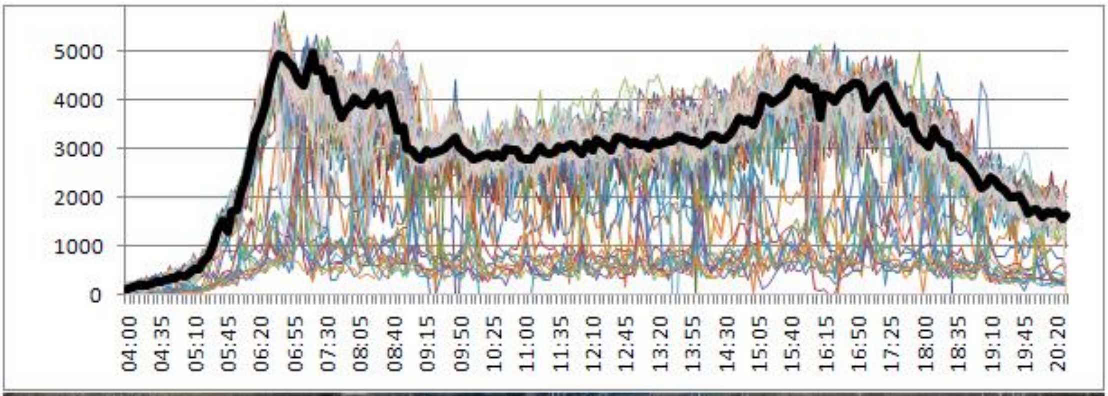

Analysis of traffic congestion on freeway

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Master of Science Thesis in the Master's Programme Geo and Water Engineering

SEBASTIAN HASSELBLOM

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CHALMERS UNIVERSITY OF TECHNOLOGY

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Master's Thesis 2010:32E

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Cover:
Upper image: Flow curves for E6/E20 northbound in Gårda in Göteborg, Sweden. Flow curves for Mondays - Fridays for 15 weeks is plotted, together with the black line which is calculated with the so-called Stockholm model. Lower picture: The traffic on a weekday morning at the Lindome junction, E6/E20 outside Lindome, Sweden.

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ABSTRACT

One way to increase the public transport journeys and reduce journeys with car is to introduce congestion taxes. This is considered in Göteborg and will be introduced in 2013. The basic principle is that the higher the demand for travel is, the higher the tax will be. To find out how high the demand is, it is necessary to obtain flow data from a longer period and run this in different calculation models. During this process, different types of computational models has been developed and tested. This led to the conclusion that a model called Stockholm model was used. When the weighted graph of flows and speeds had been developed, this was used to form the tax rates for Göteborg. The diagram was successful and worked well to be used for decide the different congestion tax levels.

In some cases, a heavily congested freeway ramp creates problems for the traffic on the freeway. If many vehicles want to enter the freeway at the same, it will be difficult to find a gap and be able to enter the freeway without causing problems. Better would be if there is one and one vehicle on the ramp. One way to create such a flow is to set up signals at the ramp that allow one vehicle per green period. The work is about how ramp meters works and analyzes how the algorithms can be written for the system to work as good as possible. Appropriate places in the Göteborg area where this could be installed are also investigated. The result shows the northbound on-ramp in Lindome junction is appropriate for ramp metering.

Contents

Preface

This report describes how computational models can be designed to merge data from longer periods of flows and speeds. The report also describes what ramp meter is and how it is used. The report was written during the period January to June 2010 and is the last part of the master programme Geo and Water Engineering on Chalmers University of Technology.

The thesis is written at the Swedish Transport Administration with Bertil Hallman, Swedish Transport Administration, as the local supervisor and Gunnar Lannér, supervisor and examiner at Chalmers University of Technology. During the first months of the thesis I worked with the congestion tax project in Göteborg. I was a member in a group whose task was to investigate the time-differentiated traffic congestions tax rates, therefore, different tax rates are used at different times during the day. My main task in the group was to develop merge flows and speeds from different measuring sites in Göteborg from a long time measurements. Much of the methods included in this thesis are developed for the congestion charge project. The work was mostly about to develop many different models, tests them and develop them further. I had great help of my colleagues in the time-differentiation group when it came to assessing how well the various models produced worked. Particular, I thank Carl-Henrik Sandbreck, Sweco, he helped me more than anyone else with this.

I came up with the congestion tax project because of an inquiry by Per Bergström Jonsson, Swedish Transport Administration, Project Manager for the Congestion Tax Project Resources. Both for the thesis and my future career, it meant a lot for me that I could join the project. For this, I would like to thank Per Bergström Jonsson, but also the colleagues Bertil Hallman and Per Lindholm, Swedish Transport Administration. Even my closest colleague Viktor Hultgren, Swedish Transport Administration, helped me to come up with the project.

Throughout the work, my local supervisor Bertil Hallman supported me. It was Bertil who gave me the chance to write the thesis, combined with employment, at the Swedish Transport Administration. I want especially to thank Bertil for this. Finally, I thank my supervisor Gunnar Lannér.

Göteborg, June 2010

Sebastian Hasselblom

1 Introduction

1.1 Background

In many parts of the world there are congestion problems on freeways, especially on freeways in urban areas. In many cases, working commuting is the greatest problems. Of that reason, the problems is usual greatest in the morning and afternoon during weekdays. Congestion problems are usually due to the demand for car travel is greater than the capacity of the roads. It is many solutions to solve the problems. One solution is to improve road network capacity, partly by widening the existing roads and partly by building new.

Another solution may be to reduce people's demand for car travel. Trying to reduce the overall demand for travel is in many cases not desirable, on the contrary, we want to try and improve commuting possibilities so that more people can choose where to live and work independently of each other. In the vicinity of large cities, it is better from an economic perspective to working commuters use public transport than they go in their own cars. In the vicinity of large cities, many people travel the same route. If the working commuters travel alone in their cars, each person occupies a much larger surface area than if they go together in the bus or train. In addition, the emission of carbon dioxide reduced significantly by increased public transport.

One way to increase the public transport and reduce car journeys is to introduce congestion taxes. This is considered in Göteborg and will be introduced in 2013. To make the system as best as possible, different tax rates to be charged at different times during the day. The basic principle is that the higher the demand for travel is, the higher the tax will be. To find out how high the demand is, it is necessary to obtain flow data from a longer period and run this in different calculation method. During this master thesis, different types of computational models are developed and tested.

In many cases, the overall capacity of the road is high enough to handle the traffic, but some places can have too low capacity. Such places known bottlenecks and may include a junction where the traffic from the local road will enter the freeway lanes. When the inflow to the bottle neck is larger than the capacity, queues formed upstream of the bottleneck. When a road user gets stocked in the queue, he can be located several miles away from the bottleneck. Immediately after the bottleneck, it is common the speed significantly increase again. To improve this situation you can install a traffic signal at the ramp to emit one vehicle per green period. Without traffic signal, traffic on the ramp can be very irregular. Sometimes many vehicles come at once and sometimes nobody. Instead of the irregular traffic on the ramp, the traffic flow much better with the so-called ramp meter. This reduces the problem for the traffic on the freeway. This report describes how ramp meters can be designed and also takes up a few places in the area of Göteborg in which this could be interesting to use.

1.2 Purpose

The purpose of this work is to develop better computational models for combining measurement data for the creation of flow and speed diagrams, and increasing understanding of ramp meters and investigate if there are places in the area of Göteborg in which this might be appropriate. Both better computational models and installation of ramp meters helps to optimize the traffic network. This is the link between the otherwise separate parts of the work.

1.3 Delimitations

The master thesis only study modeling that aims to create flow and speed diagrams. The calculation models are specially developed to fit the format as presented from the database with the flows and speeds from the Swedish Transport Administration. The understanding of ramp meters is just on a basic level. When the places in the area of Göteborg suitable for ramp meters are selected, it does so after a quick analysis. A detailed analysis of these is not done.

1.4 Method

Calculation models developed by making many different variations of models and tested them. The results of the tests are analyzed by the author of this report, but also by traffic planners who work together with the author in the congestion tax study in Göteborg. Although studies of existing models is done. To find information, Internet is used. To learn more about the ramp meters, fundamental studies are done, where results and analysis from places that use ramp meters are collected. This information is also collected by using Internet.

2 Algorithms for flow and speed

When to analyze how the traffic situation is on a road, a good measurement is to study how flows and speeds various along the road. If you want to get a good picture of how the traffic situation looks like at a given location or route, it is not enough to study individual vehicles. These individual vehicles may experience behave differently from the normal, which means that you get a false picture of the situation. We might also ask ourselves what is normal, the flow of traffic at a particular location never look exactly the same from day to day. Instead, it is important to try to find out approximately how traffic usually looks.

2.1 The quality of the input data

Looking to get a fair picture of how the traffic looks like at a particular location, it is important that the quality of the input data is high. Depending on the type of analysis to do the inputs may vary. If we will study how much traffic going on a road in a week it is sufficient to obtain flow input data such as per hour or per day. However, if we must study the situation on a crowded stretch of road, it is important to obtain data much more frequently than once an hour. It says not so much that the average speed was 80 km/h between 7AM and 8AM. We don´t know if the congestion started at 6:45, 7:15 or 7:30. In this case, you must obtain data fairly closely, for example, every fifth minute. If you want to get a more accurate picture of the situation you might want to know flows and speeds for each lane, while in other cases may be content to know the total for the whole road.

It is also important that the time interval from where you pick up input data is good. If you want to get a fair picture, the time interval cannot be too short. You should look at several weeks, but even if you do that, it can be wrong. Maybe it was a road work during the weeks that made the flow of traffic looked very different from the normal situation. We must also study the reliability of the data. Is it often that the measuring equipment has faulted and incorrect data stored? Where the measuring equipment stored zero values, this is relatively easy to detect, but if it store values other than the correct, this may be difficult to detect. Maybe you need to make some special algorithms to detect the special type of fault data that appears at the specific site.

2.2 Algorithms

When the input data is selected, an algorithm that calculates the data is necessary to use. The algorithms calculate different forms of weighted values from the input data, such as the mean flow at different time during an average day. Because of measurement errors and other anomalies, the algorithms needs to be more advanced that you thought. It is not necessary to just calculate the mean value; a lot of selections must be done. Other types of weighted values may be different percentiles. When you are presenting the weighted values, you would often do this in a chart. Even when making the chart, it is appropriate to let a program makes this, instead of doing this manually. To create all the diagrams manually, it would take an extremely long time.

2.3 The congestion tax investigation in Göteborg

The investigators of the congestion tax in Göteborg advocated from the beginning that the same amount of tax would apply throughout the day. Later they changed the mind and wanted to investigate how it would work with time-differentiated tax rates, the taxes is different at different times during the day. To investigate that, a special group for this was founded. The group includes the author of this thesis. The author was a member of the group at the same time as he wrote the thesis and it was natural that the work the author did in the group also was included in the thesis.

2.3.1 Background

The first thing to decide is what should be the basis for deciding the tax rate. Are you at random to determine the different levels at different times or do you base the tax on how large the flow is at different times? Deciding at random is not a good idea; especially it can be difficult to defend these levels if you get criticism. Setting tax rates after the flows can be a good idea. Most users should accept such a system, when the flow is high; you pay more than when you are alone on the road. Such a system could also lead to more people choose to run at other times and this results the flow peaks going down.

