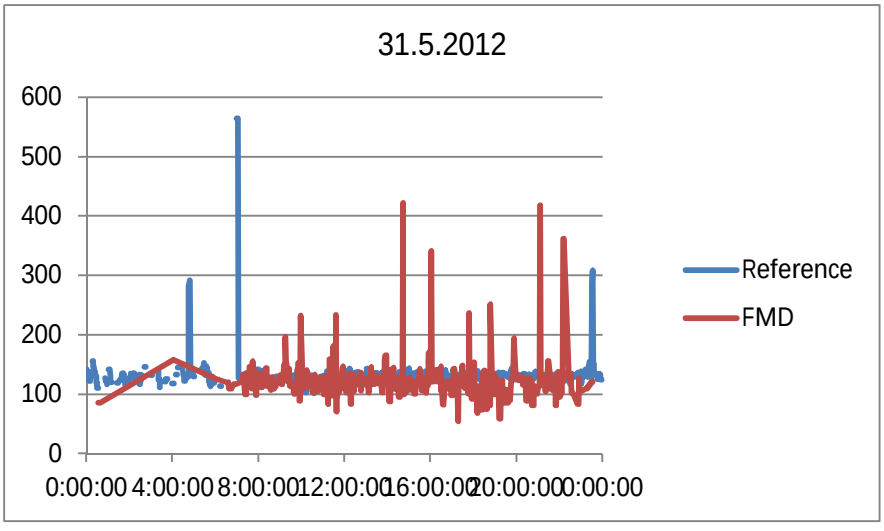
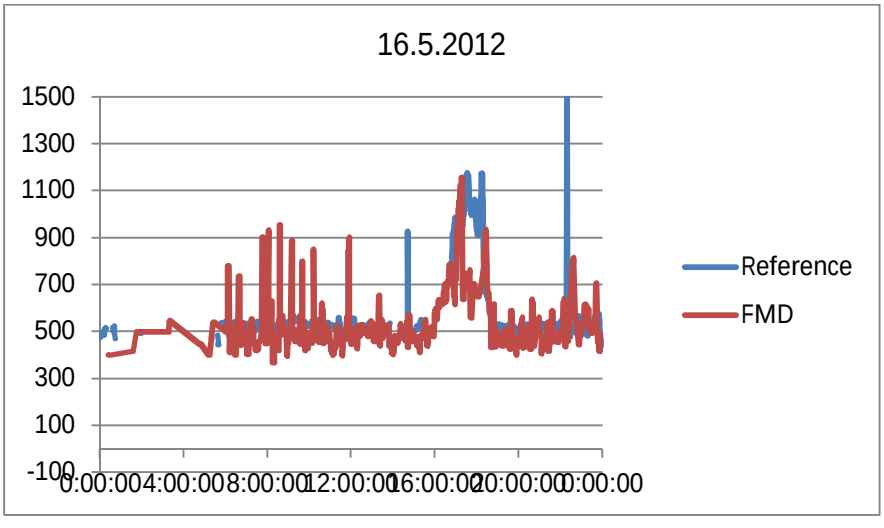
Reference
FMD

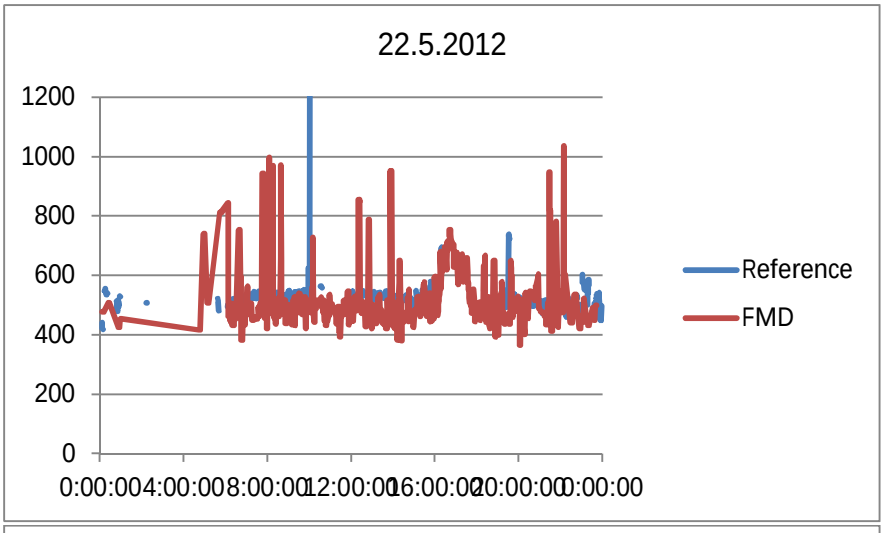
Travel time medians (seconds) on Road 51 link 3 East (NSN link 262)





Travel time medians (seconds) on Road 51 link 4 West (NSN link 301)

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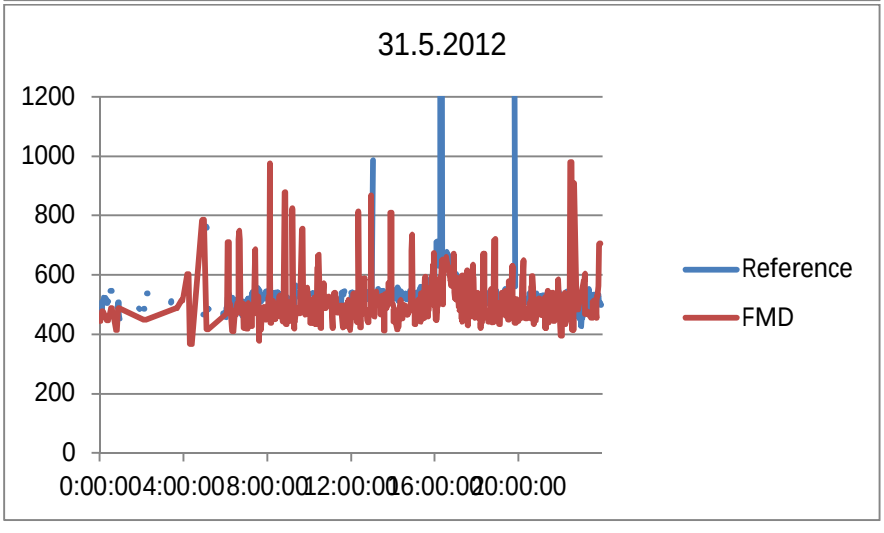
Reference
FMD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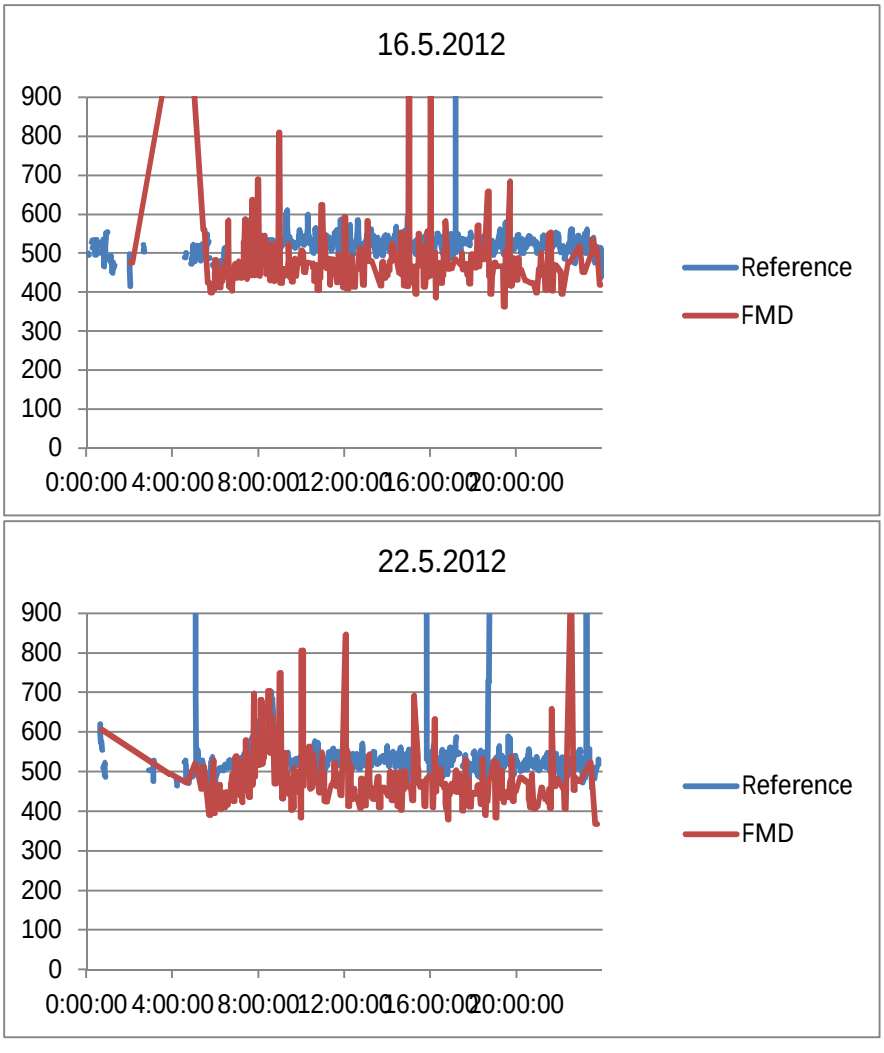
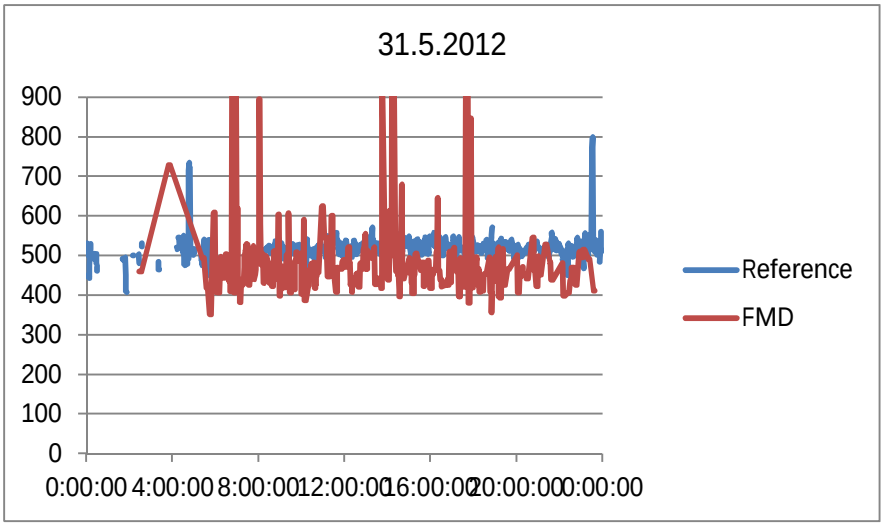
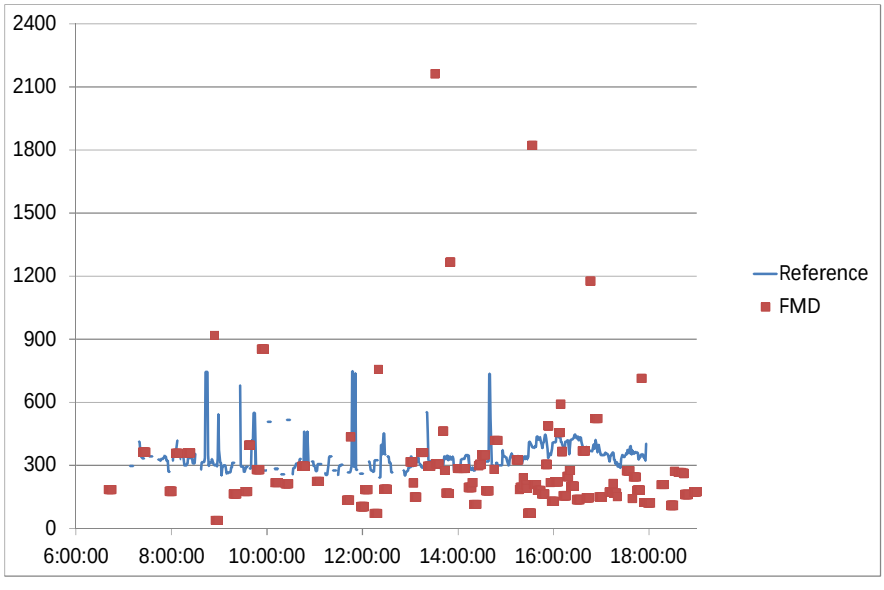
Reference
FMD

Travel time medians (seconds) on Road 51 link 4 East (NSN link 302)

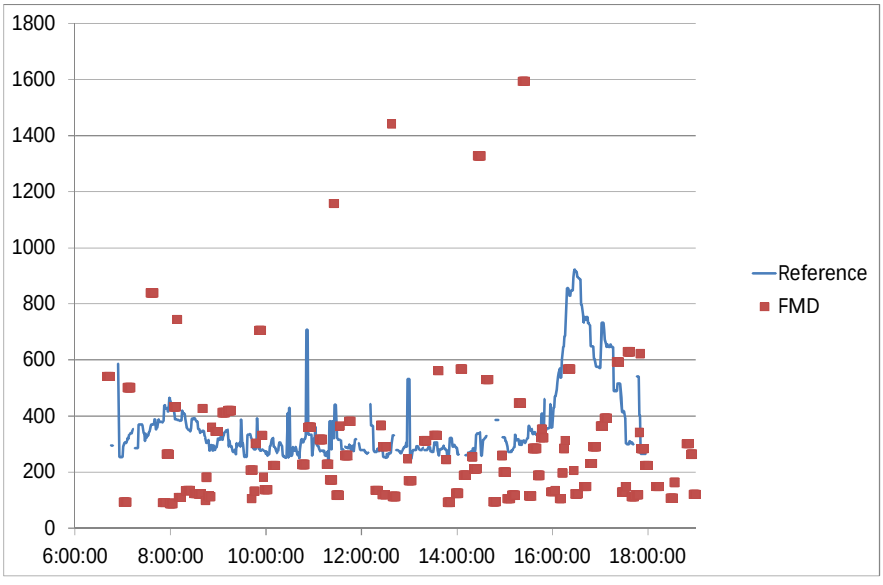




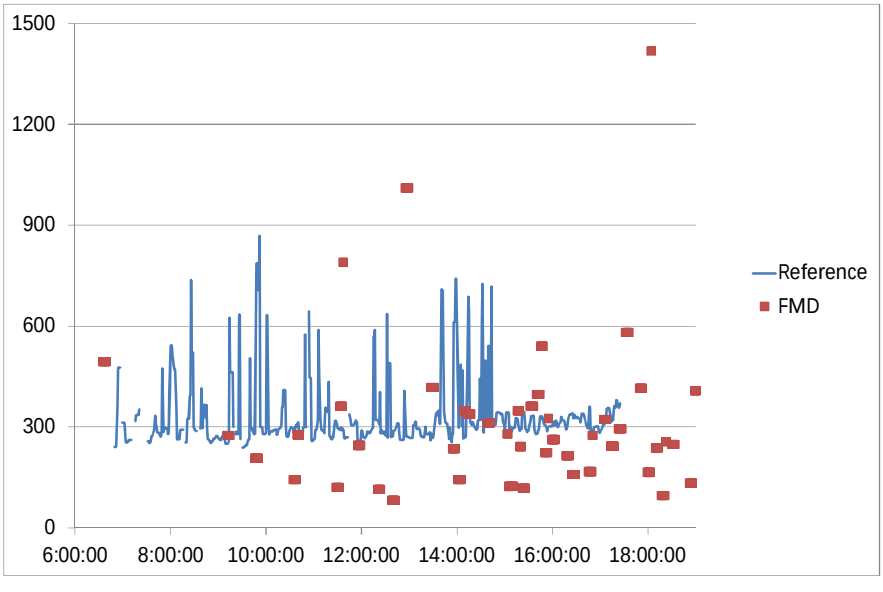
Travel time medians (seconds) on Road 110 West (NSN link 292)