In addition to flow measurements you can also get speed and travel time measurements. Flow and speed measurements made at fixed sites, while the travel time measurements made at different stretches. When flows are above certain levels, the speed will begin to decrease. When the speeds decrease, the travel times increase. Looking briefly may therefore find it does not matter if one chooses the flows, speeds or travel times to control when tax rates to be charged. If you go into more detail, however, shows that flows, speeds and travel times get differences results. For example, flows usually reach their peaks earlier than when travel times reach their peak. During rush hour traffic, the difference may be up to half an hour. The group had difficulties in deciding whether there would be flow or travel time that would determine when tax rates would be highest.

To understand the problem you have to understand why the peak flow can occur earlier than travel time. During the night, the flow is very low and speeds are high, in many cases significantly above the speed limit. The travel times are low. During the early morning the flow increase significantly, but still flows are so low that the vehicles can run unimpeded. Shortly before 7 o'clock, the flow has become so high that speeds are forced down a little. Instead of traffic flowing at 90 km/h perhaps traffic is flowing in the 70-80 km/h. Travel times will increase slightly.

After 7 o´clock the flow increasing evens more and increase up to around 1700 vehicles per hour per lane. This is the limit on how many vehicles one lane can handle. There is simply impossible to get more cars. Now the speed has decreased to 50 km/h and travel times have obviously increased. The reason that maximum flow can be achieved when the speed is as low as 50 km/h due to the distance between the vehicles is much smaller. In theory, one could get a higher flow if all vehicles held a short distance to the vehicles in front of them in combination with high speeds, but that situation is obviously not reasonable or desirable, mainly for security reasons.

When the inflow will increase even more the system collapses. Because the vehicle is changing lane, when they enter the freeway from ramps etc, they cannot find a gap and it let to the vehicles on the freeway need to brake. As a result of this, all vehicles need to slow down and a queuing situation has occurred. The inflow to the queue continues to be high so the queues are growing fast backward. Due to the very low speeds, the flow forced down. This is the reason why the queue growing rapidly backwards, the inflow is greater than the outflow. Figure 2.1 shows the situation.

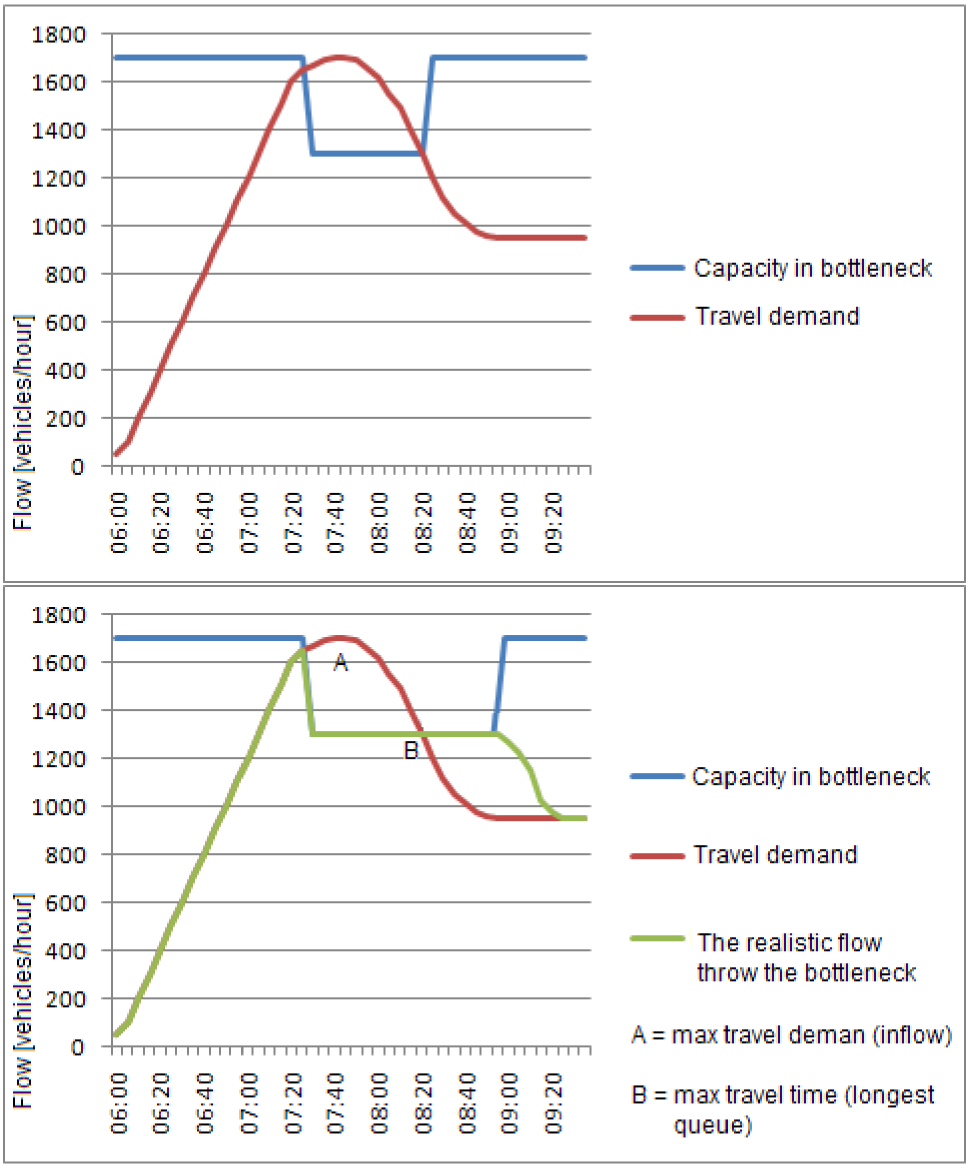

Figure 2.1 When the travel demand (inflow) is larger than the capacity, queues is building up. It takes time to get away all cars from the queue, why the realistic flow is still high even when the demand has decreased. When the traffic is queuing, the capacity is decreased.

Because of the queue situation the flow is forced down to a lower level, perhaps to about 1300 vehicles per hour. When the clock is just before eight the inflow starts to go down due to the demand goes down. Inflow is still higher than 1300 vehicles per hour, so even if demand falls, the queues are growing. When the clock is around 8:20, the demand has decreased so much that it is on the same level as the flow which can pass through the bottleneck. Of that reason, the queues not grow anymore and the travel time reaches the peak level at this time. When the clock has been 8:40 the queue has been dissolved and the speed increase again. Since the inflow is at a low level, it will not take so long before the vehicles can run without obstacles. The conclusion is, although the demand goes down (inflow goes down) the travel time still increases for about half an hour.

On other roads where the situation is not as serious, and you never going to collapse, the time for flow peak and travel time peaks is the same. As the flow increases, the speed decreases and travel time increases. When the flow is at its maximum point, the speed is maybe 60 km/h. When demand goes down, the flow goes down. This almost momentally leads to higher speeds and lower travel times. In other words, there is no time differences between flow peaks and travel time peaks when they collapse never occurred. Comparing roads with collapse and roads without collapse, we see that demand looks the same, but the travel time reaches its maximum level later on roads with collapse and queue situations.

When the travel time reach its peak that also means the congestion is worst. When inflow is greatest, demand for travel is greatest. One may therefore ask whether tax levels in the first place should be highest when congestion is greatest or if it should be greatest when the demand for travel is greatest. Fair enough, many spontaneous feel that you should have the maximum amount of tax when congestion is greatest. However, there are more things we must think about. When the congestion tax has been introduced it will reduce the amount of traffic. A reduction of traffic reduced the travel times and this will lead to the peak of travel time get closer the demand peak. In addition, a new freeway will be opened in the worst area in Göteborg. The new road will also lead to a decreasing of the queuing situations. This makes the travel time peaks will not occur so late when the congestion taxes is in use as they do today. Of that reason it is not a good way to base the tax levels on travel time peaks that occurs today.

All this together leads to the group chose to look at the flows instead of travel times when tax levels were determined. Important to note is that the flows measured when it is a queue situation is not interesting because the flow has been forced down because of lack of capacity. Should we look at flows in order to find out the demand, we must look at the flows that exist on roads where there is no queue. One risk is that motorists have chosen to start earlier because they know that they are delayed by queues. For example, if we look at the flow on the E6/E20, south of Göteborg, maybe flow peak occurs earlier than the actual demand because users know that they will get stocked in queues when they reach Göteborg. However, by studying many roads in and around Göteborg, both in direction from the center and toward the center, no general differences in time can be detected. The demand peak occurs at the same time almost on every road.

2.3.2 Generating of diagrams

The author started to develop flow charts from different sites with input data. From the beginning, we knew that the best type of chart containing the flow on one axis and time on the other. The time plotted from morning to night and in this way one can easily visualize how the flow varies during the day.

When the work was started, this was done with an open mind. We didn´t know how the algorithms should look like. Many different algorithms was developed and tested and new algorithms build on the old ones.

The first thing that was done was to decide which time period that would be used for the input data. The last years showed decreased traffic and that’s why the autumn 2007 was decided to use. When you download data from the database, all data is includes in an Excel sheet. If you pick out the data with resolution every fifth minute for 15 weeks you understand the Excel sheet will be large. Right from the beginning realized that macros must be created to automate processes as it would take an extremely long time to do all the calculations manually.

The first graphs that were presented did not contain any weighted flow curve. Instead they included all plotted line for every weekday during 15 weeks from autumn of 2007. Figure 2.2 shows examples of how such a chart might look like. Although no weighted curves are included, you can still see where the flow often is located, in other word where the normal flow is located. You can clearly see the "forest" of lines, i.e. which most of the days flow is located. You can also see that a relatively large proportion of the data deviates from the norm and that the deviation is almost always lower than the normal.

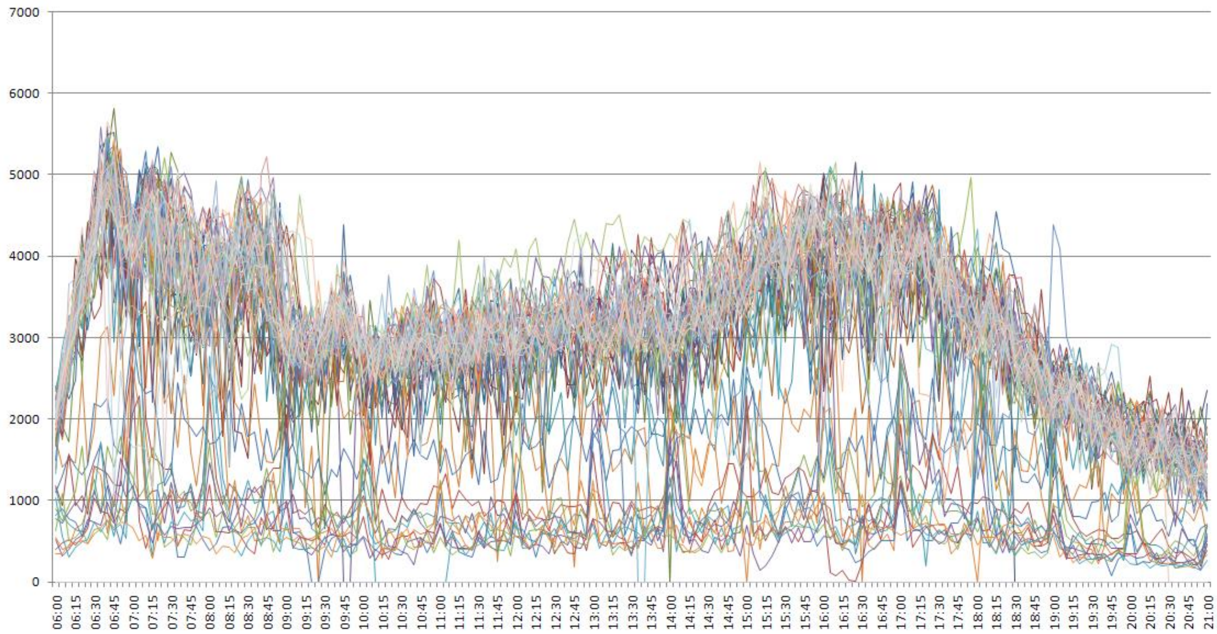

Figure 2.2 *Flows from all weekday from 15 weeks during autumn of 2007 plotted together. The measurement is made on E6/E20 northbound in Gårda in Göteborg. During the morning peak between approximately 7:00 and 8:30 can be clearly see how the flow was forced down due to traffic jams. The flow is expressed in vehicles per hour.*

The next step was to develop a weighted flow line, plotted along with the lines for each day. First test was a method to calculate the mean value of the flow during the day, but because of measurement errors, disruptions to traffic, etc. this mean flow often fall outside the "forest" of curves. A calculation of the median was also tested, but this fall also outside the “forest”. Different percentile levels were tested, such as the 80 percentile. This ended up pretty good, but if you theoretically only include the “correct” flows, probably the 80 percentile actually representative a lower percentile. It is not easy to know how much data you want to delete, even on days when the disruption has meant that the flow has been different, after all, is still one of the days and might therefore still be included.