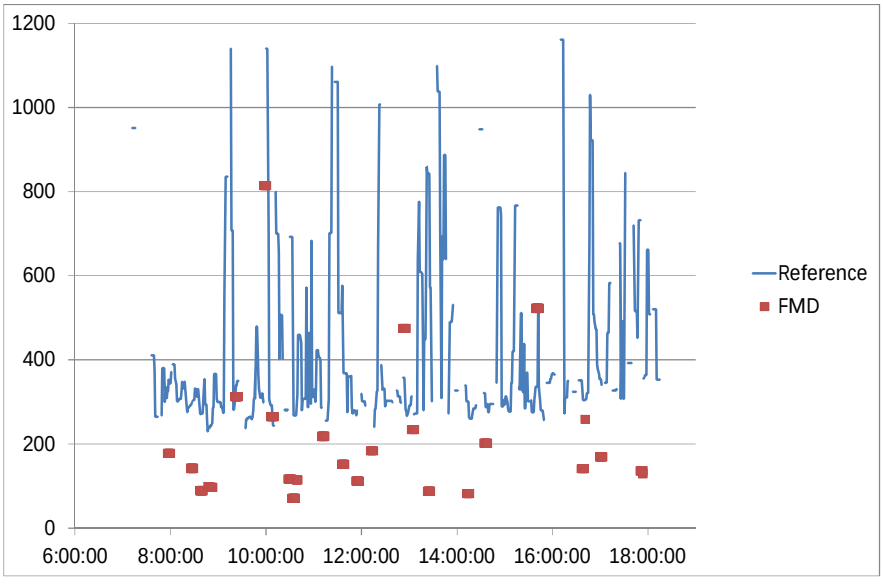
Travel time medians (seconds) on Road 110 East (NSN link 171)



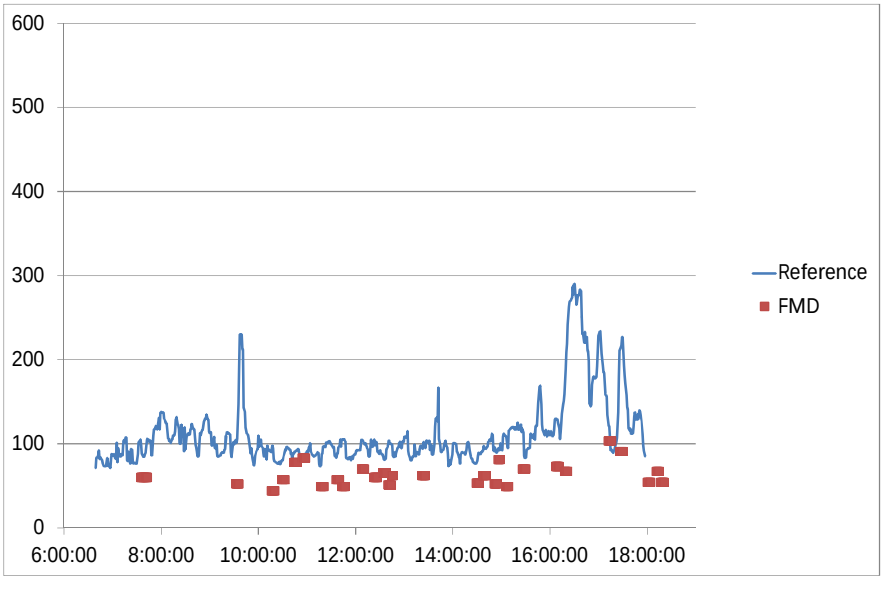
Travel time medians (seconds) on Kuitinmäentie-Martinkyläntie West (NSN link 142)



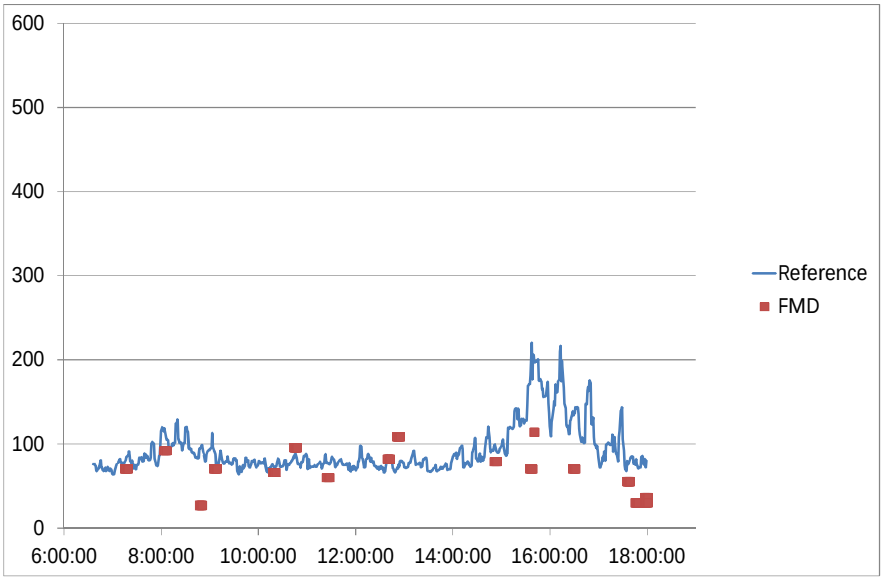
Travel time medians (seconds) on Kuitinmäentie-Martinkyläntie East (NSN link 141)



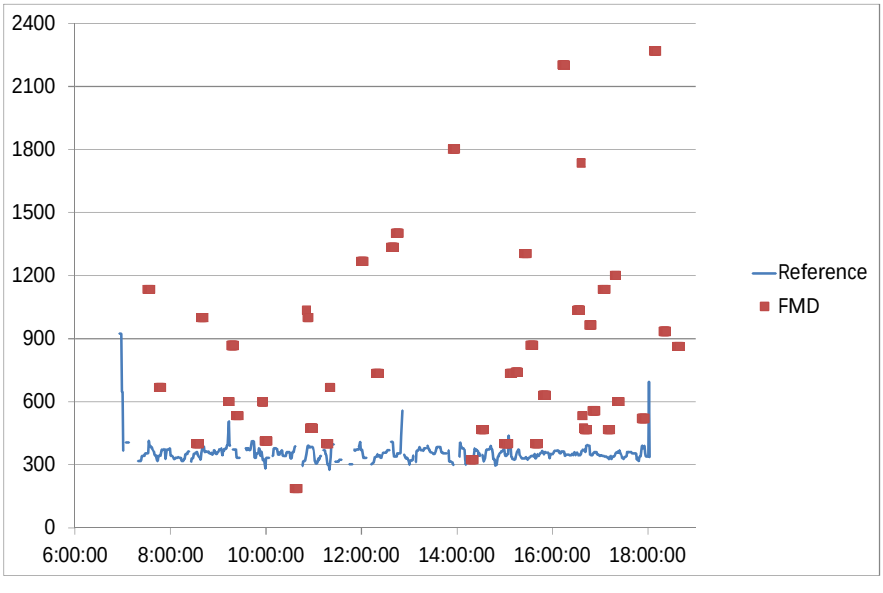
Travel time medians (seconds) on Kalevalantie West (NSN link 131)



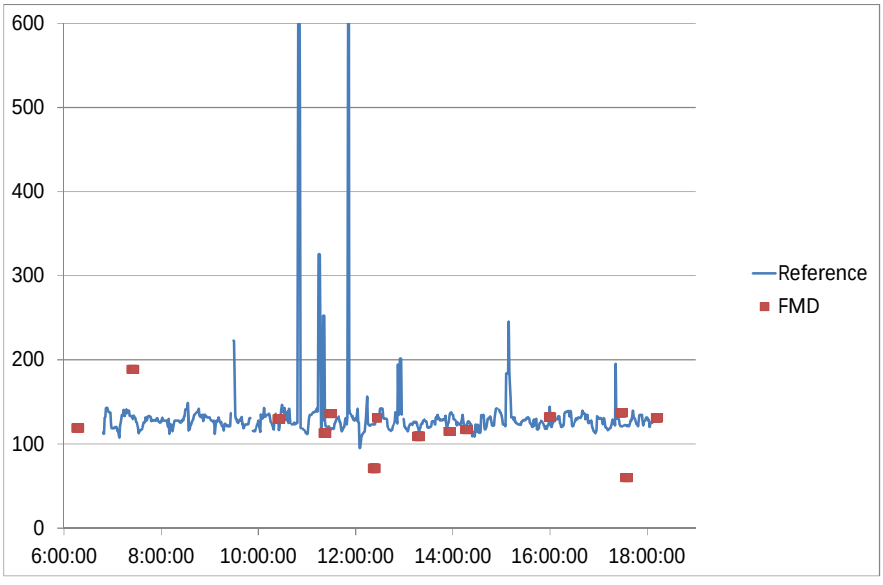
Travel time medians (seconds) on Kalevalantie East (NSN link 272)



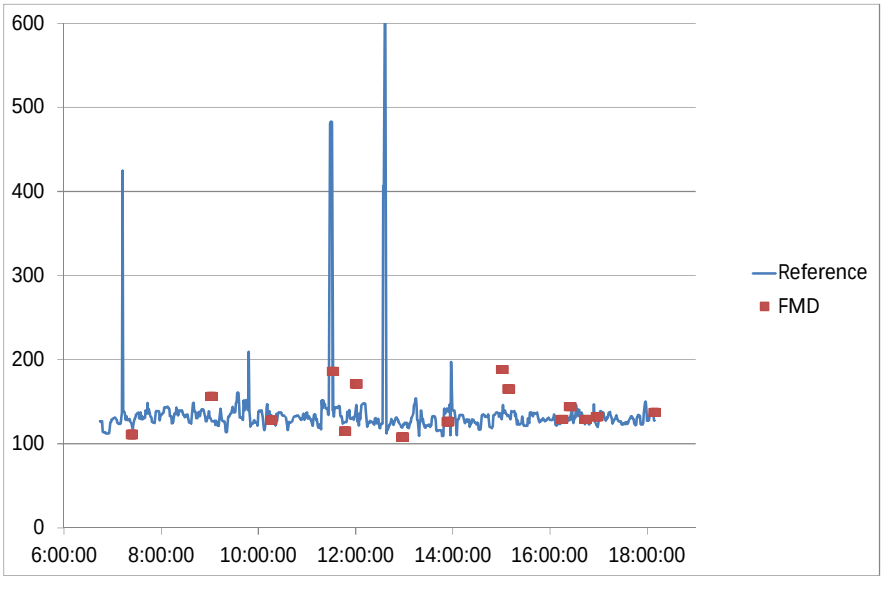
Travel time medians (seconds) on Röyläntie North (NSN link 191)



Travel time medians (seconds) on Kokinkyläntie South (NSN link 182)

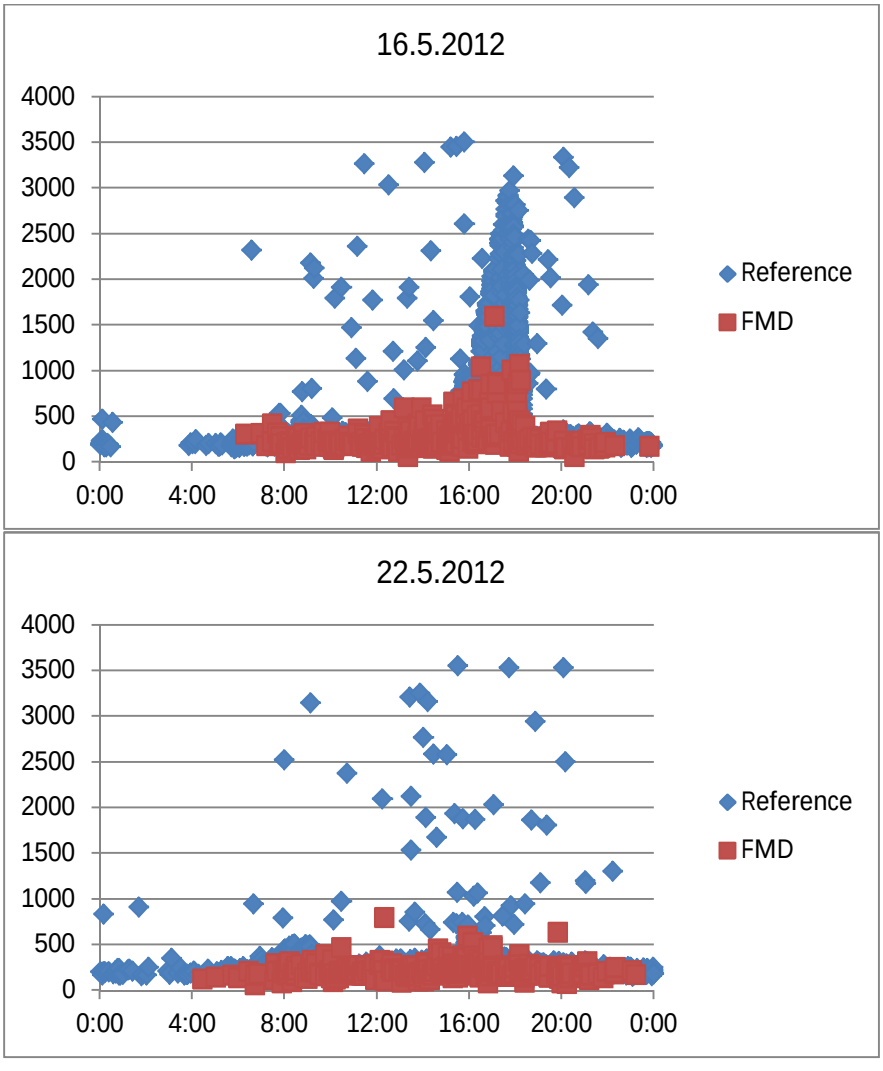


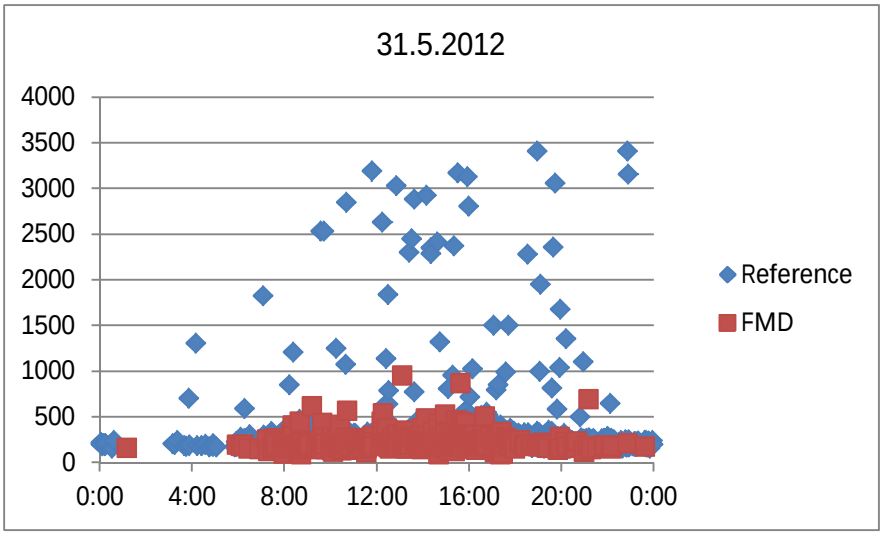
Travel time medians (seconds) on Kokinkyläntie North (NSN link 181)



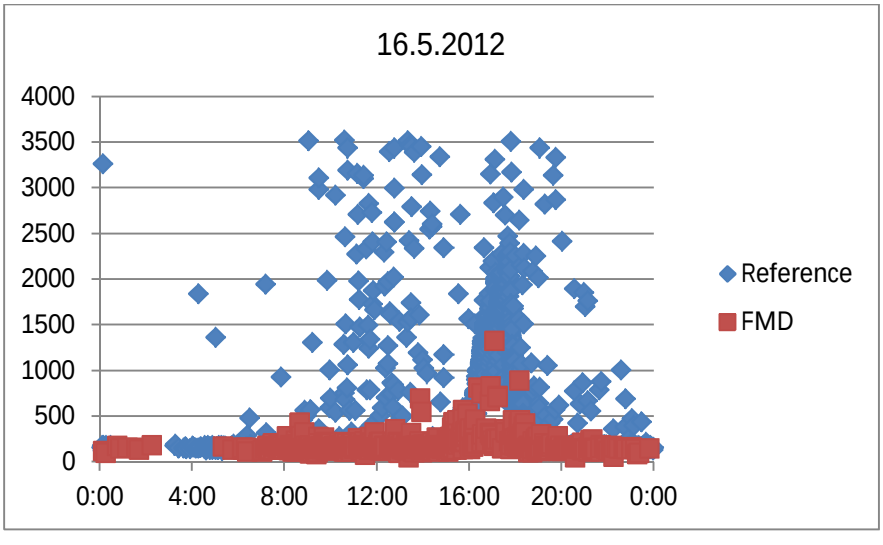
Appendix D: Travel time observations of FMD and reference data

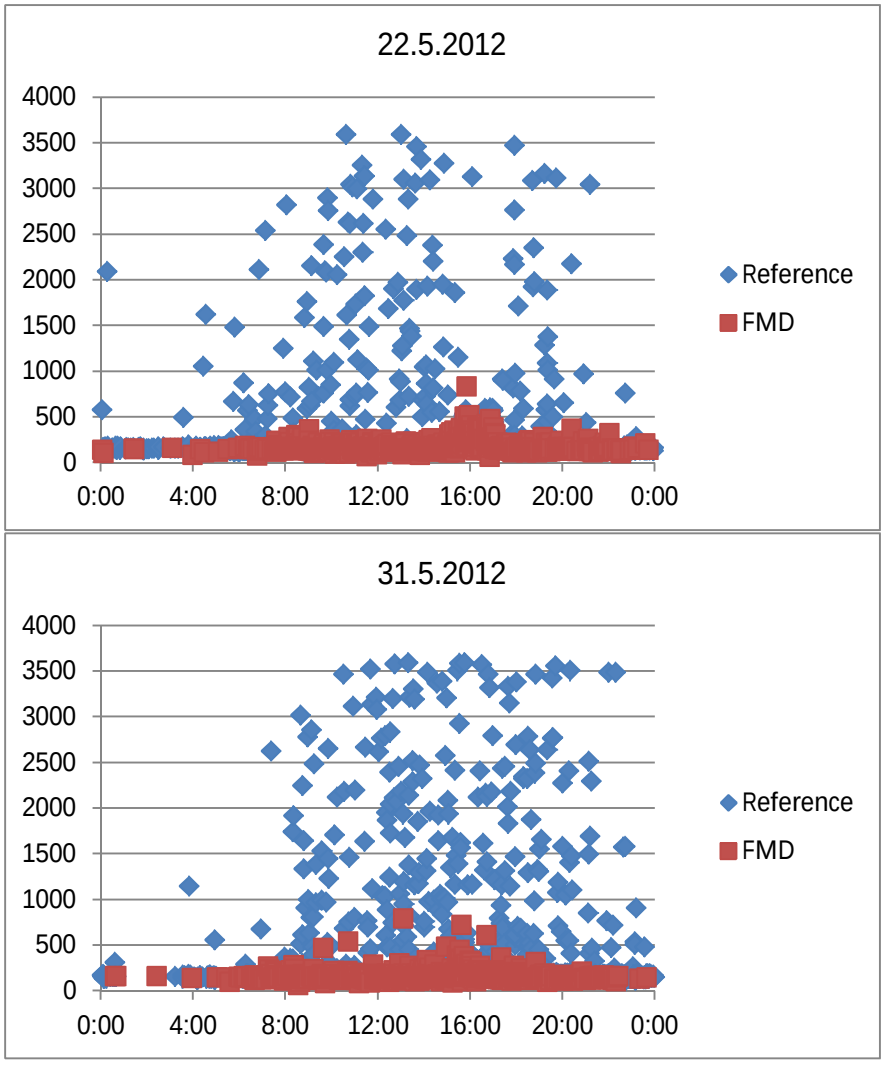
Travel time observations (seconds) on Ring I link 1 North (NSN link 41)



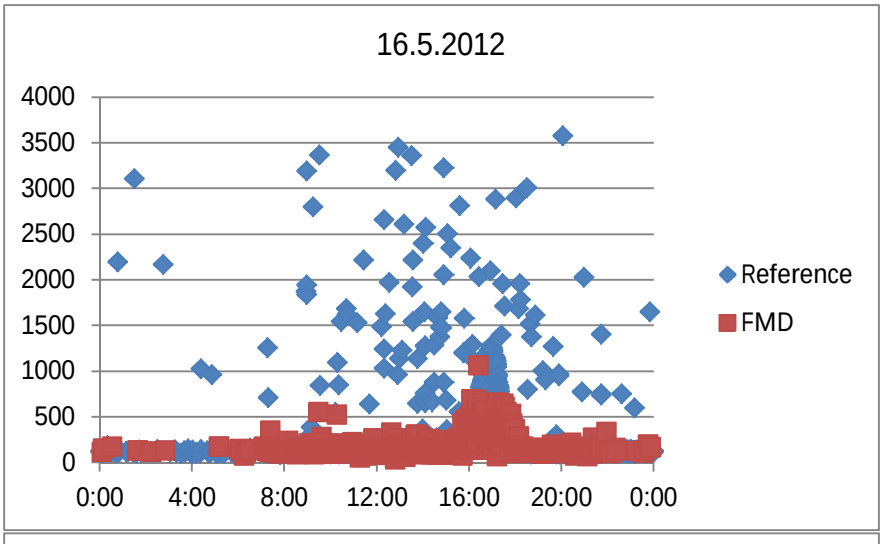


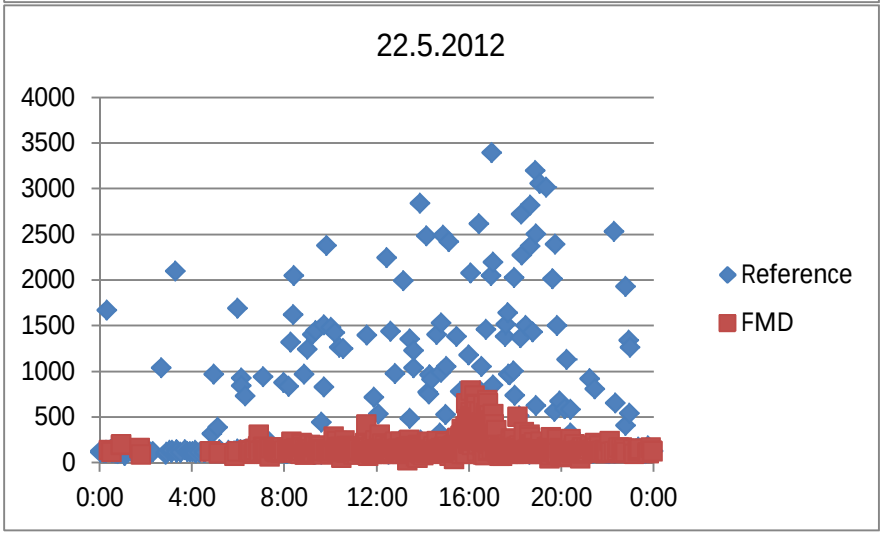
Travel time observations (seconds) on Ring I link 2 North (NSN link 31)

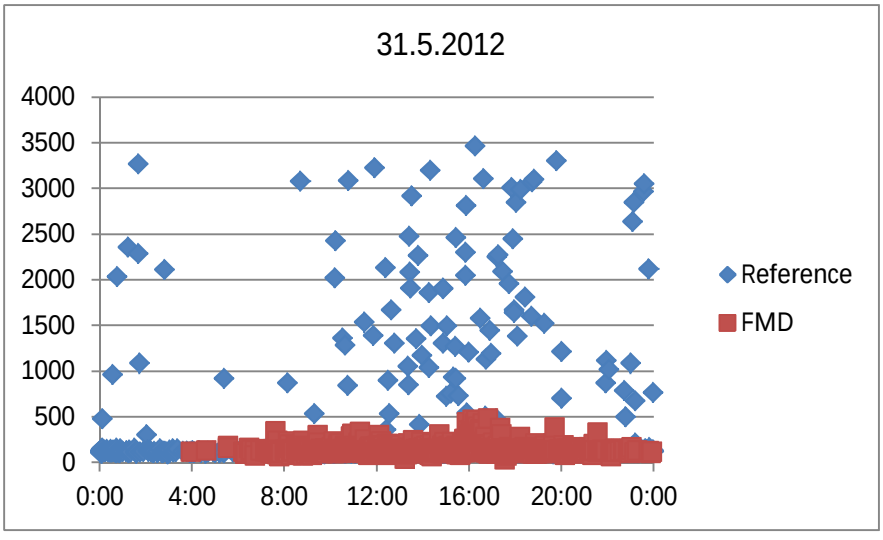



22.5.2012
4000
3500
3000
2500
2000
1500
1000
500
0
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Reference
FMD
31.5.2012
4000
3500
3000
2500
2000
1500
1000
500
0
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Reference
FMD

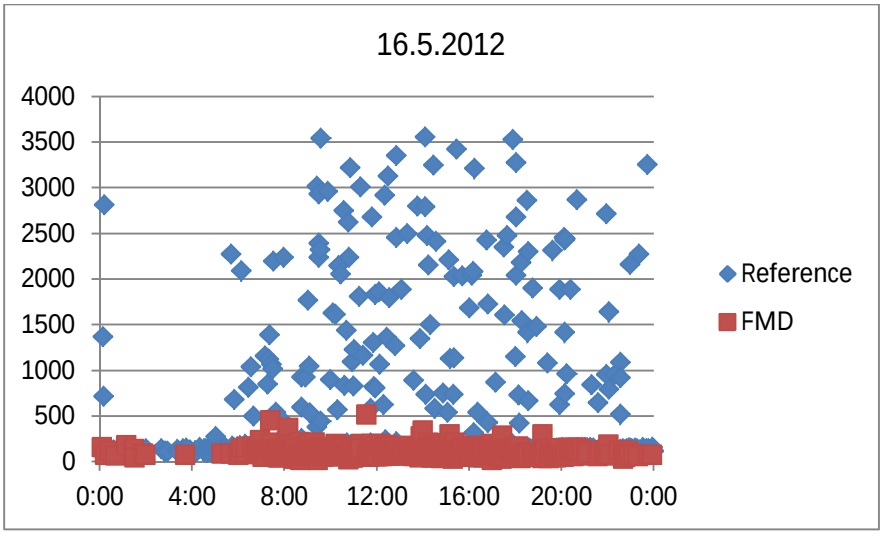
Travel time observations (seconds) on Road 1 link 1 West (NSN link 21)

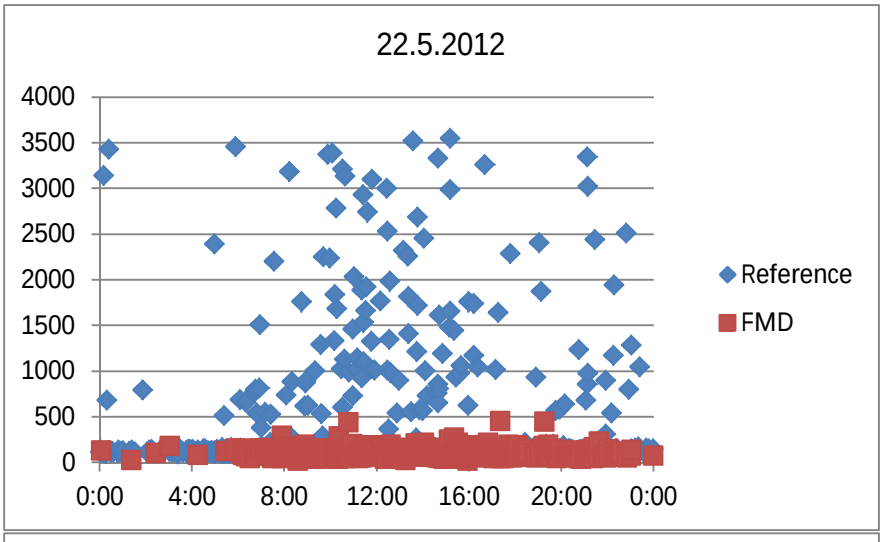


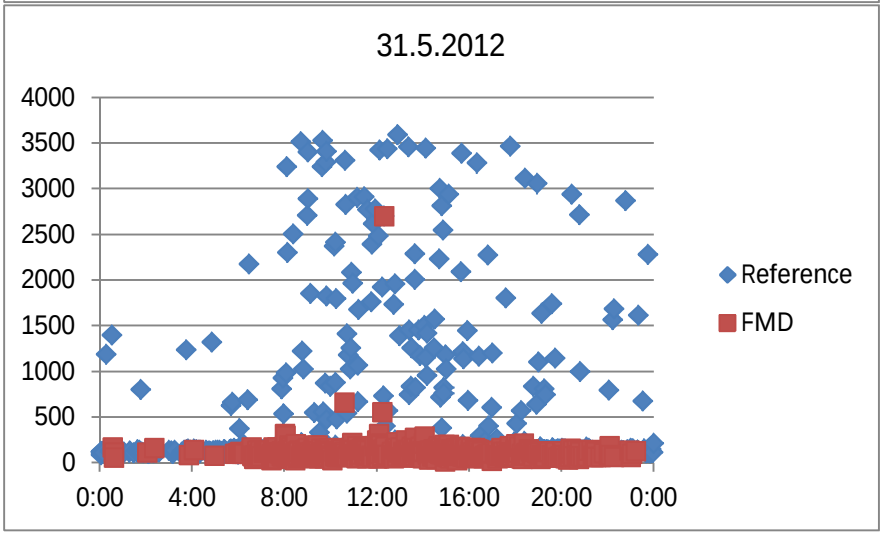




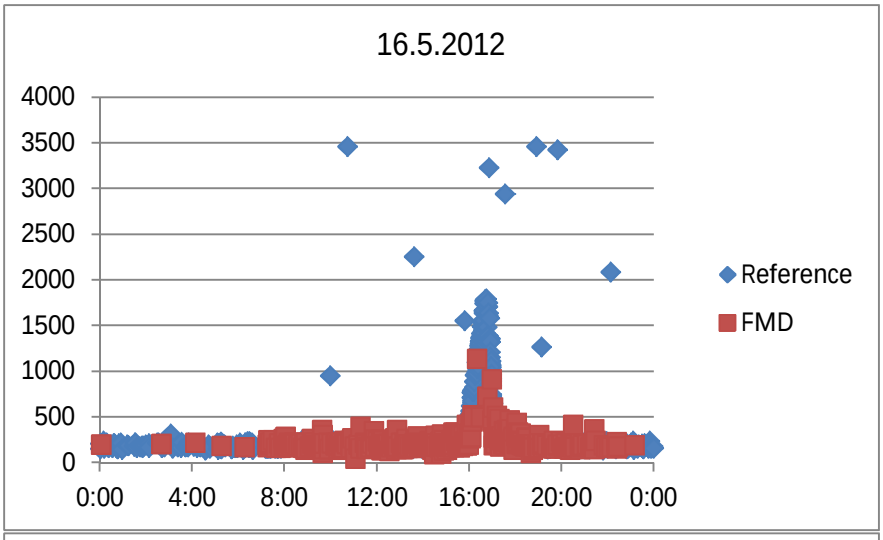
Travel time observations (seconds) on Road 1 link 1 East (NSN link 222)