After many experiments with different algorithms, the so-called Stockholm model thoughts to be the best one. This algorithm was programmed in part by use of a short description of how an algorithm would have looked like that was used in Stockholm for the so-called Stockholm Trial. After some adjustments, including the zero value removal, it turned out that this worked best. Figure 2.3 shows examples of plots of a line calculated with the Stockholm model, together with the lines from every day. More information about what makes the Stockholm model works best, see the discussion in Section 2.3.5.

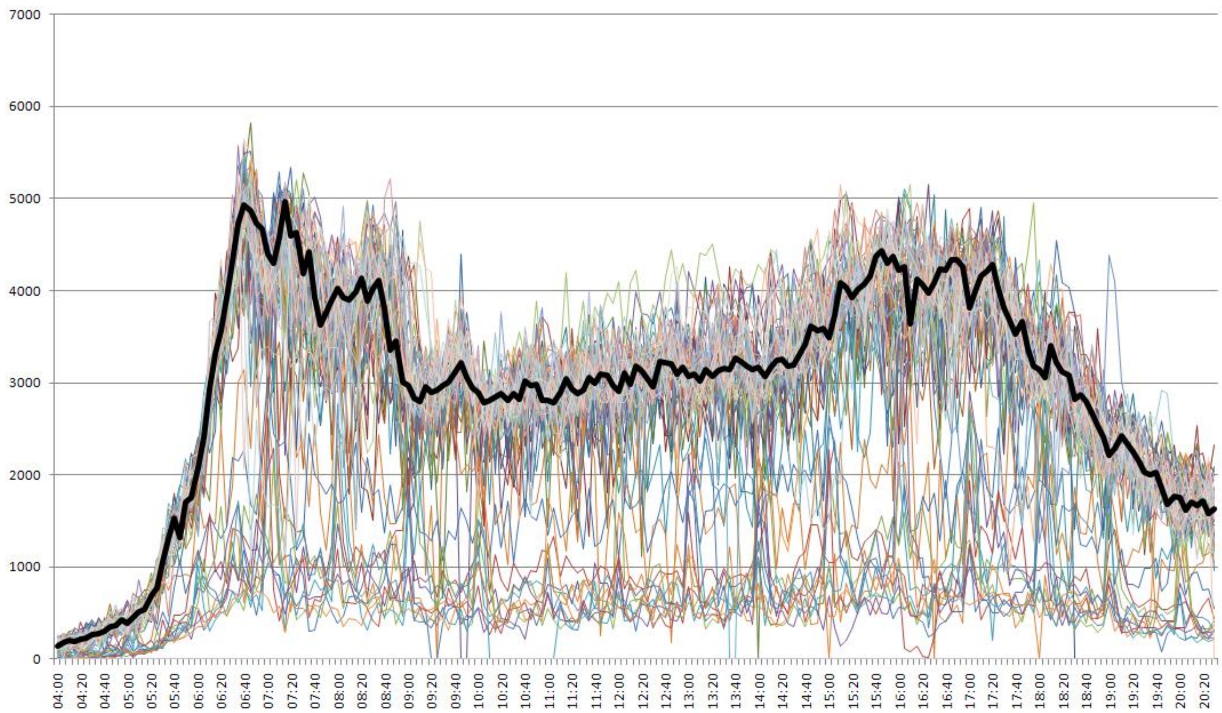

Figure 2.3 Flows from all days together with the black line calculated with the Stockholm model. The flow is expressed in vehicles per hour.

2.3.3 Algorithm for flow/time diagram

Description of process for generating of charts where flow (or speed) plotted on one axis and time on the other. The process described below is done separately for flow and speed.

1. The input data is collected from the Swedish Transport Administration database. The options in the database is done like this:

    a. No separation between lanes in same direction
    b. We want data in the period 2007-09-03 00:00 - 2007-12-17 00:00
    c. The resolution is set to every 5 minutes (the highest availability resolution)
    d. No separation between different types of vehicles
    e. We want information about the flow and speed

2. The database generates an Excel sheet where we get the flow and speed for every 5 minute, 24 hours per day, and all days in the period. Due to the quality it is important to include data from a longer period.

3. The flow respectively the speed runs in the Percentile model or the Stockholm model. See Section 2.3.4 respectively 2.3.5 for description of these.

4. When all 5 minutes over all the day has runs in the Percentile model or Stockholm model, a chart is generated showing how the flow and speed looks during the day.

5. To illustrate how the suggestion of different tax rates is connected to the flow, also a line illustrate the tax rates is includes in the diagram. To get vertical lines on tax levels, it is necessary to increase the time resolution for all data presented in the graph. This is done by linear interpolation within each five-minute intervals.

When the calculation models were developed, many different algorithms were created and hence many different source codes. All source codes were written in Visual Basic which was running as macros in MS Excel, directly in the files that the database generates (with flows and speeds for every fifth minute 24 hours per day for 15 weeks in autumn 2007). After testing of the different algorithms, the best algorithm for flow-time charts were the Stockholm model, where data are presented from 04:00 to 20:30. It was this algorithm that was used for generating the charts which was included in the report by the Swedish Transport Administration in February 2010. The source code of this algorithm can be seen in Appendix 1.

2.3.4 The algorithm for the Percentile model

1. Input data from all weekdays puts in different lists, one list for every time. One list for all data from 04:00, another list for all data from 04:05, etc. All data which is zero removes. These steps are running for every list separately.

2. The list will be sort with the lowest value in the top and the highest in the end. We call the lowest row in the list for 1, the second lowest to 2, etc.

3. One of the flows in the list will be selected as the flow which representative this time, for example 05:00. Different calculations calculate which flow will be selected. (sista kolumnen = last column)

   a. If it is a flow, this formula are used:
      $$kolumn = Round\big((sista\ kolumnen + 1) * percentil\big) \quad (2.1)$$
   b. If it is at speed, this formula are used:
      $$kolumn = Round\big((sista\ kolumnen + 1) * (1 - percentil)\big) \quad (2.2)$$
   c. The result of the calculations tells you which column you will pick the flow from which will be the selected flow.
   d. If there for example are 70 rows in the list, *sista kolumnen* is equal to 70. If it is the 80 percentile you want to calculate, *percentil* is equal to 0.8. *Round* means you round to the closest integer.

2.3.5 The algorithm for the Stockholm model

Worth noting is that Stockholm model also has been used in other algorithms than the one used in the Congestion Tax Project (flow/time diagram). This is why a model called the Connection model is named in the description. See Section 2.4.2 for information about the Connection model.

1. Input data from all weekdays puts in different lists, one list for every time. One list for all data from 04:00, another list for all data from 04:05, etc. All data which is zero removes. These steps are running for every list separately.

2. The list will be sort with the lowest value in the top and the highest in the end. We named the lowest row in the list to 1, the second lowest to 2, etc.

3. The mean value and the standard deviation are calculated from the values in the list. For the standard deviation, this formula will be used (medelvärdet = mean value)
   $$\sqrt{2} \times \sqrt{medelvärdet} \quad (2.3)$$

4. A lower and an upper limit are calculated from a 99.5 percent confidence interval. For the lower limit, this formula is used (standardavvikelsen = standard deviation)

   $$medelvärdet - 2{,}807 \times standardavvikelsen \quad (2.4)$$
   and for the upper limit
   $$medelvärdet + 2{,}807 \times standardavvikelsen \quad (2.5)$$

5. That value located most far away from the confidence interval will be removed from the list. Maximum one value will be removed, even if there are many values outside the confidence interval. If it is the lowest value which is the value located most far away, the first row in the list will be removed. If it is the highest value, the lowest row will be removed.

6. Step 3 – 5 repeats until there is no values outside the confidence interval. Every time the step runs, the list will decrease with one row. That means every time the step runs, it is a new mean value, a new standard deviation and new confidence interval.

7. From the rows still left in the list, the mean value is calculated. When the Stockholm model is running inside the Connection model, it is a type of median value calculated instead of the mean value. The calculated mean value (or the median value) will be that value which will represent this time, for example 04:00.

Discussion Stockholm model

The model calculates how close measurements are to each other and create a span with a lower and an upper limit. The measured value which is most far away from the span is removed from the list. From the remaining values in the list a new calculation will be done. In this way it disappears one row every time and the remaining list goes in the direction where the density is greatest. If the density of such measurements is greatest in the upper half of the list, more values removes from the lower half. The model continues to create new limits and remove values until it is no longer any measured value outside the last calculated limit. Then calculates the mean value of the remaining values and this will be the weighted value for this time.

When the model is running in Connection model, it is necessary the speed which will be chosen as the representative speed, is chosen from one of the rows. If you calculate a mean value, the answer maybe not will be exactly the same as one of the values in the rows. Of that reason a kind of median is calculated instead of mean value. A normal median value picks the value in the middle of a sorted list if the list has an odd number of data points. If the number of data points is even, the mean value is calculated of the two middle values. Since it is a necessity to pick the value from one of the rows, the higher of the two middle values is taken in this case. Since the measurements are dense and includes many rows it does not matter if you choose to pick the higher or lower value of the two in the middle.

Stockholm model was developed when the work was under way to create diagrams for the flows and speeds from different test sites. Already from the beginning, data picked out from the Swedish Transport Administration database, with data from autumn 2007. The first model that was used to create a kind of medium line was a line that calculates the mean value for every time for the day. Although the median value was tested to be calculate. When you plot all the days in the same flow diagram, you can see the "mass" of lines lying on each other. Here are the most of days located and it is therefore here that the flow tends to be. Outside the "mass" it is a lot of lines, for different reasons, both measurement errors and disturbance on the roads. It is more often the line got below the “normal” situation in comparation to cases where it got above.