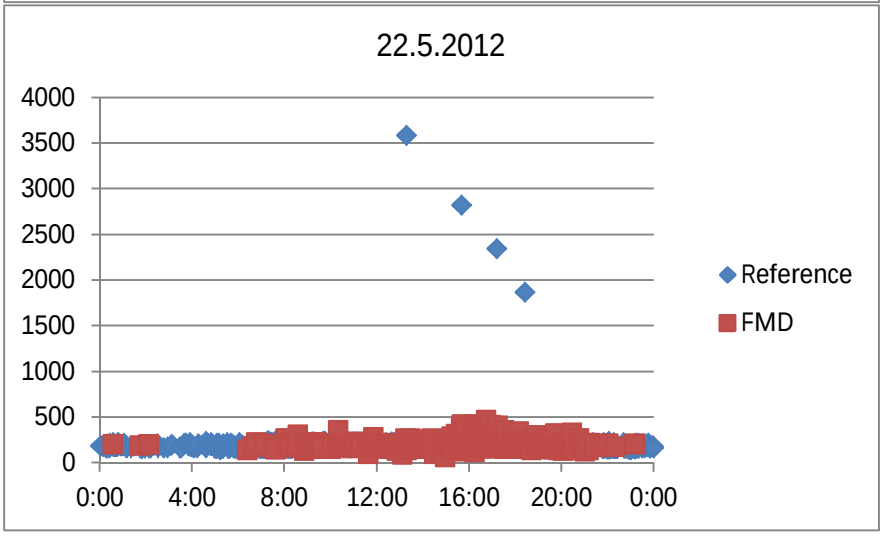


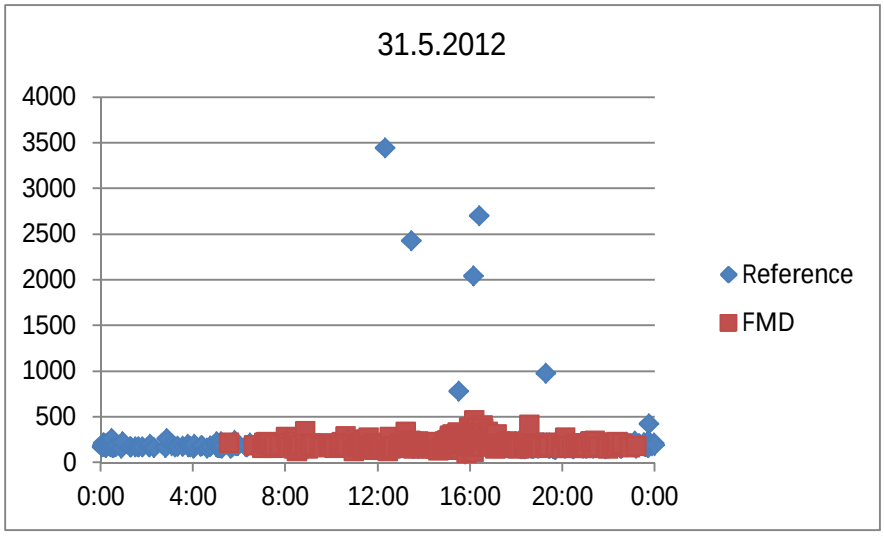

22.5.2012
4000
3500
3000
2500
2000
1500
1000
500
0
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Reference
FMD


31.5.2012
4000
3500
3000
2500
2000
1500
1000
500
0
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Reference
FMD

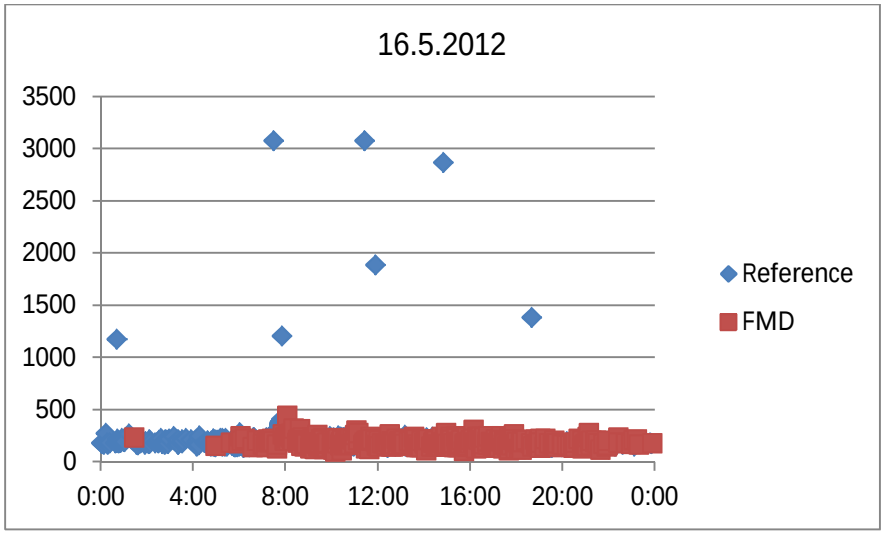
Travel time observations (seconds) on Road 1 link 2 West (NSN link 11)

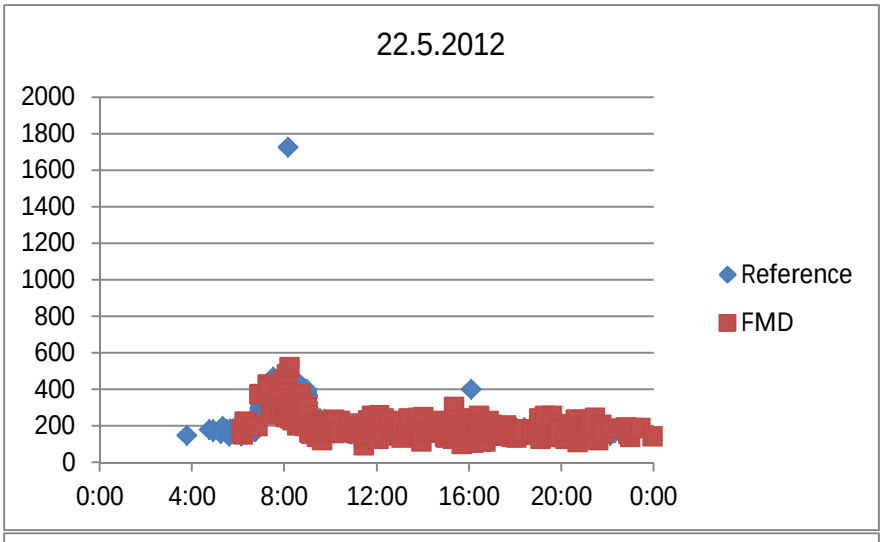


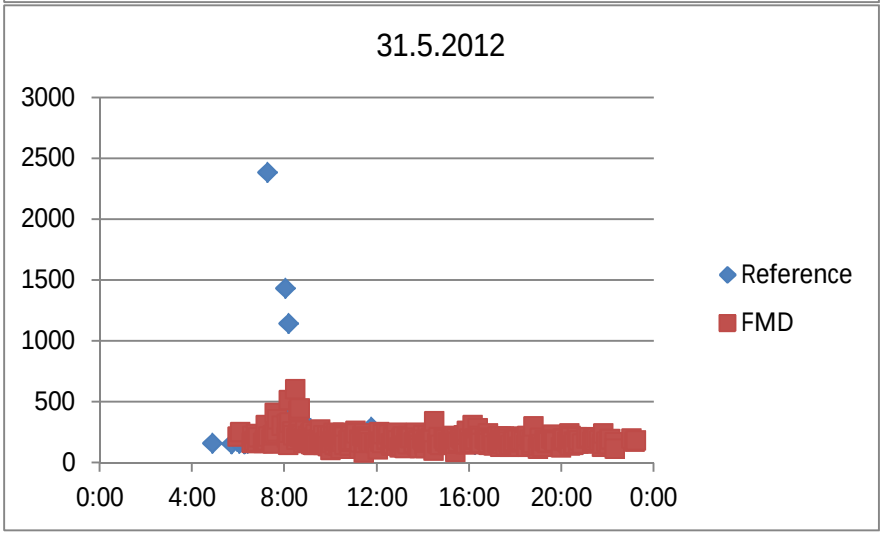




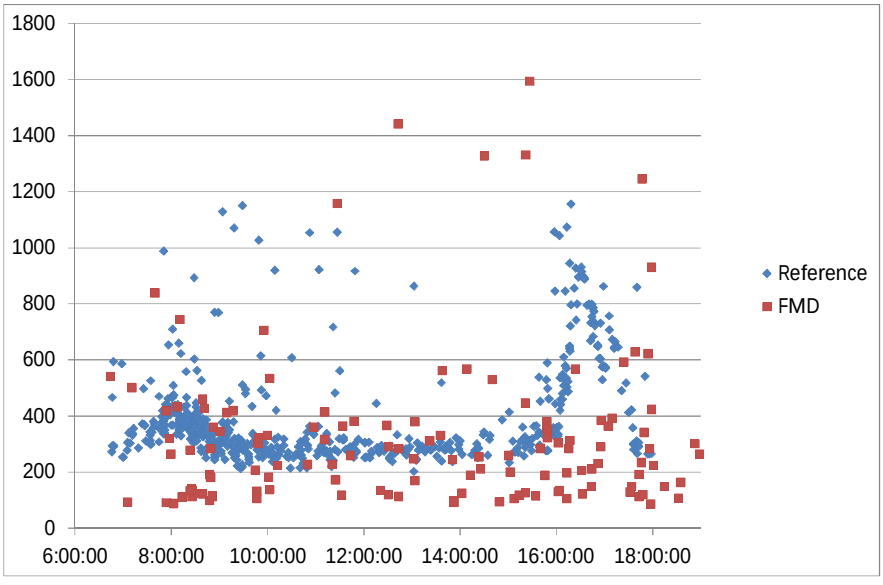
Travel time observations (seconds) on Road 1 link 2 East (NSN link 212)



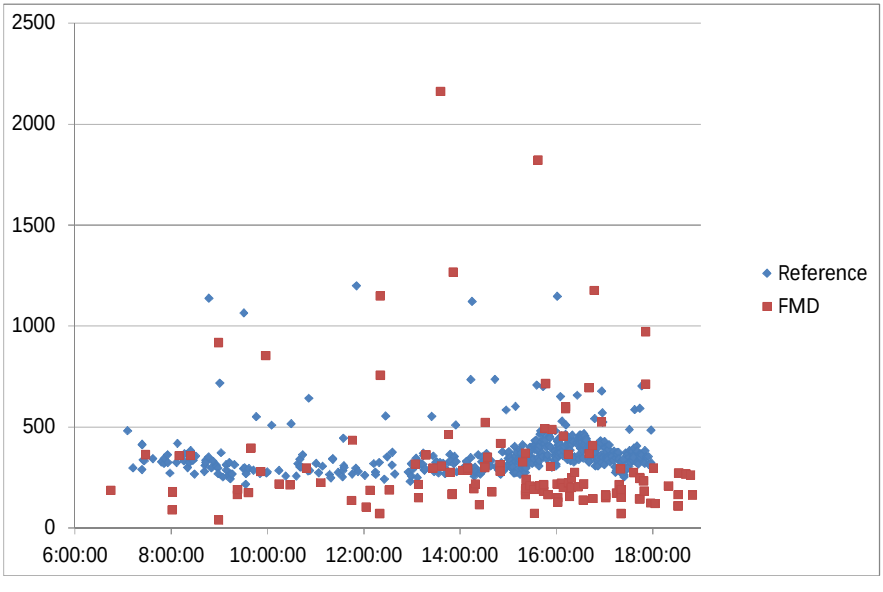

22.5.2012
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Reference
FMD


31.5.2012
3000
2500
2000
1500
1000
500
0
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Reference
FMD

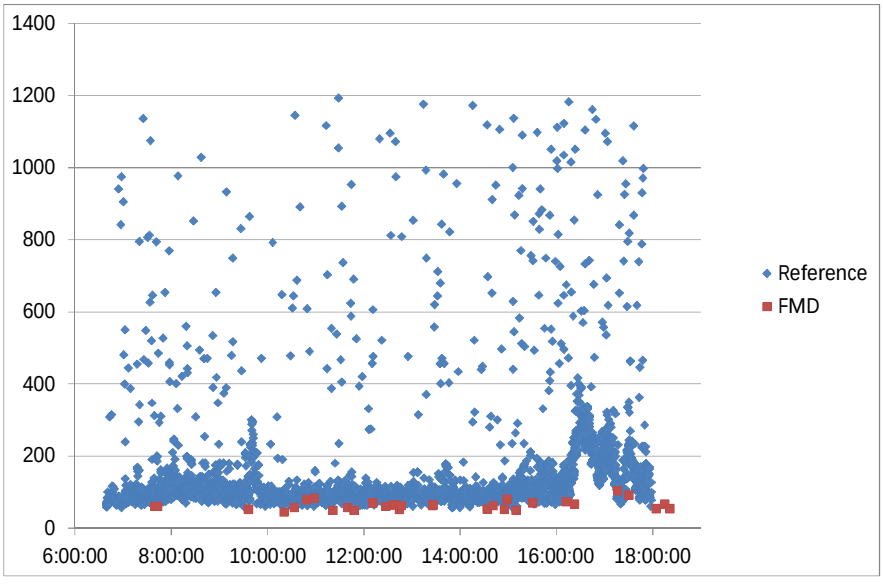
Travel time observations (seconds) on Road 110 East



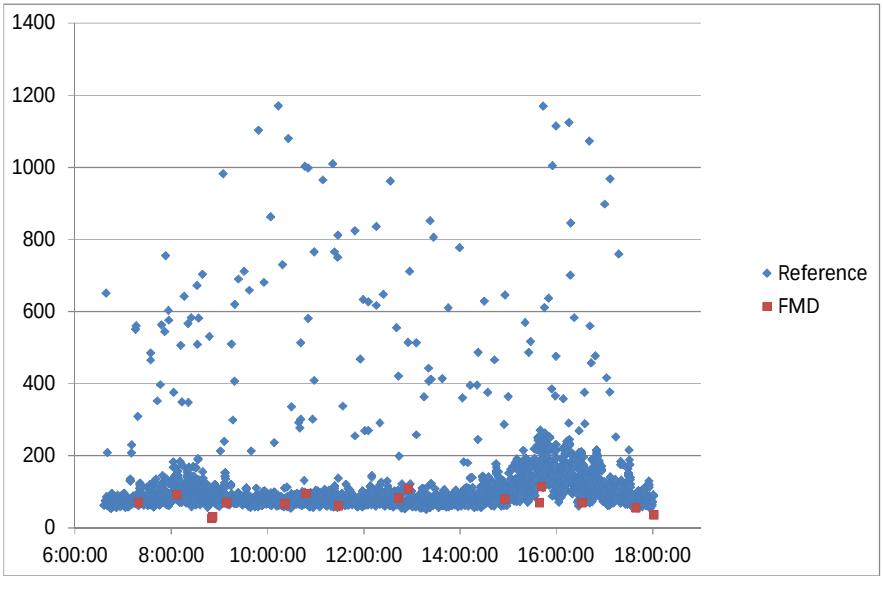
Travel time observations (seconds) on Road 110 West



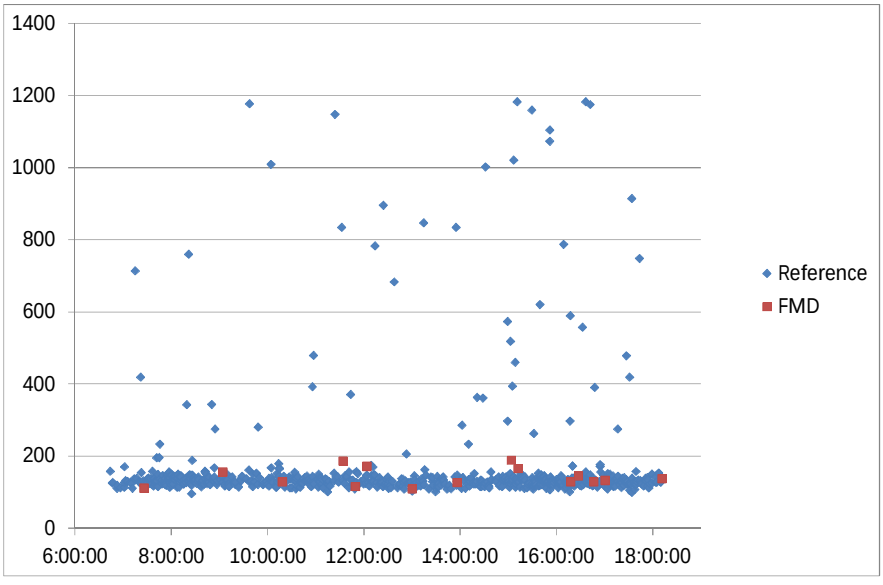
Travel time observations (seconds) on Kalevalantie West



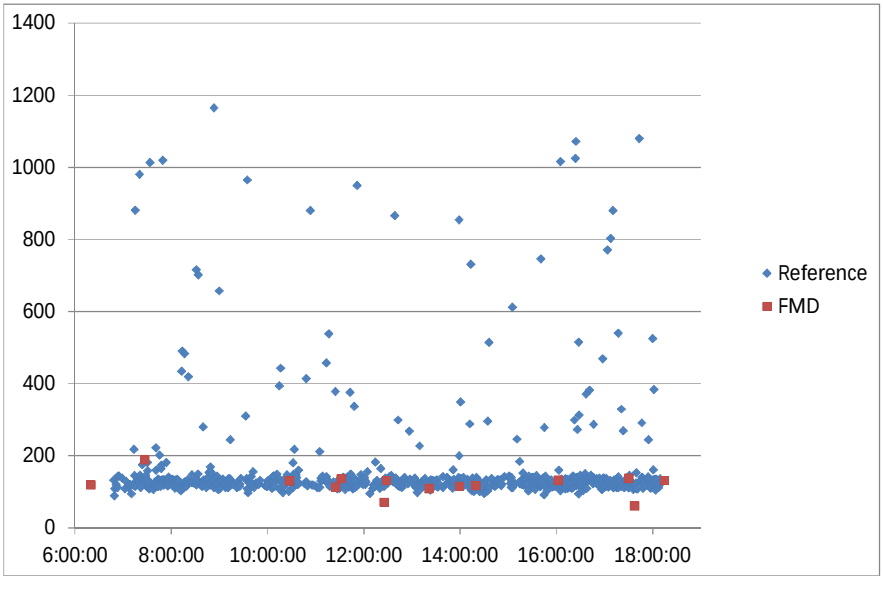
Travel time observations (seconds) on Kalevalantie East



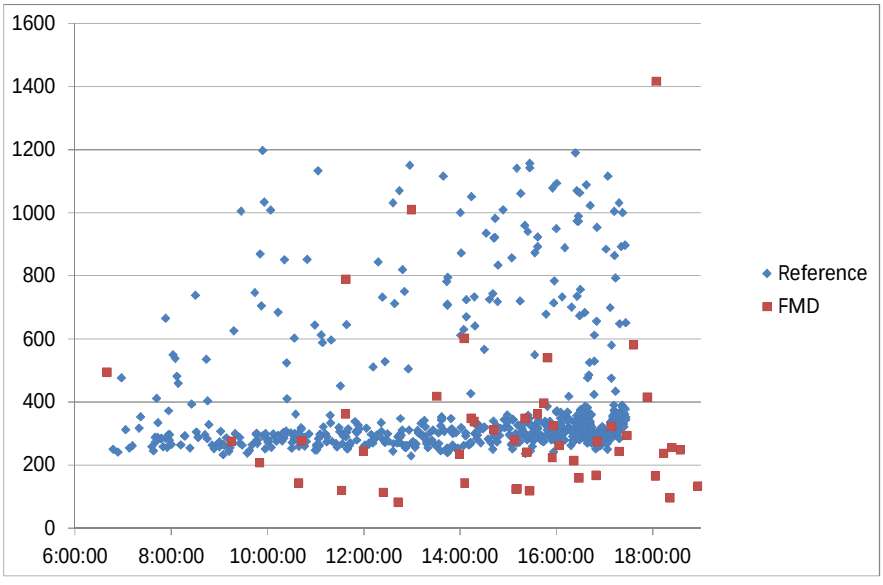
Travel time observations (seconds) on Kokinkyläntie North



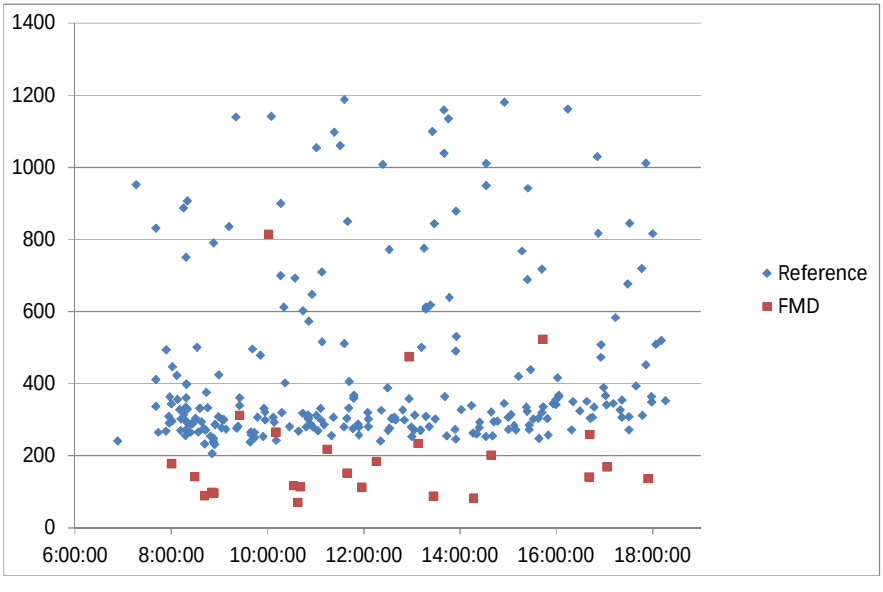
Travel time observations (seconds) on Kokinkyläntie South



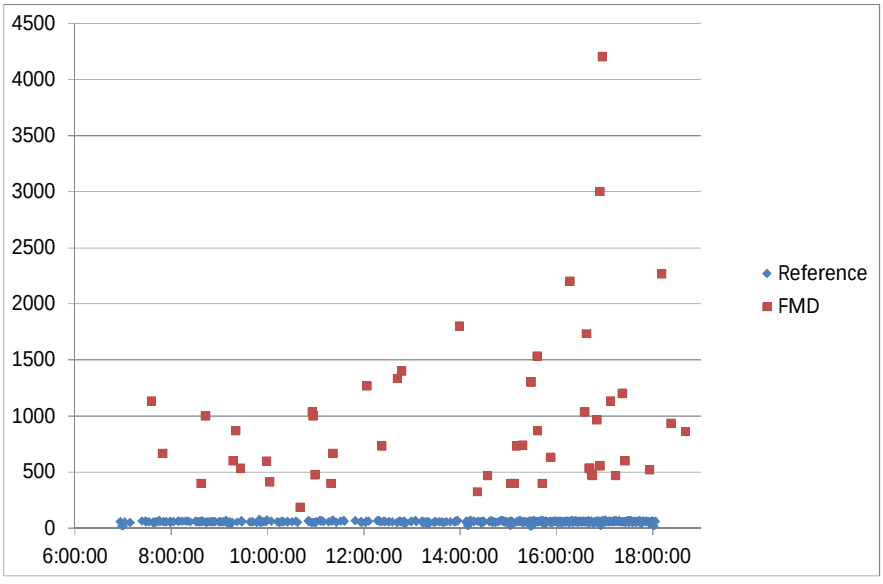
Travel time observations (seconds) on Kuitinmäentie-Martinkyläntie West



Travel time observations (seconds) on Kuitinmäentie-Martinkyläntie East



Travel time observations (seconds) on Röyläntie North



Appendix E: Number of observations

Table E1. Average number of observations used in the calculation of the 5-minute median, average Monday to Friday traffic volume per 5 minutes (LAMxxx/direction) when available

NSN Link	Link	Method	Time																						
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
41	Ring I link 1 North	FMD	1,0	1,0	1,0	1,0	1,0	1,0	1,1	1,5	2,1	2,1	2,1	2,3	2,3	2,5	2,8	3,9	3,4	2,7	2,2	1,9	1,8	1,5	1,2	1,2
		Reference	1,8	1,4	1,3	1,1	1,3	3,3	9,2	18	23	8,0	7,2	5,4	7,2	8,6	9,0	12	16	28	24	15	12	9,0	5,0	2,9
		LAM116/1	12	8,0	5,7	6,0	10	36	132	204	205	138	127	132	140	153	195	238	183	187	156	118	103	70	42	27
242	Ring I link 1 South	FMD	1,2	1,0	1,3	0,0	1,0	1,4	2,0	2,3	3,0	3,3	2,8	3,0	2,8	2,8	2,6	3,3	4,5	3,2	2,0	2,2	1,8	1,6	1,3	1,4
		LAM116/2	16	10	7,4	6,7	14	50	218	286	268	199	139	144	152	153	165	227	237	203	154	127	106	77	48	32
31	Ring I link 2 North	FMD	1,1	1,1	1,0	1,1	1,1	1,0	1,5	2,4	4,5	4,6	4,5	4,5	4,8	5,2	6,0	7,2	5,6	5,7	4,3	3,3	3,0	2,5	1,6	1,3
		Reference	2,5	1,4	1,5	1,6	2,9	10	29	61	81	48	43	31	28	31	23	16	16	27	40	42	32	22	13	5,8
		LAM126/1	14	10	6,6	7,0	13	48	183	289	284	179	154	160	170	190	250	321	256	250	195	143	121	86	53	31
232	Ring I link 2 South	FMD	1,5	1,9	1,8	1,7	1,8	1,8	3,1	4,0	6,8	7,0	5,6	6,0	5,7	5,9	6,7	9,0	10	7,7	5,5	4,3	3,7	2,9	2,2	1,8
		LAM126/2	19	11	7,9	7,2	15	62	268	318	298	224	151	157	162	167	187	271	289	236	175	143	120	87	55	38
51	Ring II North	FMD	1,0	1,0	1,7	0,0	1,0	1,0	1,0	1,6	2,1	2,1	1,7	1,8	1,8	2,0	2,1	2,4	2,1	2,1	2,0	1,7	1,9	1,5	1,2	1,2
		Reference	4,2	2,7	2,3	2,0	5,2	17	40	42	50	33	32	31	32	41	40	45	38	42	43	47	42	33	18	12
		LAM162/1	8,5	5,4	3,7	3,6	7,2	27	100	189	202	130	105	109	113	125	145	198	175	169	139	115	97	63	32	20
		LAM163/1	10	6,5	4,2	4,0	8,2	30	112	220	242	155	125	129	135	147	175	224	180	190	161	128	108	72	37	23

NSN Link	Link	Method	Time																							
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
252	Ring II South	FMD	1,2	1,1	1,4	1,3	1,2	1,2	1,4	1,8	2,6	2,7	2,4	2,4	2,1	2,2	2,8	3,0	3,9	3,5	2,5	2,4	2,1	1,8	1,5	1,2
		Reference	4,4	2,9	2,2	2,7	4,3	15	59	80	59	73	45	28	30	28	46	47	70	59	74	65	53	36	21	12
		LAM162/2	6,3	4,3	2,6	2,5	4,7	19	99	164	173	128	90	85	74	63	71	109	133	137	115	87	60	37	20	16
91	Ring II turning road 1 East	FMD	1,1	1,1	1,1	1,0	1,1	1,1	1,8	2,8	5,6	4,5	3,5	3,5	3,2	3,4	3,5	4,4	3,8	3,1	2,7	2,3	2,0	2,0	1,7	1,2
222	Road 1 link 1 East	FMD	1,1	1,1	1,1	1,0	1,1	1,1	1,8	2,8	5,7	4,6	3,6	3,5	3,2	3,5	3,5	4,4	3,8	3,2	2,8	2,2	2,0	2,0	1,7	1,2
		Reference	2,3	1,3	1,1	1,4	3,2	15	55	73	86	52	32	28	27	25	21	20	21	21	26	24	19	15	7,6	3,7
		LAM144/2	13	7,9	6,5	7,3	15	57	245	381	390	231	154	151	155	154	172	211	205	187	157	124	103	75	46	26
21	Road 1 link 1 West	FMD	1,5	1,4	1,4	1,6	1,1	1,6	1,7	2,3	3,3	4,4	4,3	4,8	5,3	6,1	8,0	12	14	11	6,1	5,0	4,3	3,1	1,9	1,7
		Reference	2,7	1,7	1,5	1,5	1,9	2,3	2,9	5,0	4,5	6,4	8,0	7,8	12	16	25	31	30	29	20	16	12	9,1	8,2	4,2
		LAM144/1	18	11	7,5	7,4	12	34	124	186	187	157	134	147	159	178	226	373	353	290	207	162	137	103	64	39
11	Road 1 link 2 West	FMD	1,3	1,0	1,4	1,0	1,0	1,0	1,2	1,4	1,9	2,1	2,3	2,2	2,4	2,9	3,7	5,2	5,7	4,6	2,9	2,2	2,2	1,8	1,4	1,4
		Reference	2,1	1,5	1,4	1,3	1,7	2,8	4,3	4,9	4,2	5,9	5,3	3,8	4,5	6,7	10	18	19	21	14	13	9,7	7,9	5,8	4,0
		LAM167/1	13	8,0	5,2	4,8	6,9	19	68	136	136	117	119	127	140	159	215	325	308	275	193	144	120	84	48	31
212	Road 1 link 2 East	FMD	1,1	1,0	1,0	1,0	1,0	1,0	1,5	1,7	3,0	3,2	2,3	2,2	2,1	2,3	2,1	2,4	2,5	2,2	1,8	1,9	1,8	1,6	1,4	1,1
		Reference	1,8	1,4	1,4	1,7	3,5	15	46	58	64	33	21	20	16	13	9,3	7,0	7,6	6,4	9,1	4,3	8,8	10	6,1	2,6
		LAM167/2	9,4	5,4	4,8	5,1	11	55	250	344	332	209	134	129	134	134	137	159	167	154	130	119	101	73	38	20