When you run the model to generate the mean value, you want this line to be placed inside the "mass" of lines and also pretty in the middle of this. The problem with the mean value and the median value is that these lines end up further down than the middle of the "masses", as a result of that more flow is lower than higher outside the "mass". Of course, this may be offset by anticipated higher than 50 percentile (50 percentile is equal to the median), but it is difficult to find a model that generates lines that end up in the middle of all measuring points. Due to different sites has different numbers of measures error, the specific median in some cases generate lines that are too high and sometimes too low.

What generates the visual "mass" of lines is that their density is greatest here. Therefore it is obviously best if the model that will generate the mean line where the density is highest. A model that calculates the density can obviously be done in a variety of ways and there is really no way that is more right or wrong than any other. Again, the difficulty of trying to find a density model that generates good lines for all data points, where different sites has different conditions.

The basis of the Stockholm model assumes that the boundaries are created from a 99.5-percent confidence interval, where the standard deviation calculated by the formula (medelvärdet = mean value)

$$\sqrt{2} \times \sqrt{medelvärdet} \tag{2.6}$$

This method of creating external borders was used when analysis was made by the flow curves of the Stockholm Trial (try of congestion tax in Stockholm). Since this method of calculating the external borders were already tested, we think this way was a good way to go. This is also the reason why the model has been named the Stockholm model.

How the model used in Stockholm looked like was not easy to know. The description was only written very briefly, why it has not been possible to ascertain exactly how it looked. Various tests have been done to try to create a similar model, but tests shown that a similar model was not too worked very well. With data from some sites, the line has been generated got outside the "mass". The reason that these models has not worked may be due to the measurement sites in Göteborg has contained a larger amount of errors data than they did in Stockholm. Another reason can be we did not success to built a model exactly as the model was in Stockholm, because the bad description of it.

To obtain such an appropriate model as possible, the various designs tested, all of which has kept the same basis as used in Stockholm. The tests led to the model used today. Crucial to the model to work are that it is only one value that is removed from the list each time new confidence interval is calculated. The model got wrong result if it removes all values outside the range each time the new limits are calculated. It is also wrong if you allow that you can delete one value above and one below the limits each time. It is also necessary with the initial zero values removal, otherwise the answer in for some sites end up at zero.

The current design of the Stockholm model has proved to work very well. The line which be generated by the model is almost always located in the middle of the "mass" and reflects in a very good way the normal situation for the actual time.

2.3.6 The final charts

The Stockholm model is the best model to use for calculating the weighted lines. When the group based on flow charts had decided what hours the different levels of taxes would apply, they presented everything in a report. The report also includes some illustrative diagrams that showed the link between the flows and the levels of taxes. We picked out the flow charts from a few sites and plotted them in a chart together with the proposed tax rates. Two proposals were presented, one with three levels of taxes and one with two. The proposed three-level were the main proposal by the group. Figure 2.4 shows the graph with three levels and Figure 2.5 the graph with two levels.

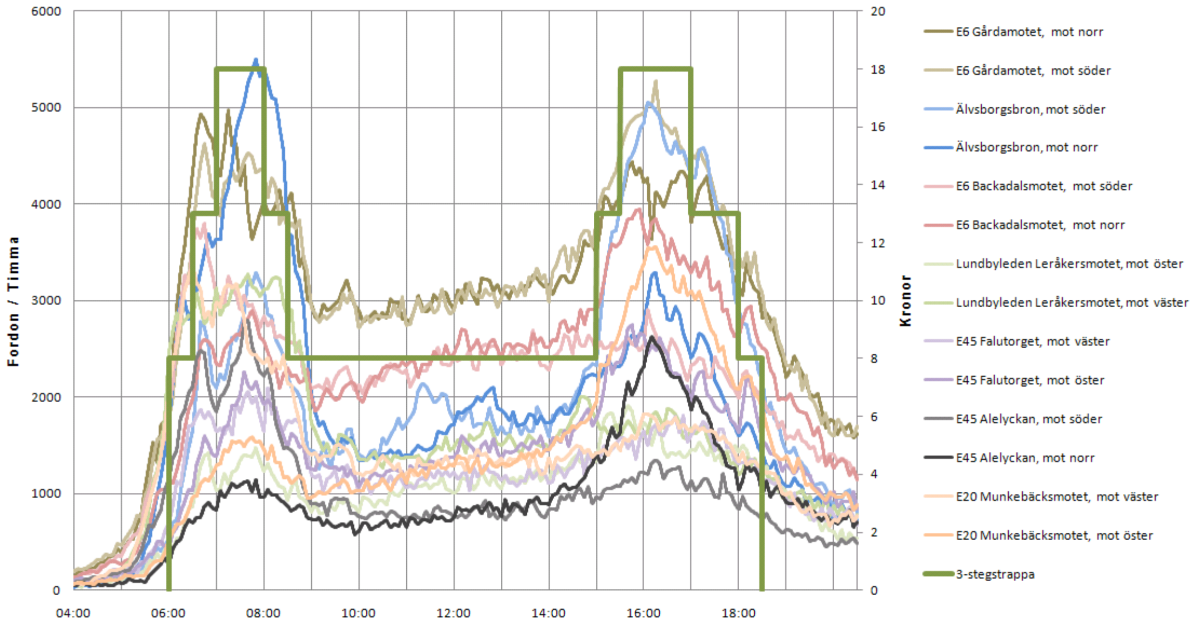

Figure 2.4 Flows from some sites together with the suggested tax rates with three levels. The flows are calculated with the Stockholm mode. This diagram was included in the report by the Swedish Transport Administration about the Congestion taxes, published in February 2010.

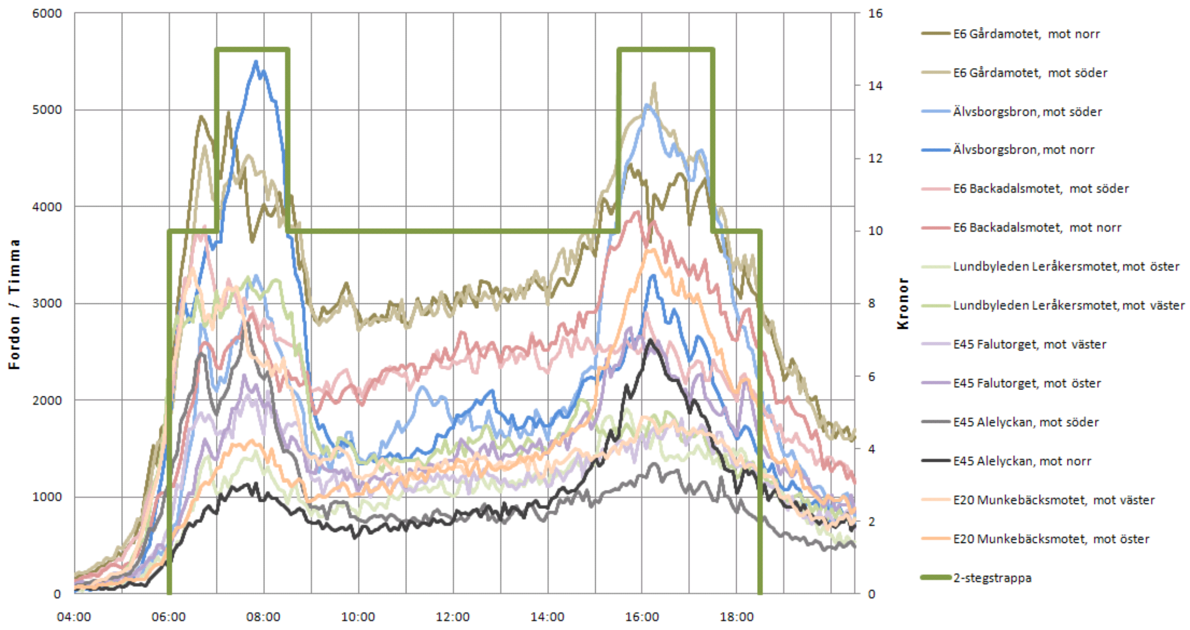

Figure 2.5 *Flows from some sites together with the suggested tax rates with two levels. The flows are calculated with the Stockholm mode. This diagram was included in the report by the Swedish Transport Administration about the Congestion taxes, published in February 2010.*

2.4 Congestion charts

Following the work of the congestion tax investigation, another type of diagram was developed. This diagram plots the flow on the horizontal axis and speed on the vertical. This chart shows very well how the speed decreases when the flow increases and how it will look like when the collapse occurs. Figure 2.6 shows an example of this, plotted during morning rush hour.

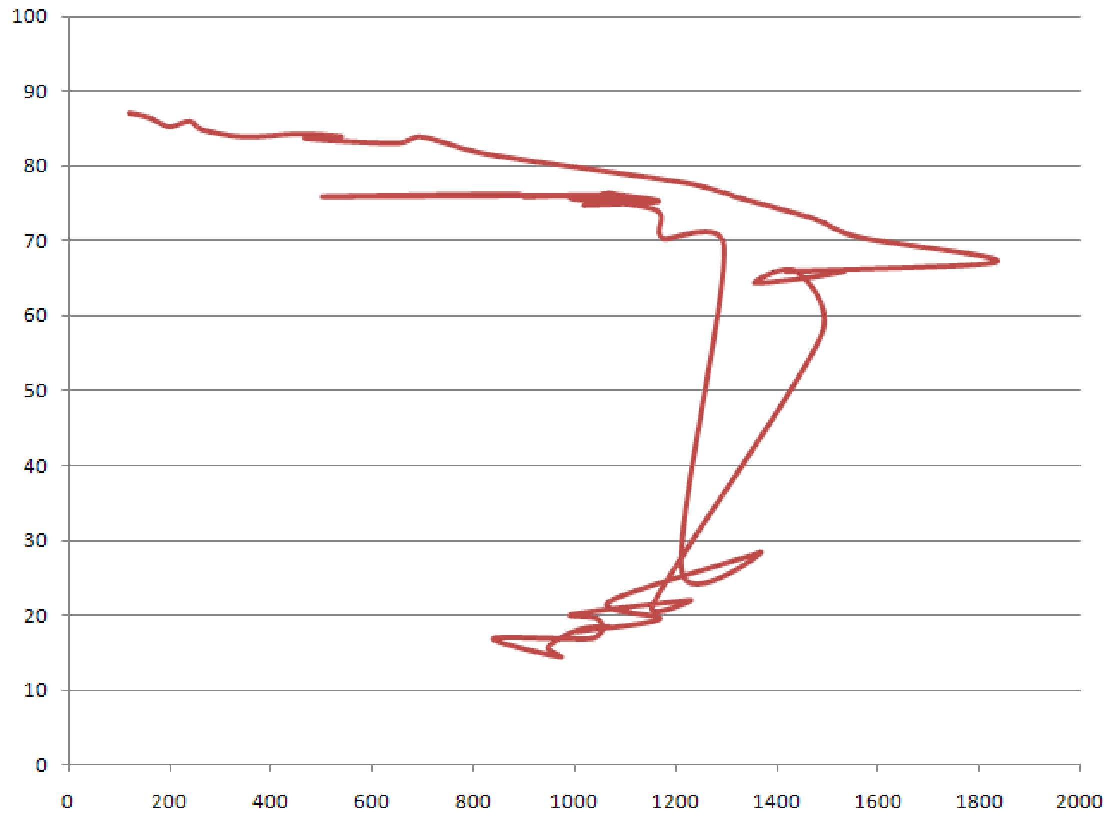

Figure 2.6 *One of the northbound lanes of E6/E20 in Gårda in Göteborg in the morning rush hour, calculated with the Connection model and the Stockholm model, with data from Mondays - Fridays from autumn 2007. In the early morning the line starts on the upper left part of the diagram and then goes in right direction. The flow increases, speed decreases slowly. The collapse occurs at the far right of the diagram and it is clear how the speed drops sharply and forced the flow down. When the inflow has going down the speed goes up again. The flow is measured in vehicles per hour and the speed in km/h.*

The disadvantage of such a chart is that you cannot see the times at which the flow and speed is at different levels. We should have an additional axis of the graph showing the time. You can create diagrams in three dimensions, but such a chart would hardly be visible in this case because it would be too complex to read. Another way would be to color the lines differently depending on what hours they occur, but then it will be very imprecise because you cannot see exactly what time it occurs. With different colors, every color must span over a given time, for example, one color between 7-8, another between 8 and 9, and so on. Using many colors to create small range is also hardly possible because it becomes too hard to read.

Instead, another method was developed. The script programmed to generate a diagram every fifth minute. The first diagram shows the series of flow and speed, which occurred between 05:00 and 05:05. The second diagram shows the line between 05:00 to 05:10, and so on. Chart is created right up until the rush hour is over, for example, until 10:00 am. The final chart contents when the line has been generated between at.

05:00 to 10:00 am. By quickly switch between charts you get the illusion that the line "grows up". One can also see exactly where the flow and speed is at different times and one can see, for example, the time at which the collapse occurs. Figure 2.7 - 2.10 show examples of an extract from the series. Four graphs are selected, picked where the collapse occurs. The black lines are part of the added portion of the line since the last chart in the series.

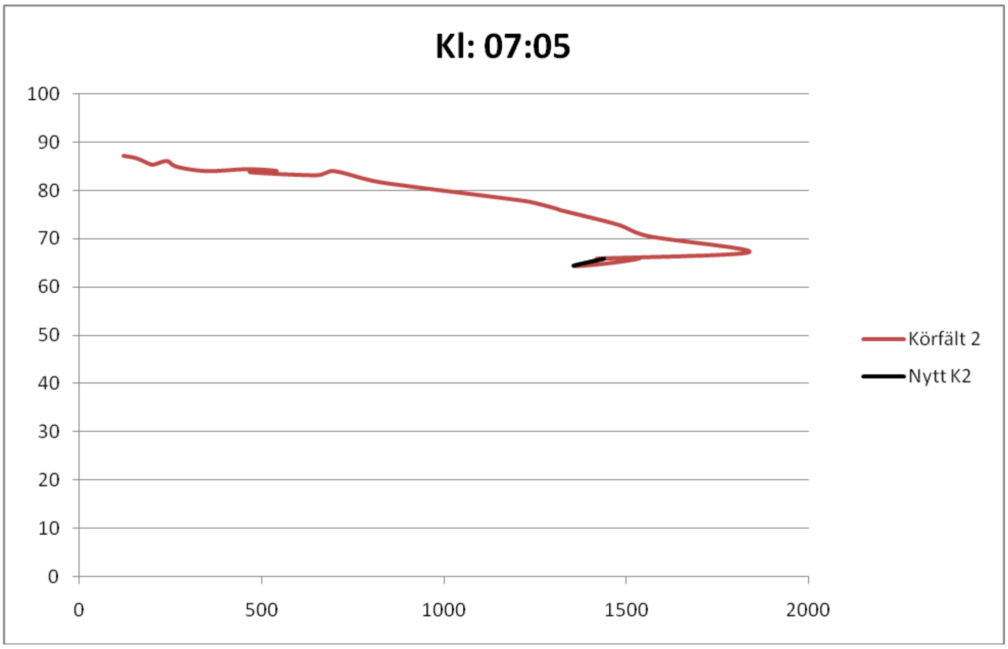

Figure 2.7 The first picture. E6/E20 in Gårda in Göteborg, the middle lane northbound. The diagram is calculated with the Connection model and Stockholm model, with data from weekdays during autumn 2007.

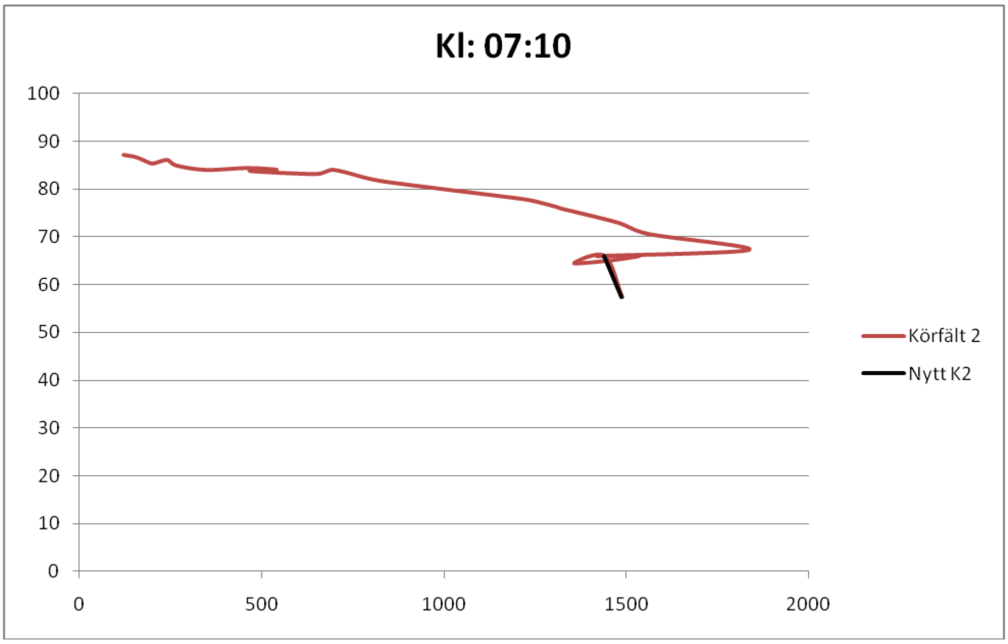

Figure 2.8 *The second picture. E6/E20 in Gårda in Göteborg, the middle lane northbound. The diagram is calculated with the Connection model and Stockholm model, with data from weekdays during autumn 2007.*

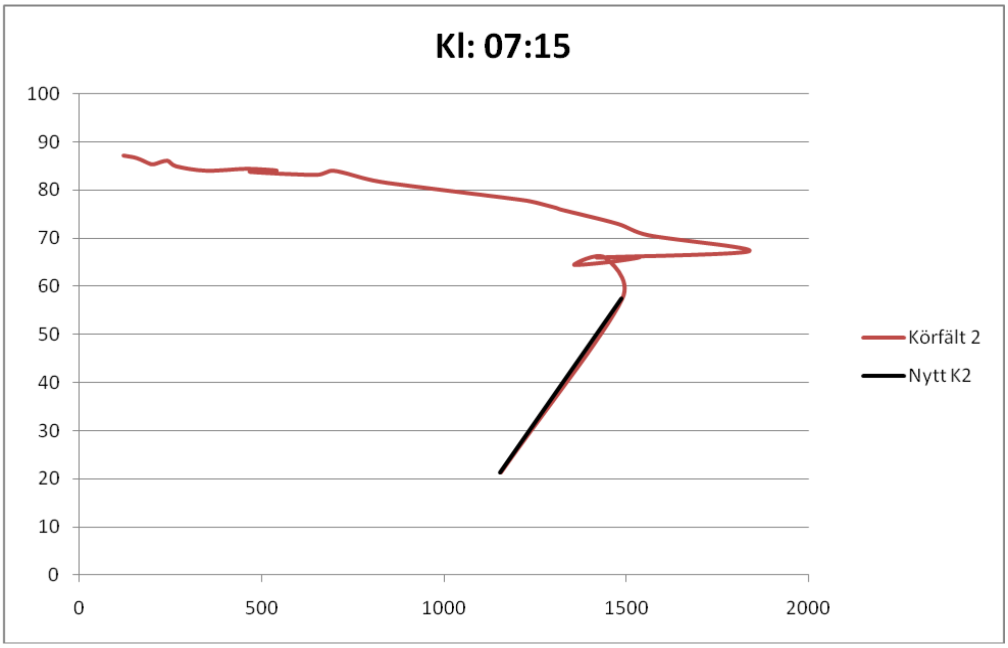

Figure 2.9 *The third picture. E6/E20 in Gårda in Göteborg, the middle lane northbound. The diagram is calculated with the Connection model and Stockholm model, with data from weekdays during autumn 2007.*

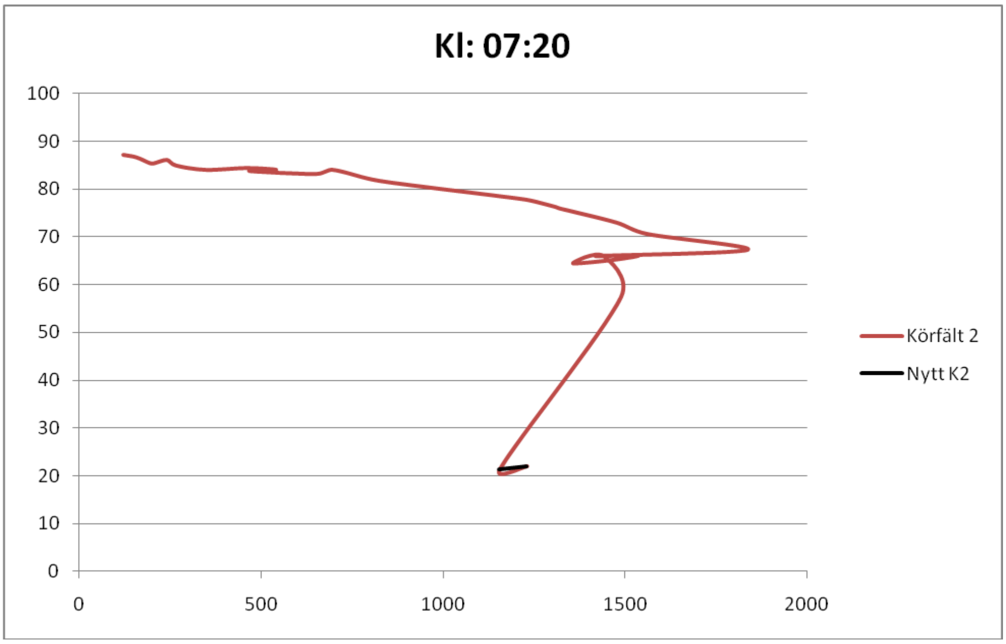

Figure 2.10 *The fourth picture. E6/E20 in Gårda in Göteborg, the middle lane northbound. The diagram is calculated with the Connection model and Stockholm model, with data from weekdays during autumn 2007.*

2.4.1 Algorithms

The creation of congestion diagrams required special algorithms to generate weighted flows and speeds. Different algorithms were created and tested, which led to the two main algorithms. One is called the Connection model and the other for the Separate model. Here comes a description and discussion of these two models. Both models include either the Percentile model or the Stockholm model. To read more specifically about these, see Section 2.3.4 or 2.3.5.

2.4.2 The Connection model

1. Input data for flows and speed is collected from database. The data shows every lane separately. The data is given for every 5 minutes from the period 070903 – 071214.