NSN Link	Link	Method	Time																							
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
81	Road 1 turning Ring I North	FMD	1,1	1,1	1,0	1,0	1,0	1,0	1,3	1,7	2,7	2,4	2,3	2,2	2,1	2,4	2,6	2,9	2,5	2,5	2,1	1,9	1,8	1,5	1,3	1,2
71	Road 1 turning Ring I South	FMD	1,2	1,0	1,0	0,0	1,0	1,2	1,9	1,9	2,7	2,8	2,3	2,4	2,4	2,3	2,0	2,6	3,1	2,4	1,8	1,9	1,6	1,4	1,2	1,4
101	Road 1 turning Ring II South	FMD	1,4	1,4	1,5	1,7	1,1	1,6	1,7	2,3	3,2	4,3	4,1	4,7	5,2	5,9	7,7	12	14	11	5,9	4,8	4,1	3,0	1,8	1,6
152	Road 51 link 1 East	FMD	1,7	1,8	2,0	0,0	1,0	1,7	2,1	3,6	7,8	6,6	4,8	4,6	5,1	4,3	4,6	5,4	6,9	5,7	4,2	3,5	3,3	2,9	2,2	1,7
		Reference	3,3	2,3	1,7	1,4	2,2	6,1	9,9	47	46	25	21	17	26	39	30	30	32	34	39	36	27	18	8,9	7,9
		LAM101/2	16	9,5	6,9	5,9	7,2	30	149	294	360	241	160	163	166	151	150	191	233	208	157	130	112	74	47	31
151	Road 51 link 1 West	FMD	1,2	1,2	1,3	1,1	1,2	1,0	1,2	1,7	2,6	3,2	3,2	3,3	3,7	4,4	4,5	6,6	8,8	7,4	4,5	3,6	3,4	2,7	1,7	1,4
		Reference	3,8	2,7	1,7	1,3	1,6	2,4	11	24	26	38	45	53	55	51	57	65	54	44	54	29	40	33	17	12
		LAM101/1	18	13	8,0	6,5	6,2	12	56	147	195	156	144	149	157	174	197	288	318	274	204	156	145	99	59	46
162	Road 51 link 2 East	FMD	1,0	1,0	1,0	1,0	1,0	1,0	1,3	2,4	5,0	4,2	2,9	3,2	2,9	2,7	2,9	3,1	3,6	3,0	2,7	2,2	2,3	1,9	1,3	1,1
		Reference	1,5	1,3	1,2	1,0	1,4	2,9	1,2	18	23	16	12	14	20	23	19	13	4,1	6,1	12	12	11	8,0	4,4	3,0
161	Road 51 link 2 West	FMD	1,3	1,7	1,8	1,9	1,4	1,0	1,3	1,9	2,4	2,6	3,0	2,7	2,9	3,7	3,9	5,8	6,3	5,6	4,5	3,4	3,6	2,5	2,2	1,6
		Reference	1,3	1,2	1,0	1,0	1,0	1,1	7,2	15	16	21	21	21	20	25	25	14	9,3	8,0	19	18	18	9,8	4,3	2,7

NSN Link	Link	Method	Time																							
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
202	Road 51 link 12 East	FMD	2,0	1,7	1,4	1,4	1,7	5,5	24	40	41	29	20	19	21	19	19	24	28	23	18	14	13	8,4	5,0	3,2
		Reference	1,9	1,6	1,1	1,3	1,8	3,3	3,3	25	28	23	14	15	20	25	21	18	17	19	16	13	11	8,7	4,9	3,8
		LAM101/2	16	9,5	6,9	5,9	7,2	30	149	294	360	241	160	163	166	151	150	191	233	208	157	130	112	74	47	31
201	Road 51 link 12 West	FMD	3,3	2,7	2,3	1,8	1,6	2,1	7,7	17	20	19	19	19	20	24	29	46	55	49	33	25	27	20	12	8,8
		Reference	2,5	2,1	1,5	1,2	1,4	1,9	9,2	17	18	27	32	37	37	42	49	33	15	13	21	25	35	24	13	8,6
		LAM101/1	18	13	8,0	6,5	6,2	12	56	147	195	156	144	149	157	174	197	288	318	274	204	156	145	99	59	46
		LAM163/2	11	6,4	5,1	4,4	7,7	27	151	239	242	166	121	123	129	131	153	201	219	195	153	123	99	68	43	22
262	Road 51 link 3 East	FMD	1,0	1,0	1,0	1,0	1,0	1,0	1,2	2,5	5,5	4,0	3,4	3,0	2,7	2,7	2,5	3,1	3,1	2,9	2,5	2,5	2,2	1,8	1,5	1,1
		Reference	1,9	1,4	1,5	1,1	1,8	4,0	1,3	22	30	21	21	27	36	31	31	18	4,4	7,7	19	19	16	12	6,0	3,9
61	Road 51 link 3 West	FMD	1,5	1,0	1,2	1,4	1,0	1,2	1,0	1,2	1,3	1,3	1,5	1,4	1,4	1,4	1,7	1,9	2,0	1,8	1,7	1,6	1,4	1,3	1,2	1,0
		Reference	1,4	1,3	1,1	1,2	1,0	1,2	8,2	21	29	22	21	21	21	25	25	15	17	34	34	18	18	10	4,3	2,7
302	Road 51 link 4 East	FMD	1,1	1,0	1,1	1,3	1,1	1,4	3,5	5,0	4,0	3,0	2,5	2,3	1,9	2,1	2,2	2,8	2,9	2,4	2,1	1,9	1,5	1,7	1,4	1,1
		Reference	1,2	1,1	1,0	1,2	1,4	2,7	4,2	39	26	18	8,1	7,5	7,0	6,8	6,4	6,1	3,8	4,0	7,1	10	10	7,9	3,9	2,4
		LAM102/2	4,2	2,1	1,7	1,4	3,6	18	94	173	165	97	64	61	61	61	63	76	88	80	65	53	44	33	19	8,8
301	Road 51 link 4 West	FMD	1,4	1,9	1,5	1,4	1,1	1,3	2,0	2,8	5,1	4,5	4,0	4,1	3,7	3,9	4,8	7,7	8,6	7,1	5,0	4,2	4,4	3,4	2,3	1,8
		Reference	1,1	1,1	1,0	1,0	1,1	1,5	6,1	11	10	11	4,2	1,8	3,9	3,7	4,6	3,2	3,7	14	21	18	14	8,5	3,4	1,8
		LAM102/1	5,2	2,7	1,6	1,5	2,4	6,5	30	54	64	54	54	59	65	67	86	138	145	124	96	76	65	41	20	13

NSN Link	Link	Method	Time																							
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
171	Road 110 East	FMD	1,1	1,0	1,0	0,0	1,0	1,0	1,0	1,3	1,9	1,5	1,6	1,4	1,4	1,4	1,6	1,9	2,2	1,7	1,4	1,5	1,6	1,4	1,2	1,1
		Reference								4,6	14	6,6	3,5	3,5	2,5	2,5	1,9	4,2	5,4	2,2						
292	Road 110 West	FMD	1,3	1,3	2,0	0,0	0,0	2,0	1,1	1,6	1,8	1,8	1,7	1,8	1,6	1,9	2,0	2,8	3,0	2,3	2,1	2,0	2,2	1,9	1,6	1,3
		Reference									2,6	2,1	1,7	1,8	1,9	3,2	3,9	8,9	11	6,3						
272	Kaleval-antie East	FMD	1,0	1,0	0,0	0,0	0,0	0,0	0,0	1,0	1,2	1,0	1,0	1,1	1,1	1,1	1,1	1,1	1,0	1,1	1,0	1,0	1,2	1,0	1,0	1,0
		Reference								27	30	17	15	17	20	21	29	32	31	18						
131	Kaleval-antie West	FMD	0,0	1,0	0,0	0,0	0,0	1,0	1,3	1,1	1,2	1,2	1,1	1,2	1,4	1,3	1,1	1,4	1,2	1,3	1,2	1,2	1,3	1,1	1,0	1,3
		Reference								28	26	26	18	22	22	21	24	35	46	39						
182	Kok-inkyläntie West	FMD	0,0	1,0	0,0	0,0	0,0	0,0	1,3	1,0	1,0	1,0	1,1	1,0	1,1	1,0	1,1	1,1	1,0	1,0	1,1	1,0	1,0	1,0	1,0	1,0
		Reference								7,1	6,5	4,2	4,1	5,1	4,2	4,9	5,0	6,0	8,5	7,4						
181	Kok-inkyläntie East	FMD	1,0	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,2	1,1	1,1	1,0	1,1	1,1	1,1	1,2	1,2	1,2	1,1	1,1	1,0	1,0	1,0	1,0
		Reference								5,4	7,1	3,2	4,9	3,8	3,9	3,7	5,1	8,6	9,0	6,6						
142	Kui-tinmäentie-Mar-tinkyläntie West	FMD	0,0	0,0	2,0	0,0	1,0	1,0	1,3	1,0	1,1	1,3	1,3	1,3	1,3	1,2	1,2	1,4	1,4	1,3	1,4	1,2	1,3	1,1	1,1	1,0
		Reference								2,4	2,2	2,9	3,7	3,7	4,1	4,1	4,7	9,0	15							
141	Kui-tinmäentie-Mar-tinkyläntie East	FMD	1,0	1,0	1,0	0,0	0,0	1,0	1,0	1,1	1,1	1,1	1,1	1,1	1,3	1,0	1,1	1,1	1,1	1,1	1,1	1,0	1,1	1,0	1,0	1,0
		Reference								2,4	4,0	2,4	2,1	2,5	2,2	2,6	1,8	2,2	1,7	1,9						
191	Röyläntie North	FMD	1,0	1,0	0,0	0,0	1,0	1,0	1,0	1,1	1,1	1,0	1,1	1,2	1,1	1,2	1,1	1,2	1,3	1,1	1,1	1,2	1,1	1,0	1,0	1,0
		Reference								2,0	2,5	2,3	2,0	1,7	2,1	2,3	4,1	6,5	13	6,8						

Table E2. Percentage of 1-minute time slots with 5-minute median

NSN Link	Link	Method	Time																						
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
242	Ring I link 1 South	FMD	2	2	4	0	1	11	48	67	85	93	84	82	84	87	86	95	97	90	78	73	68	50	28	17
41	Ring I link 1 North	FMD	4	5	1	1	4	5	20	58	81	73	83	84	84	87	93	97	92	91	81	68	62	51	25	18
		Reference	56	35	29	23	46	79	86	82	68	79	66	70	96	96	96	100	100	100	100	95	94	91	89	92
232	Ring I link 2 South	FMD	10	14	8	5	6	19	75	91	97	98	96	99	97	98	99	99	100	100	96	93	90	76	53	40
31	Ring I link 2 North	FMD	14	14	10	5	8	16	54	84	96	95	97	93	95	99	100	100	91	98	97	93	87	84	58	33
		Reference	76	23	32	59	78	93	86	83	70	89	69	77	100	100	100	100	100	100	100	95	94	92	93	99
252	Ring II South	FMD	6	5	1	2	3	9	32	63	85	85	79	80	82	88	94	95	98	93	86	80	72	71	33	16
		Reference	99	88	82	89	78	100	100	100	100	100	100	82	66	91	100	100	100	100	100	100	100	100	100	100
51	Ring II North	FMD	2	2	2	0	2	4	14	36	68	73	66	68	62	70	73	88	77	77	76	61	55	45	24	8
		Reference	98	93	79	78	78	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
91	Ring II turning road 1 East	FMD	15	12	6	4	7	16	55	87	96	95	96	92	93	96	97	99	98	97	90	86	82	77	53	25
222	Road 1 link 1 East	FMD	15	12	6	4	7	16	57	86	96	95	96	93	93	97	97	99	98	96	91	88	82	77	53	27
		Reference	71	39	36	62	88	91	86	85	71	94	98	99	100	100	100	100	100	100	100	96	95	92	93	92
21	Road 1 link 1 West	FMD	13	12	7	5	8	12	50	83	90	95	94	98	98	99	100	100	100	100	100	99	96	91	63	39
		Reference	81	68	52	54	63	77	79	78	61	90	96	98	100	100	100	100	100	100	100	96	96	92	93	96

NSN Link	Link	Method	Time																							
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
212	Road 1 link 2 East	FMD	3	4	3	3	3	11	47	57	84	90	77	77	84	83	86	88	88	83	75	73	71	67	36	15
		Reference	83	52	53	56	77	92	86	85	71	94	98	99	100	100	99	99	98	100	96	85	88	86	77	77
11	Road 1 link 2 West	FMD	9	1	5	1	4	3	20	48	67	75	78	83	86	94	93	100	95	99	88	84	83	67	36	16
		Reference	84	62	57	56	70	79	78	62	44	64	78	87	93	98	100	100	100	100	100	96	93	89	91	94
81	Road 1 turning Ring I North	FMD	10	10	7	4	4	13	43	62	88	83	87	79	80	85	86	93	83	89	82	73	70	69	46	20
71	Road 1 turning Ring I South	FMD	2	3	4	0	1	8	44	62	84	92	78	80	80	81	76	87	91	81	65	63	56	45	25	12
101	Road 1 turning Ring II South	FMD	13	12	6	5	8	12	48	84	89	94	94	97	97	99	100	100	100	100	100	98	97	90	62	38
152	Road 51 link 1 East	FMD	10	6	4	0	1	8	33	79	99	99	96	96	96	93	94	98	99	95	94	87	91	75	46	27
		Reference	91	86	71	61	73	99	83	36	49	67	99	99	100	100	100	100	100	100	100	100	100	100	100	100
151	Road 51 link 1 West	FMD	14	10	9	3	5	3	17	58	88	93	92	95	97	98	99	99	100	100	100	97	93	84	61	35
		Reference	98	93	89	53	64	93	100	100	100	100	100	100	100	100	100	100	100	100	58	73	100	100	100	100
162	Road 51 link 2 East	FMD	10	3	1	1	3	6	31	73	94	94	88	87	90	91	91	93	96	93	85	83	83	73	46	22
		Reference	77	52	29	24	51	82	18	98	100	100	100	100	100	100	100	100	95	96	93	100	100	100	100	94
161	Road 51 link 2 West	FMD	7	6	8	3	3	4	19	43	61	82	80	80	87	88	92	99	98	99	94	88	88	70	44	29
		Reference	52	33	13	10	23	32	99	100	100	100	100	100	100	100	100	81	63	66	49	55	100	100	97	97