2. All data outside weekdays 05:00 – 19:00 is removed. Even zero values are removed.

3. Speed data from all days for the first 5 minutes period (05:00) puts in a list. One of the speeds in the list will representate the actual 5 minutes period. This is done by a calculation method, the Percentil model or the Stockholm model.

4. From the list with the speeds, the representative speed is collected. Even the four speeds right under and over the representative speed is collected. That means totally nine speeds is collected. These nine speeds put in a new list.

5. The nine flows, from the same nine days as the nine selected speeds, also puts in a new list. If some of the nine flows are equal to zero, these flows will be removed. The new list with the flows is sorted and that flows which got in the middle of the sorted list takes as the representative flow for the 5 minutes period.

6. Step 3 – 5 repeats for all 5-minutes periods during the morning and the afternoon. When everything is finished had a speed and a flow chosed to representate each 5 minutes periods between 05:00 – 11:00 (morning) and 13:00 – 19:00 (afternoon).

7. Step 3 – 6 runs many times, one time for every calculation model (many different percentiles and one time for Stockholm model). The steps run for every lane and for all sites.

8. When every calculation is finished, everything will be plotted in diagrams. The flow is plotted on the horizontal axis and speed on the vertical. The same diagram can plot many different calculations. For example, you can put the calculations for the different lanes in the same diagram. One can instead choose to display results from the same lane but with different calculation methods, for example different percentiles and the Stockholm model.

9. When you plot speed against the flow in a chart, you cannot see the times at which different speeds and flows occur. Therefore, the model automatically generates several diagrams. The first plot line at. 05:00 to 05:05, the second plot line, 05:00 a.m. to 05:10, the third 05:00 a.m. to 05:15, and so on. The final graph plots the board for the morning, i.e. 05:00 to 11:00. Similarly, the plotted graphs of the afternoon, at. 13 - 19. By looking at the charts one after another you can see how the line "grows up".

2.4.3 The Separate model

1. Input data for flows and speed is collected from database. The data shows every lane separately. The data is given for every 5 minutes from the period 070903 – 071214.

2. All data outside weekdays 05:00 – 19:00 is removed. Even zero values are removed.

3. Speed data from all days for the first 5 minutes period (05:00) puts in a list. One of the speeds in the list will representate the actual 5 minutes period. This is done by a calculation method, the Percentil model or the Stockholm model.

4. Flow data from all days for the first 5 minutes period (05:00) puts in a list. One of the flows in the list will representate the actual 5 minutes period. This is done by a calculation method, the Percentil model or the Stockholm model.

5. Step 3- 4 repeats for all 5-minutes periods during the morning and the afternoon. When everything is finished, a speed and a flow have been chosen to representate each 5 minutes periods between 05:00 – 11:00 (morning) and 13:00 – 19:00 (afternoon).

6. Step 3 – 5 runs many times, one time for every calculation model (many different percentiles and one time for Stockholm model). The steps run for every lane and for all sites.

7. When every calculation is finished, everything wills we plotted in diagrams. The flow is plotted on the horizontal axis and speed on the vertical. The same diagram can plot many different calculations. For example, you can put the calculations for the different lanes in the same diagram. One can instead choose to display results from the same lane but with different calculation methods, for example different percentiles and the Stockholm model.

8. When you plot speed against the flow in a chart, you cannot see the times at which different speeds and flows occur. Therefore, the model automatically generates several diagrams. The first plot line at. 05:00 to 05:05, the second plot line, 05:00 a.m. to 05:10, the third 05:00 a.m. to 05:15, and so on. The final graph plots the board for the morning, i.e. 05:00 to 11:00. Similarly, the plotted graphs of the afternoon, at. 13 - 19. By looking at the charts one after another you can see how the line "grows up".

2.4.4 Discussion and comparison

Both models are selected a speed to represent each fifth minute period. This is done in both models by a percentile calculation or Stockholm model runs. When the flow is calculated in the Connection model, this is done based on the result from the calculation of the speed. This means that the flow is calculated depending on the speed in the Connection model and independent of the speed in the Separate model.

To test how well the models reflect reality, you can plot speed against the flow for all days which is the basis for calculations. Some days have naturally a different flow and speed, making the lines plotted here and there in the chart. However, there is often an apparent "mass" of lines. By plotting the line generated by the models in the same chart you can see if the calculated line is within the "mass".

Even if the Separate model calculates the flow and speed independent of each other, often the calculated lines correspond to the “mass”. This is because the fundamental relation between high flows and low speeds. If the flow is extremely high, the speed often is extremely low. Consider the difference that an extreme speed is a low speed (almost completely stopped traffic); while an extreme flow is a high flow. Of course the Percentile model takes this opposite relationship into account.

This makes the Separation model works well overall, although the speed and flow is calculated independently. However, there are several cases where the plotted line is not credible properly located within the "mass" of lines or even completely out of "mass". This is because the relationship between flow and speed is complex and not fully apply. This means that there is a need for a better model, which gave rise to the Connection model.

If you want to create a complete dependence between speed and flow, you can choose the flow that occurs the same day as the selected speed. If the calculation model (any percentile calculation or Stockholm model) for example, calculates the speed from Day 3 represent the current time, you can choose the flow from the same day. The problem with such a model is that the line too often deviates from the "mass". For example, Day 3 can be a day when the flow is not consistent with the normal. Although the flow deviates from the normal, the speed can be pretty normal, so it is not surprising that the flow is abnormal and the speed is normal in Day 3. In general, it is relatively unusual the flow is abnormal if the speed is normal, but sometimes it happens.

This means that you have to find a model that is somewhere between totally independent and totally dependent between the speed and flow. It is in this way that the Connection model works. First the representative speed is calculated by using a percentile calculation or the Stockholm model. From a sorted list also noted the four speeds immediately above and below the selected speed. Including the selected speed is therefore nine speeds recorded. The flows measured the same days as these speeds noted. The flows are sorted in a list, zero values are removed and then the median flow. Median flow is the flow that represents the current time.

This means that the selected flow can be picked from any of the nine days; it must not be the same day as the speed picked from. This also significantly reduces the risk that the selected flow will deviate from the norm. Although the flow measured the same day of the selected speed deviates, it is very unlikely that the median flow of these nine flows will make it. In general, all these nine flows are normal and the probability that all nine will be abnormal is extremely small. Of all tests made with the Connection model, there is no recorded case in which the line has been generated outside the "mass".

If the model had included more than four flows on each side of the chosen speed, the model had gone more to the independent side. Had the model noticed all flows around the selected speed model had the model in principle worked the same as the Separate model. Four speeds on each side have proven to be a good balance between dependent and independent.

Something that also has been tested is to reverse the order flow and speed is calculated in the Connection model. There is nothing that says that the speed must be calculated first, then the flow. You can also change and let the flow be calculated first and pick nine flows and let the speed be calculated dependent of the flow. We call this model for the Reverse Connection model. The lines generated in the Connection model and the Reverse Connection model is pretty equal, but after studying many charts Connection model has proven to be better. The Reverse Connection model has a tendency to get lower speeds than we want, although both models are correct in relation to the "masses".

3 Ramp meter

3.1 Background

In many parts of the world there are congestion problems on freeways. Congestion problems are usually due to the demand for travel is greater than road capacity. In many cases, the overall capacity of the road enough, but that one or more sites have lower capacity. Such places known bottlenecks and can be a junction where the traffic from the ramp will enter the freeway lanes. When inflow to the bottleneck is larger than the capacity, queues formed upstream of the bottleneck. When a road user gets stocked in the queue he can be located several miles away from the bottleneck due to the long queue. Immediately after the bottleneck, it is common the speed significantly increases again.

3.2 Introduction

When the bottleneck is a junction where the problems causes by the traffic entering the freeway from the local road, is it usually the amount of traffic on both the freeway and the ramp is relatively high. When traffic will change lane from the ramp to the regular lane, it can be problem to find a gap and of that reason the traffic on the freeway need to brake. The braking effect is spreading from one car to another and traffic is flowing more slowly further and further upstream. Worst are the problems when many vehicles coming at the same time on the ramp. This makes it even harder for the cars to find a suitable gap, which means that traffic on the freeway must slow down even more. The fact that many vehicles will come on the freeway at the same time is due to various things, such that a slow truck has time to accumulate a few cars, the junction is preceded by a traffic signal. When many vehicles has enter the freeway, it usual this following by a period where there will be no vehicles at all. After a while a new wave of vehicles comes again. Figure 3.1 shows how the situation might look like with and without ramp meter.

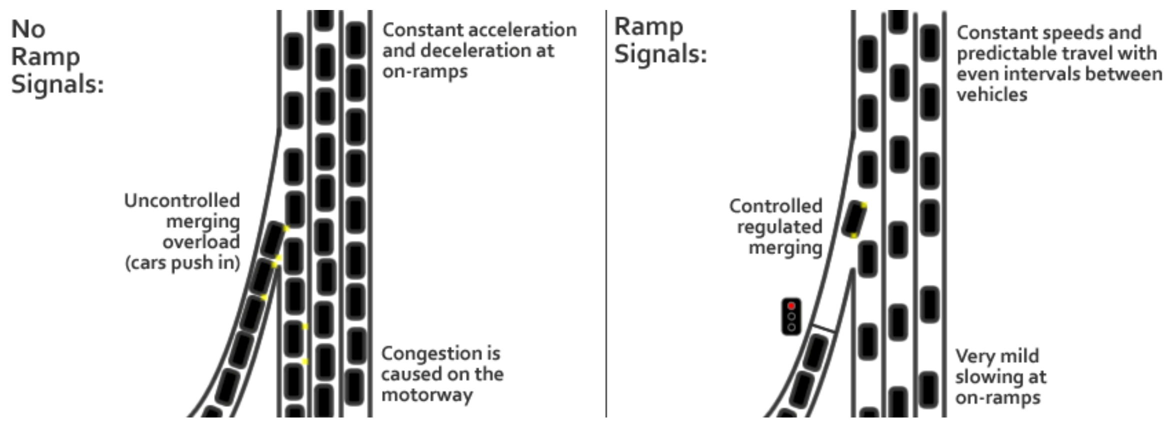

Figure 3.1 The situation on a freeway with left hand traffic. Without ramp meter to the left and with ramp meter to the right. The traffic flows much better with ramp meter. (Auckland Motorways)

To let the vehicles come in this irregular way, first many at once, then none at all, is the worst possible way for the traffic situation. It would be optimal if the vehicles come one and one, for example one vehicle every tenth second. This makes it easier for the vehicles to find a gap and traffic on the freeway does not have to change their driving behavior as a result of the ramp. To change the situation, we can use ramp meter. By putting up a traffic signal at the on-ramp, we can decide how often the vehicles can enter the freeway. Traffic signal is distinguished from other signals in that it usually only allows one vehicle per green period. Green period is thus very short and then it turns red for a few seconds. By setting the frequency of green periods you can decide how often the vehicles can enter.

The ramp meter makes the traffic going better on the freeway, but on the other hand, it makes the traffic going worse on the ramp. Maybe some cars must wait in a queue due to the signal. It is necessary the benefits of shortening travel time on the freeway are greater than the travel time extension on the ramp. A prerequisite for using ramp meter is that the ramp meets certain requirements. Depending on how often the signal shows green, you can release different number of vehicles per hour. It is not appropriate to release the vehicles more frequently than one every four seconds, equivalent to 900 vehicles per hour. This also means that the ramp flow is more than 900 vehicles per hour, the queue at the ramp gradually grow. Although the entrance ramp can handle a long queue, sometimes the queue will reach the local road, which causes problems even for other traffic. If you want to use ramp meter in this case, you should broad the ramp to two lanes. With two lanes, you can release the vehicle more frequently than every four seconds, and also have more space for queuing vehicles. If a widening of the ramp is necessary, this often implies a relatively high cost and then maybe you should instead think about other solutions, such as adding a lane on the freeway downstream the junction. *(California State, 2000)*

Provided that the amount of traffic is below 900 vehicles per hour, you can use one lane on the entrance ramp. Even if you theoretically can drop 900 vehicles per hour, it is better for traffic on the freeway if you let fewer cars enter. The challenge is to optimize the signal time due to the freeway condition and conditions on the ramp. As conditions change all the time that is controlled by detection points both on the freeway and the ramp. The detection point indicated flows, speed, etc. and a computer handles the information and decides how often the signal will switch. In most cases, there is at detection point downstream the junction, but in many cases supplemented with a detection point just upstream the ramp entrance. In order to avoid the queues grow too long on the ramp, it is important to have a detection point in the beginning of the ramp. If the queues growing out on the local road, the time period on the signal should be shorter and release the vehicles more frequently. The detection point must be I little bit from the local road so a more frequent green signal had time to affect on the queues. Figure 3.2 shows examples of ramp meter with one entrance lane.

Figure 3.2 Ramp meter with one lane, on a freeway with left hand traffic. (Auckland Motorways)

3.3 Algorithms

Given the traffic situation is thus how often vehicles will be released from the ramp. There is no obvious algorithm for how this should be done, but there are many algorithms used for this. Research is ongoing to continually construct better algorithms.

One of the simplest algorithms is based on releasing as many vehicles as possible with respect to the maximum capacity on the freeway downstream the junction. If the maximum capacity downstream for example is 5400 vehicles/hour and there are 4700 vehicles/hour on the freeway upstream of the junction, 700 vehicles/hour can be released. If the demand on the ramp is big enough you release this amount of vehicles. The capacity downstream is affixed value, so this algorithm only needs one detection point, located upstream the ramp. Even if the algorithm only need one detection point, of course all the ramp meter system needs more, for example one in the beginning of the ramp. If you do not want to use the maximum capacity downstream of the junction as the maximum level, you can set a lower limit. Using the maximum capacity is obviously a greater risk for problems than if you use a lower limit. The local situation should be the basis on which level you choose, including how large the demand is on the ramp. *(KTH)*

Another more advanced algorithm is ALINEA. It was developed in the early 1990s by Papageorgiou and is used today in many countries. The algorithm is based on the flow emitted from the ramp at all times adapted to the situation prevailing on the freeway. To some extent this is similar to the previously described algorithm, but due to some factors this can be tailored more for the conditions prevailing in a given location.

The ALINEA algorithm use this formula

$$r(k) = r(k-1) + K_R \cdot (\hat{O} - O_{out}(k)) \quad (3.1)$$

$r(k)$ is the release flow from the exit that will take effect *[vehicle/hour]*

$r(k-1)$ is the current release flow from the ramp *[vehicle/hour]*

K_R is a constant *[-]*

$\hat{O}$ is the desired occupancy downstream the ramp *[-]*

$O_{out}(k)$ is the current occupancy downstream the ramp *[-]*

A new release flow is calculated at regular intervals. The frequency of updating is usually somewhere between 30 seconds and five minutes, but the most optimal time is about 30-60 seconds. The occupancy is a percentage of maximum uses. A load rate of 100% means that all vehicles are one after each other without spaces, of course not practicable. It is necessary with a detection point downstream the ramp for the algorithm to work. It is not specified an exact distance how far downstream junction of the detection point should be placed, but it is important that the detection point is not placed too far away, the disturbance which generates of the ramp will still be felt. If the release flow is updated frequently often, the detection point should be closer the ramp, otherwise a lag effect can occur.

The detection point is usual located 40-500 meters downstream of the beginning of the ramp, but research has shown that the optimum distance is about 120-140 meters.

The constant K_R should be somewhere between 70 and 200. The occupancy load should be 19% - 21% or 30% - 31%, research showed. *(Chu, Yang, 2003)*

The above algorithms adjust the flow emitted from the ramp only to the situation on the freeway. What also should affect the flow is how long the queue is on the ramp. In many cases, it is acceptable that the queue is growing all the way back to the local road, but not longer. Queues growing out to the local road network would be avoided because this often causes problems for other traffic that is not at all on the way to the freeway. What determines how often the vehicles are permitted to run out from the exit is, in reality, how often the signal shows green. As well as this is determined by the situation on the freeway and the queue situation on the ramp, it is also determined by how fast the vehicles are running away from the traffic signal when it switch to green. When the signal turns green, but the vehicle is slow away, the signal must continue show green until the vehicle has passed the signal. If the vehicle is a truck or bus, the red time before next green should be extended to avoid the vehicle behind to catch up before it came out on the freeway. If the vehicle behind also is heavy, there is no need to extend the time.

If the indication point located on the freeway indicates that traffic volume is low, traffic signal will be switched off. At the beginning of the ramp, it will be some type of sign telling the drivers if the signal is turned on or off. You can use a standard sign, for example a warning sign for traffic light, and use flashing lights together with the sign. If the light is flashing the signal is on, otherwise it is off. The sign can also be a digital sign with different information. A sign will be placed closed to the traffic signal with information about it is only admitted for one vehicle to pass per green period.

If the traffic signal is activated, but no vehicles are on the ramp, the signal should show constant red. When a vehicle approaching, the signal change to green. When the vehicle has passed the signal, the signal switch to yellow and then red. To control the signal it is therefore required many detection points. Some points are more or less completely necessary, while some can be used to control the system more effectively. Different sites may have different conditions, so different sites can require different number of points and different locations of them.

3.4 Detection points and algorithms

The optimal placement of the detection points varies between different sites. Depending on where the detection points are located, the algorithm also looks different. Figure 3.3 shows an example of where detection point should be located and examples of an algorithm.

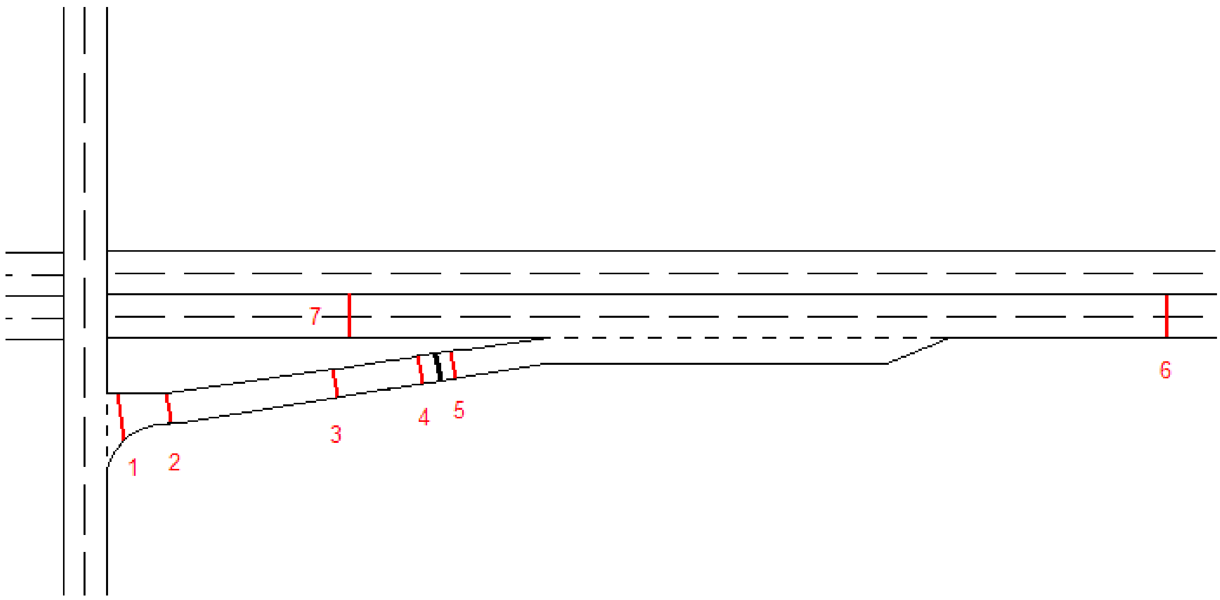

Figure 3.3 The locations of the detection points

Detection point 1 – Detection of queue #1

Detection point 2 – Detection of queue #2

Detection point 3 – Detection of vehicle before the traffic signal #1

Detection point 4 – Detection of vehicle before the traffic signal #2

Detection point 5 – Detection of vehicle after the traffic signal

Detection point 6 – Detection of the flow downstream the ramp

Detection point 7 – Detection of the speed upstream the ramp

Short description of the algorithm

1. If detection point 6 detects a lower flow than a certain number of vehicles per hour and detection point 7 detects a higher speed than a certain km/h, the traffic signal will be switched off. At the beginning of the ramp some form of adjustable sign indicates that the traffic signal is off. Which critical flow to form the boundary for detection point 6 do you get when the system is new-installed and you test different values. You do the same for the speed for detection point 7.

2. If detection point 6 detects a higher flow than a certain number of vehicles per hour, or detection point 7 indicate a lower speed than a km/h, the traffic signal will be switched on. The sign in the beginning of the ramp show the signal is turned on.

3. If neither detection point 3 or 4 indicates any vehicle, the signal will show constantly red. Detection point 3 is used as a complement to detection point 4. If the vehicle waiting for green signal stops a little bit before the signal, detection point 4 do not detect that, but detection point will do.

4. If detection point 3 and/or detection point 4 indicate a vehicle, the further steps will be running. The first times the detection points indicate a vehicle, the signal with immediately switch to green.

5. When detection point 5 then indicates a vehicle, this means that the vehicle has passed the signal. When this happens, the signal turns on to yellow and after some more seconds; to red. The time for yellow can be kept short because there are no additional vehicles which will pass the signal. In some countries the yellow signal is removed, but in Sweden it probably needs due to legal reasons.

6. A variable controls how long the signal will wait between the green periods. The variable is called *m* and is equal to the time in seconds. The time between

the green periods include time for yellow, time for red and time for red/yellow (when the signal switch back to green). The period of time for yellow and red/yellow are fixed times, for example, two seconds respectively one second. This means that the time for red is equal to *m - 3 seconds*.

7. After the time of *m* the signal switch back to green, then step 5 - 6 is running again. If detection point 5 indicates that the vehicle just passed the signal is a heavy vehicle, at the same time as detection points 3 or 4 indicates that the vehicles behind is a light vehicle, *m* will be extended. That means the time before the next green period is extended.

8. In parallel with steps 5 – 7, the time for *m* is updated at regular intervals, preferably every 45 seconds. The update is done in the form of ALINEA algorithm, which scans the occupancy level on the freeway, downstream the ramp. What values you choose to use in the ALINEA formula, the desired occupancy and the value K_R, you should decide after testing some different values when the system is new-installed. Of course you should lie within the limits 19-21% or 30-31% for the occupancy, respectively 70 – 200 for K_R.