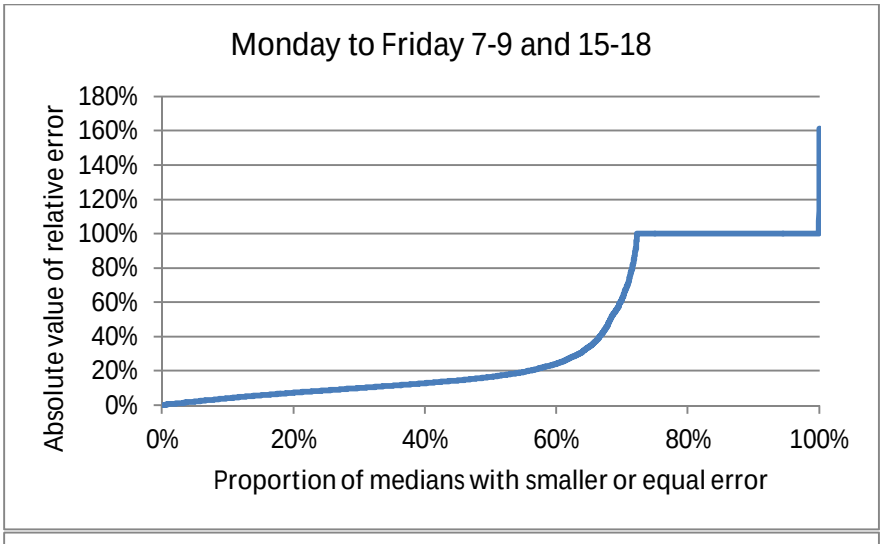
NSN Link	Link	Method	Time																						
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
202	Road 51 link 12 East	FMD	59	45	43	28	45	84	95	98	99	100	99	99	99	100	100	100	100	100	100	100	100	100	98	84
		Reference	84	58	57	33	47	93	37	74	100	100	100	100	100	100	100	100	100	100	100	100	100	100	97	100
201	Road 51 link 12 West	FMD	80	71	55	53	43	62	95	96	99	100	98	99	100	100	100	100	100	100	100	100	100	100	100	96
		Reference	98	85	74	67	57	76	100	100	100	100	100	100	100	100	100	100	99	100	100	100	100	100	100	100
262	Road 51 link 3 East	FMD	8	3	1	2	3	4	30	71	92	91	86	86	83	93	89	95	95	92	92	87	83	70	41	19
		Reference	77	52	29	24	51	82	18	98	100	100	100	100	100	100	100	100	95	96	93	100	100	100	100	94
61	Road 51 link 3 West	FMD	1	1	1	1	1	3	9	19	39	41	51	38	39	51	58	76	76	63	63	53	52	28	15	8
		Reference	52	33	13	10	23	32	99	100	100	100	100	100	100	100	100	81	63	66	49	55	100	100	97	97
302	Road 51 link 4 East	FMD	10	2	7	3	8	33	85	89	86	84	72	67	75	72	73	80	83	80	64	60	53	43	41	17
		Reference	78	35	31	24	61	96	80	25	79	99	98	100	80	80	94	73	99	96	97	88	99	100	100	89
301	Road 51 link 4 West	FMD	22	12	10	12	15	16	71	81	88	84	86	85	85	93	99	100	98	98	96	94	94	90	64	53
		Reference	41	24	6	3	27	62	100	99	87	60	48	19	38	36	27	14	16	33	38	45	100	100	98	93
171	Road 110 East	FMD	6	3	1	0	1	1	10	34	68	52	47	47	47	56	62	71	70	61	44	53	43	34	21	11
		Reference								98	100	100	100	93	97	98	65	98	100	92						
292	Road 110 West	FMD	2	3	1	0	0	0	8	19	40	41	37	39	46	55	59	74	81	71	45	53	50	38	18	12
		Reference									82	83	72	77	67	88	98	100	100	95						
272	Kaleval-antie East	FMD	1	1	0	0	0	0	0	2	10	9	12	11	13	13	13	18	16	9	7	7	8	11	3	1
		Reference								100	100	100	100	100	100	100	100	100	100	100						

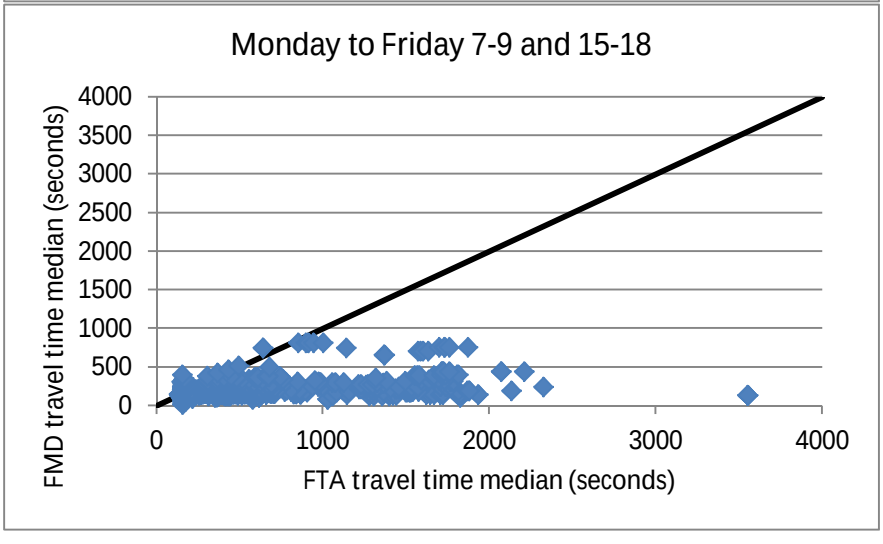
NSN Link	Link	Method	Time																							
			0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
131	Kaleval-antie West	FMD	0	1	0	0	0	1	3	9	7	11	12	7	14	10	18	18	15	18	15	11	10	6	4	2
		Reference								100	100	100	100	100	100	100	100	100	100	97						
181	Kok-inkyläntie East	FMD	1	0	0	0	0	0	1	4	8	9	10	11	9	10	8	17	25	10	11	10	12	6	3	1
		Reference								100	100	100	100	100	100	100	100	100	100	100						
182	Kok-inkyläntie West	FMD	0	1	0	0	0	0	2	2	1	4	8	6	6	5	11	16	12	11	8	6	5	4	3	1
		Reference								100	100	93	98	100	98	100	98	100	100	100						
141	Kui-tinmäen-tie-Mar-tinkyläntie East	FMD	2	0	1	0	0	1	2	7	21	18	19	16	11	14	13	11	19	19	14	15	10	3	5	2
		Reference								42	98	78	93	82	73	82	75	93	78	78						
142	Kuitin-mentie-Mar-tinkyläntie West	FMD	0	0	1	0	1	1	2	6	14	16	20	22	16	28	27	46	39	49	31	29	24	14	6	3
		Reference								78	92	97	97	98	100	100	100	100	100							
191	Röyläntie North	FMD	1	1	0	0	1	2	6	13	26	21	16	24	20	22	22	33	31	28	21	21	14	8	5	4
		Reference								80	97	87	82	78	87	88	92	100	100	100						

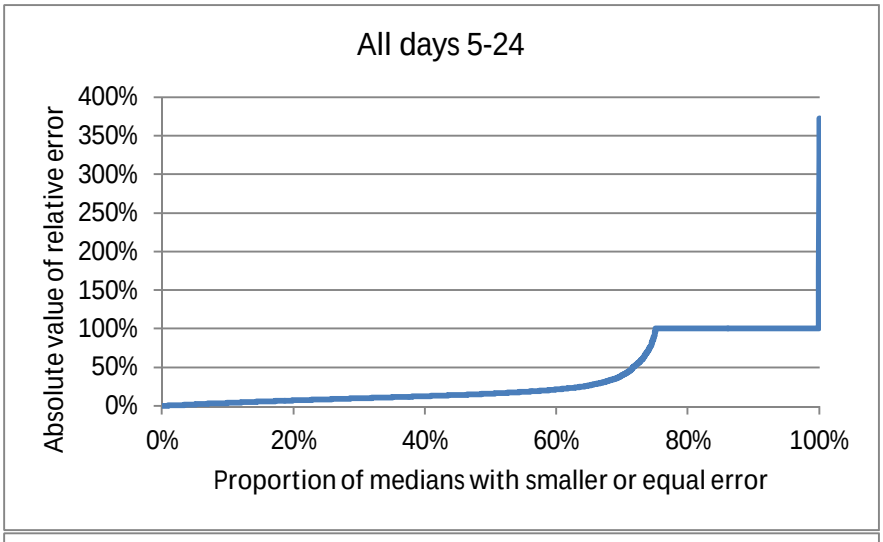
Appendix F: Error distributions

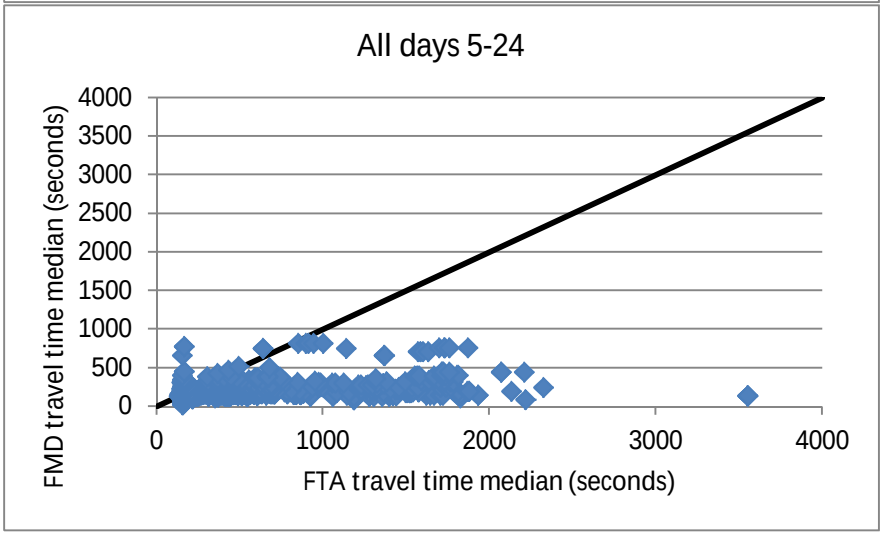
Cumulative curves for the relative error (deviation from reference data) of FMD median travel time compared to the reference median value, as well as plots of FMD and reference median pairs. In the cumulative error curves, no observation in FMD was regarded as 100% deviation. Below, FMD-FTA median plots with y = x curve (black line).

Ring I link 2 North (NSN link 31)

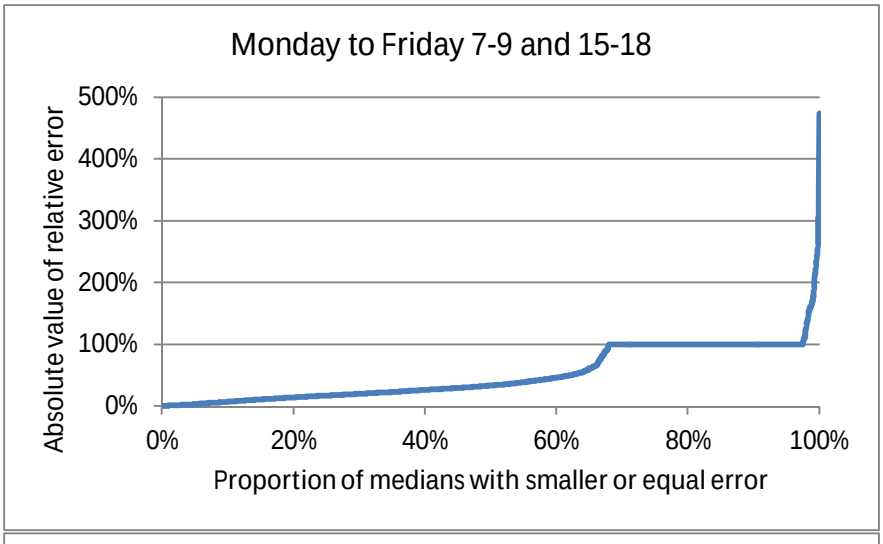


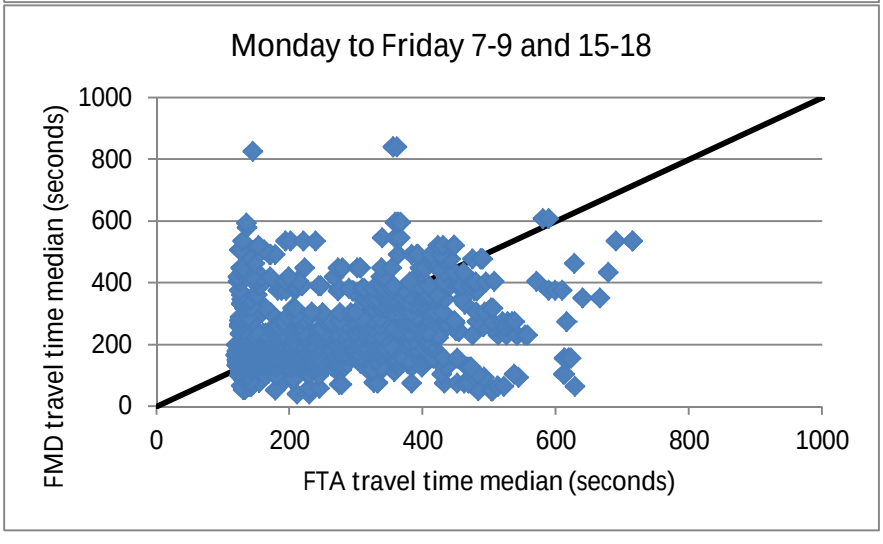


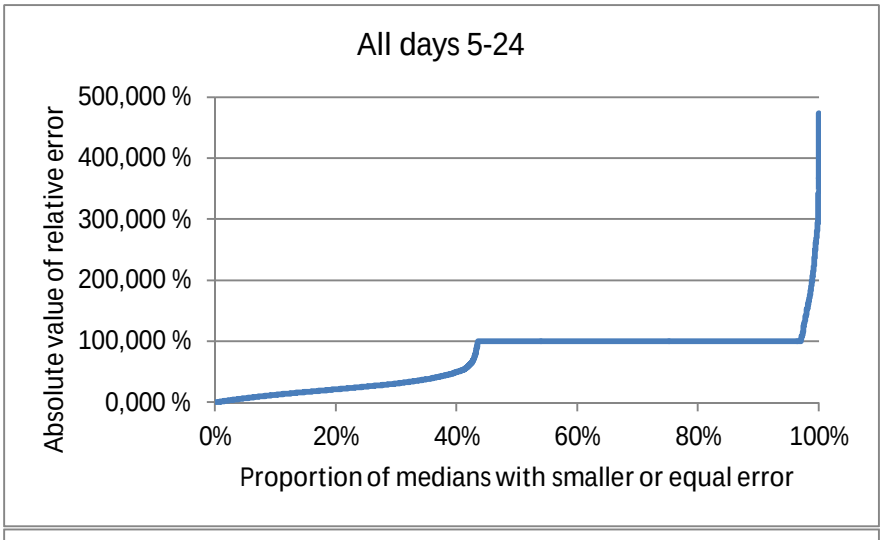

All days 5-24
Absolute value of relative error
400%
350%
300%
250%
200%
150%
100%
50%
0%
0%
20%
40%
60%
80%
100%
Proportion of medians with smaller or equal error

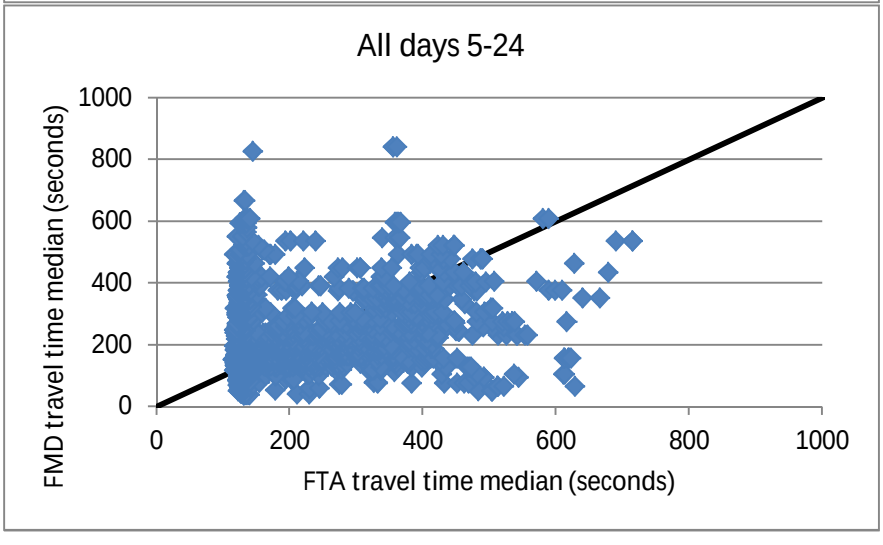

All days 5-24
FMD travel time median (seconds)
4000
3500
3000
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
FTA travel time median (seconds)

Ring II North (NSN link 51)

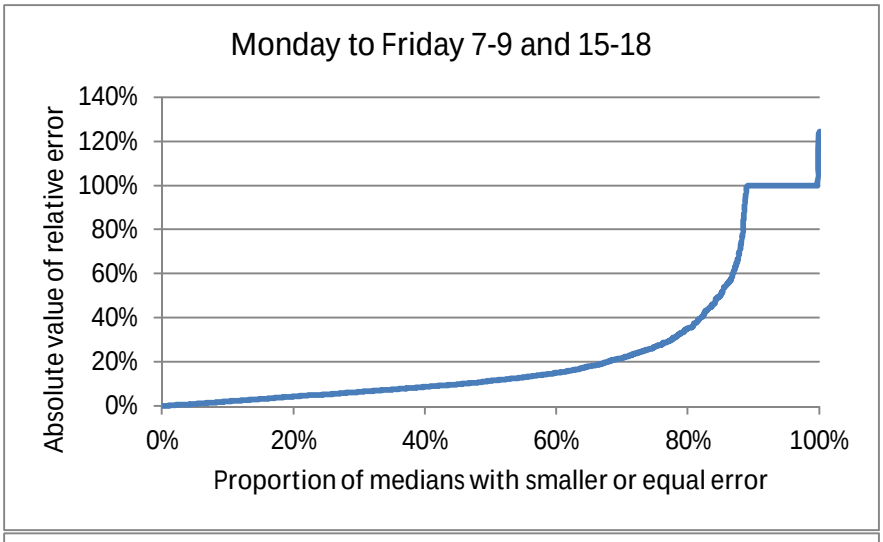


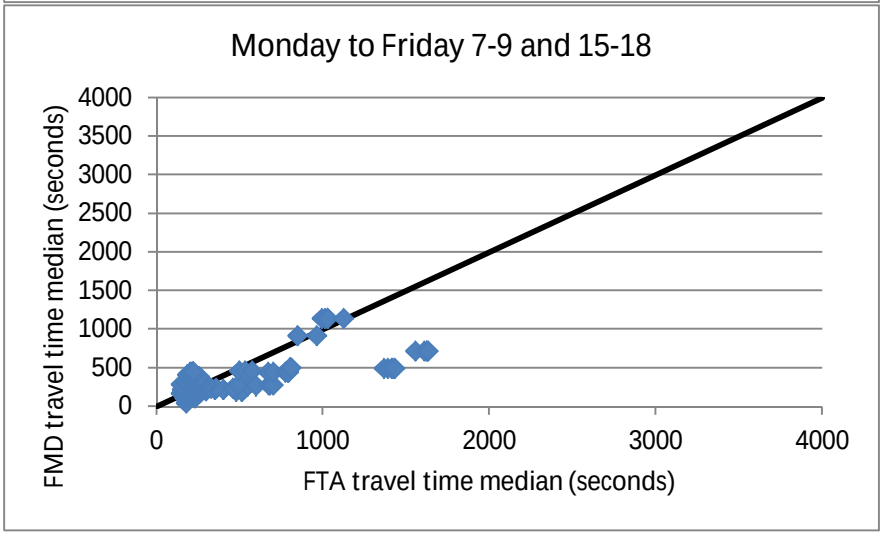


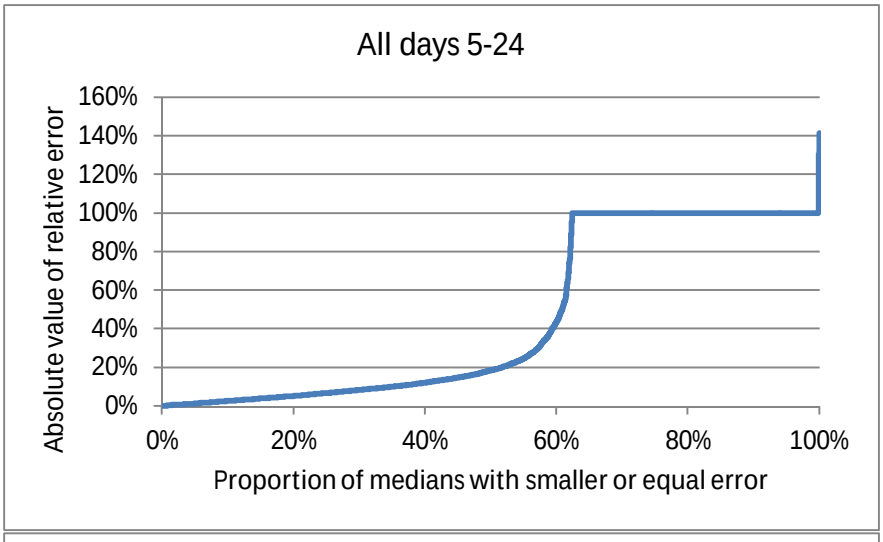

All days 5-24
Absolute value of relative error
500,000 %
400,000 %
300,000 %
200,000 %
100,000 %
0,000 %
0%
20%
40%
60%
80%
100%
Proportion of medians with smaller or equal error

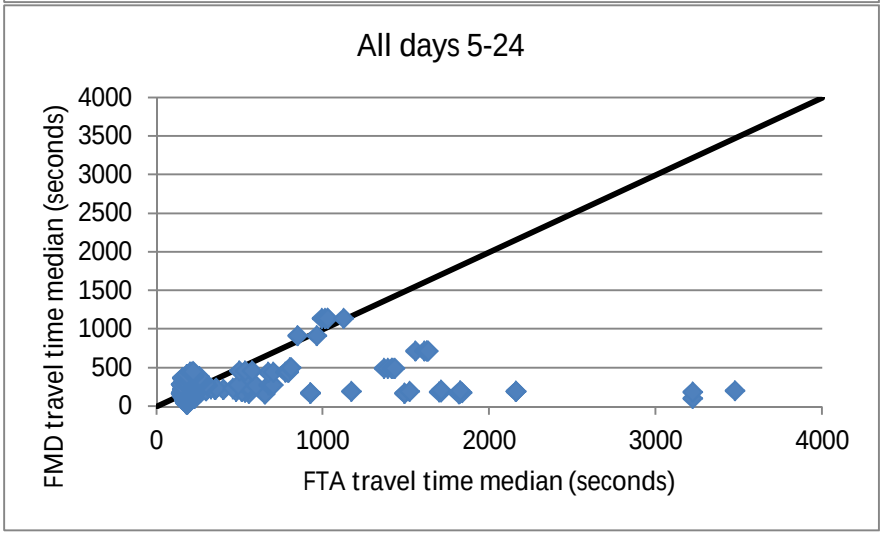

All days 5-24
FMD travel time median (seconds)
1000
800
600
400
200
0
0
200
400
600
800
1000
FTA travel time median (seconds)

Road 1 link 2 West (NSN link 11)

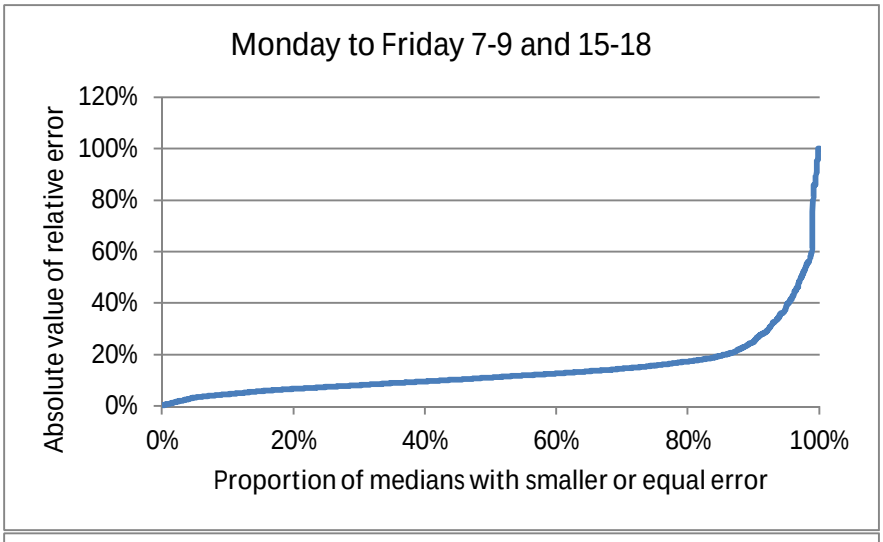


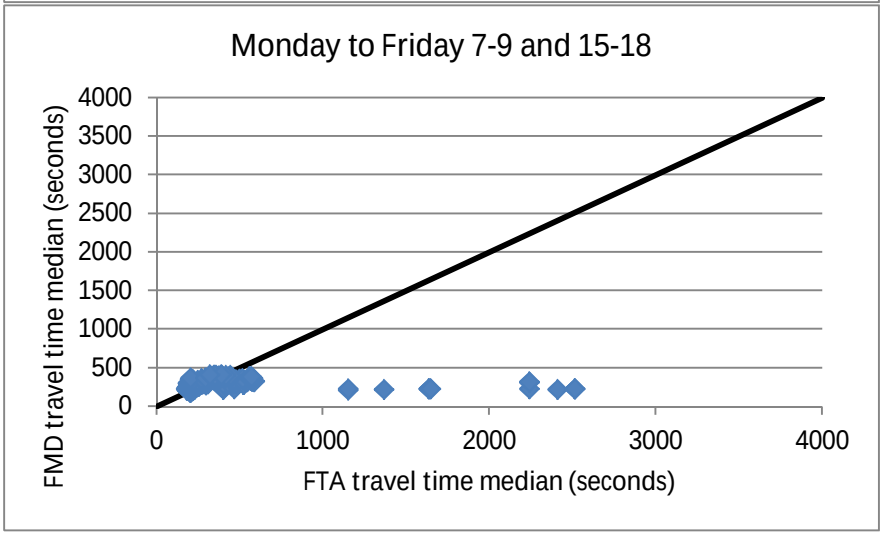


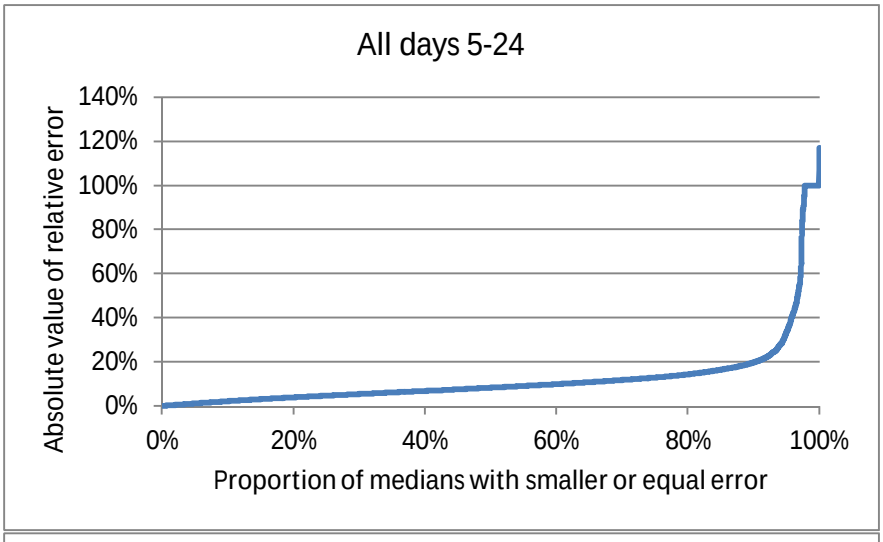

All days 5-24
Absolute value of relative error
160%
140%
120%
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Proportion of medians with smaller or equal error

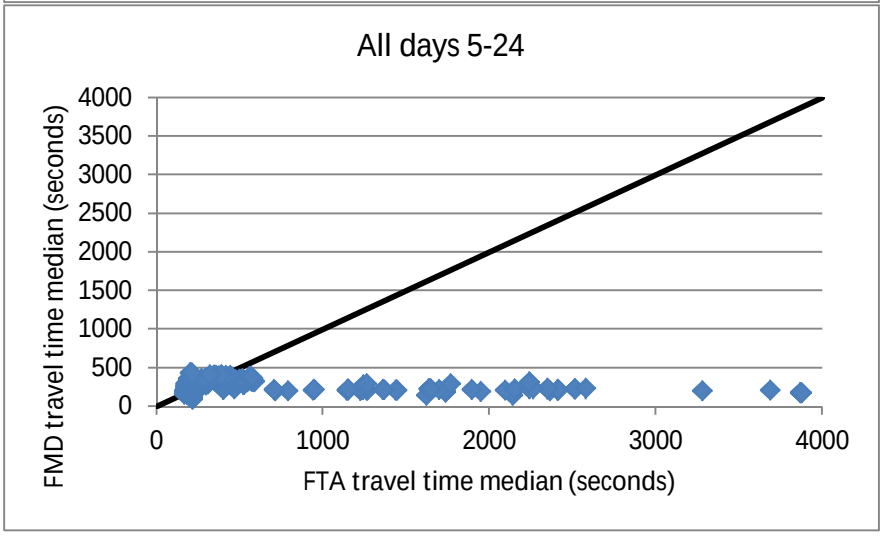

All days 5-24
FMD travel time median (seconds)
4000
3500
3000
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
FTA travel time median (seconds)

Road 51 link 12 East (NSN link 202)






All days 5-24
Absolute value of relative error
140%
120%
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Proportion of medians with smaller or equal error


All days 5-24
FMD travel time median (seconds)
4000
3500
3000
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
FTA travel time median (seconds)

Series title and number
VTT Technology 51

Title	**Floating mobile data pilot in Helsinki Metropolitan Area** **Validation of travel time data**
Author(s)	Satu Innamaa & Esko Hätelä
Abstract	The floating mobile data (FMD) pilot aimed to provide anonymous travel time information from data provided by mobile phones. The main purpose of the pilot was to validate the quality of FMD by comparing it with camera-based travel time data. Additionally, the usability of data was assessed from a traffic management point of view and some principles were tested. A travel time camera system was used as a reference. The main conclusion is that for traffic management operations, monitoring of cell handovers of active 2G phone calls does not produce a high enough number of observations. Consequently, it is recommended to select an FMD technology that is able to monitor a larger proportion of mobile phones per aggregation period per link. Independence of active phone calls would help to cover also night time traffic as well as smaller roads and main streets. Another main conclusion is that the estimation of median travel time should be developed further. Although traffic-wise homogeneous links were targeted, obviously traffic on many links is dynamic in both space and time. Consequently, it is recommended that the estimation of traffic flow status be based on part-observations, and that the weight of different zones of the travel time link be balanced. If full observations on fluent parts of a link are allowed to dominate, the estimate will be biased. The main implication related to ad hoc service is that the precision of ad hoc links was not high enough. The precision does not have to be as high as for static links, but nonetheless high enough to make validation of the data possible. Thus our recommendation is to improve it. Another recommendation is to increase the number of observations in ad hoc service to suffice for real time operations based on 5-minute medians.
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Publisher	VTT Technical Research Centre of Finland P.O. Box 1000, FI-02044 VTT, Finland, Tel. 020 722 111

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Floating mobile data pilot in hte Helsinki Metropolitan Area

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