9. If detection point 2 indicates vehicles standing still, the time for *m* will be decreased, regardless of what ALINEA algorithm calculates. Either you can reduce *m* to a predetermined value, or you can reduce it to a certain percentage of what ALINEA algorithm calculates. When the system is new-installed, you can test different values to see which perform best. If detection point 2 after a few minutes still indicates vehicles in queue, *m* should be lowered any more. When the detection point 2 after some minutes no longer indicate vehicles in queue, *m* will gradually increase again and after some time go back to the value the ALINEA algorithm calculates.

10. If detection point 1 indicates a stationary vehicle, *m* must significantly be reduced or let the traffic signal be switched off. If detection point 6 indicates a stationary vehicle, this is a mistake; the goal is that the queues never will reach this point because the reduction of *m* when the queue reach detection point 2. Exactly what action to take if the queue reach detection point 1 depends on how important you think it is to avoid the queue on the local road network vs. how important it is to maintain accessibility on the freeway. If you turn off the signal in this mode, you can expect big reduces of the freeway capacity and perhaps a queue fast grow upstream the junction along the freeway. Even after the queue has gone on the ramp, it takes a lot of time before the situation on the freeway is as it was before. Of that reason you really must think it is important to avoid queues on the local road to turn of the traffic lights. If you detect a queue you can first test to reduce *m*, and only turn of the lights if you still detect queue after some minutes.

3.5 Criterias for inclusion of ramp meter

If you want to install ramp meter, you must check so the ramp meet certain criterias. What criterias are required may vary from site to site, but some of these should be met:

1. The freeway should have congestion problems close to the junction. In some cases you want to use ramp meter even if the queues only are located downstream the ramp. In this case you use ramp meter only to reduce the flow from the ramp, not because to make a more regular outflow.

2. Traffic on the ramp will be negatively affects the situation on the freeway. This means that the amount of traffic on the ramp must be relatively high.

3. The ramp should be long enough both to make room for queuing vehicles and be long enough to allow the vehicles to accelerate before they enter the freeway. If the ramp is not long enough, you can solve this if you rebuilt the local road so the queues can be placed here without disturbing other traffic. You can also broad the ramp so you have two lanes. It is not necessary for the traffic to accelerate to the normal speed on the freeway. When you use the ramp meter, the traffic volume on the freeway make the traffic going slower than the free flow speed.

4. The amount of traffic on the ramp may not be too high. If the ramp has one lane, the traffic shall not exceed 900 vehicles per hour. If traffic is greater, you need to broaden and pick one or two more lanes before the signal, or consider other solutions such as add more lanes downstream the ramp. If you have several lanes before the signal you can release the vehicles faster and release a higher flow. One option may be to allow more vehicles than one to cross the green signal per period, but this is more complicated for the drivers and also reduces the usefulness of the ramp meter because man vehicles enter the freeway at the same time.

3.6 Change of time with regard to heavy vehicles

Before you install a ramp meter you must clearly identify what traffic volume on the ramp. When you know the maximum flow that occurs, you can calculate how often you have to release the vehicles during the busiest time period. In most cases you want to extend the red time after a heavy vehicle passes the signal to avoid the light vehicle behind reach the heavy vehicle before it enter the freeway. Time extension needs to be done only in cases where there is a light vehicle behind the heavy vehicle. If a heavy vehicle is behind you do not need any extension.

This extension makes the normal time slightly shorter. The following formula calculates the new time:

$$(1-h)\cdot t + k\cdot f\cdot h\cdot t = t_0 \quad <=> \quad t = \frac{t_0}{h(k\cdot f - 1) + 1} \tag{3.2}$$

t is the time between the green periods, when you have taken care of the extension for the heavy vehicles *[sec]*

t_0 is the time between the green periods, when you do not take care of the extension for the heavy vehicles *[sec]*

h is the proportion heavy vehicles vs. the total number of vehicles using the ramp *[-]*

k is a factor tells how many times longer time you want for the heavy vehicles between the green periods *[-]*

f is a factor tells the proportion a heavy vehicles is followed by a light vehicle vs. a heavy vehicle followed by another heavy vehicle. *[-]*

If the maximum flow for example is 600 vehicles per hour, this means you must release one vehicle every sixth second. We envisage that the proportion of heavy vehicles is 7%. With regard to the ramp looks like we imagine that we want the time between green periods shall be extended by 80% in the case of heavy vehicle followed by a light vehicle. The factor becomes 1.8. We assume that measurements have shown that heavy vehicles in 40% of the cases come directly after another heavy vehicle. This means that only in 60% of cases must be extended. The formula in this case looks like (sekunder = seconds)

$$t = \frac{6}{0{,}07(1{,}8\cdot 0{,}6 - 1) + 1} = 5{,}97\ sekunder \tag{3.3}$$

It is therefore a very marginal reduction in the time that must be made when taking into account the heavy vehicles in this case.

If we assume the ramp going upwards, we want to triple the time for heavy vehicles. The new time is: (sekunder = seconds)

$$t = \frac{6}{0{,}07(3 \cdot 0{,}6 - 1) + 1} = 5{,}68\ sekunder \qquad (3.4)$$

3.7 Applications in Göteborg area

Nowadays no places in Göteborg area use ramp meter. In Sweden, only a few places in Stockholm use it. Figure 3.4 shows examples of a ramp meter in Stockholm. The question to ask is if there are some sites in Göteborg area which ramp meter should be useful.

Figure 3.4 Ramp meter in Stockholm. (Davidsson)

3.7.1 Göta Tunnel

Already now, traffic signals for ramp meters on two ramps on E45 are installed for a few years ago, the eastbound ramp in Lilla Bommen and the westbound ramp in Järntorget. None of the sites today present need for ramp metering. At Järntorget, it is never any congestion at E45 westbound and in Lilla Bommen the lanes on the ramp continues at own lanes along the road. That´s mean the traffic on the ramp doesn't need to change lane when they enter the road. In addition, the ramp meter signals in both cases are located at the very beginning of the ramp, making the queue would grow on the local road network if signals were to be used. The signals maybe were installed as an extra protection and make it possible to cut off the inflow on E45 from the local roads to get it easier for the traffic from the tunnel to get out of the tunnel.

Although the lanes on the ramp at Lilla Bommen continue as own lanes east along E45, a ramp meter would reduce the inflow on E45 from the local roads. A reduction would make it better for the traffic from the tunnel because they don't need to share the space east of the junction with so many cars coming from the ramp. As a result of capacity problems at junction Gullberg queues occur at times even into the Göta Tunnel. If the flow from the exit had been forced down of a ramp meter fewer vehicles would have to share space on the route toward Gullberg junction and the queues would probably not grow right into the tunnel. In this case, the ramp meters should be used for purposes other than normal. Normally, ramp meters uses for better flows from the ramp, one vehicle per time, but in this case would instead use the ramp meters to reduce the flow from the ramp. Although the queues reduce the Göta Tunnel, but on the other hand, it would be a major problem at the local road network at the Nils Ericson Terminal. Already today there are problems in these areas during rush hour traffic and a situation with a ramp meter would create total chaos with completely stopped traffic. In addition to traffic traveling in the direction of Gullberg junction, this stopped traffic would also affect the traffic in other directions, such as traffic to the Göta Tunnel, the traffic from the Göta Tunnel to the Göta Älv Bridge, etc. Looking at the total picture, a ramp meter would create more problems than the benefit of it. If you want to limit the inflow from the ramp in case of an accident in the Göta tunnel (so the traffic from the tunnel easier can leave the tunnel) it should be even better to close the ramp completely.

3.7.2 Lindome junction

During morning rush hour the northbound ramp creates problems for the traffic out on the motorway. The negative impact of the ramp is clearly visible, the traffic flows very slow upstream the ramp, but goes much better downstream the ramp. The problem with very slow traffic upstream the ramp does not happen every day, but the days when it occur, the queues is growing up to five kilometers upstream the ramp. The problem starts around 07:25 and is still like that in about an hour. Figure 3.5 shows examples of how the situation might look like on a weekday morning on the E6/E20 northbound. It is not uncommon the vehicles on the ramp coming very irregular, first many cars, than nobody and then a new stream. This makes the problem even harder because it is more difficult for all cars coming at the same time to find a gap.

Figure 3.5 Lindome junction close to the northbound on-ramp.

The ramp contributes negatively to the traffic flow on the freeway, there is no doubt. The traffic flows much better a little bit downstream the ramp in comparation to how it flows upstream. The flow on the ramp is also high. Traffic counts have shown the flow in rush hour is 780 vehicles per hour. This means the requirement is met due to the traffic volume does not exceed 900 vehicles per hour. If it will exceed the limit under a very short time, it is no problems because in this case only a short queue will be make.

The ramp is also sufficiently long to accommodate both the acceleration stretch in front of the signal and place of the queue behind the signal. The signal can be placed fairly far forward, due to the junction goes downhill, and the proportion of heavy traffic is very low, around 2%. Thus, all criterias are satisfied and ramp metering would be an option in this case. While the criteria are met, it can obviously be a case that may speak against. One thing that must be investigated is whether people feel it is acceptable for traffic from the local road to eventually wait a little bit longer time due to the signal. In this case it can be some waiting time in the ramp, but totally an installation would be very good due to the reduction of queues on the freeway.

What you also have to consider is whether there is a risk that users choose other routes to avoid the junction. Most of the traffic using the ramp came from Lindome.

One option to avoid the ramp is to traveling along local roads north and enter the freeway in the Kållered junction. A potential increase in traffic at the junction Kållered would result in longer queues in the traffic signal in the intersection just before the on-ramp in the Kållered junction. A longer queue here would only affect the traffic from Lindome, so it is not a big problem if it happens. Instead a balance will be set between Lindome junction and Kållered junction where people choose the fastest route. A potential increase in traffic on the old E6 through Lindome not expected to pose some problems.

Nowadays the traffic flow on the ramp in Lindome junction is 780 vehicles per hour during peak times. Even if the flow is below the limit of 900 vehicles per hour, the flow is still very high. To release 780 vehicles per hour, the signal must show green very often. If more traffic choose Kållered junction instead of Lindome junction it would be good. The lane on the ramp in Kållered junction continue as an own lane on the freeway, that's mean the traffic don´t need to change lane to enter the freeway.

Overall, this means that Lindome junction should be used for ramp metering. The only problem that can occur is you do not have time to release all vehicles due to the high flow. Even if you are below the limit it can be problem. A discharge of 780 vehicles per hour is equivalent to one vehicle every 4.62 seconds, but this time must be corrected for time extension for the heavy vehicles. Since the ramp goes in downhill, it is considered reasonable that the time is extended to the double. Because the partition of heavy vehicles is so low, we consider all heavy vehicles comes alone, that means we must extent time in 100% of cases. The formula becomes (sekunder = seconds)

$$t = \frac{4{,}62}{0{,}02(2 \cdot 1 - 1) + 1} = 4{,}53\ sekunder \qquad (2.7)$$

Even if the limit is 900 vehicles/hour it can be problem with this relative high flow. In the beginning when the system is new-installed it can be problem because it takes some time for the drivers to learn how to drive. I skilled driver learns the rhythm and know when to run and pass the signal. He sees how often the vehicles are running away in front of him so he knows how often the signal switches the green. A problem in the beginning is if the driver don´t drive immediately when the signal switch to green. In rush hours it is mostly familiar drivers, so after some time the eventually problem with slow driver should no longer be a problem.

Because the flow already today is high, you must make an analyze about the future to watch out if the flow plan to increase. If the flow plans to increase, above the limit 900 vehicles/hours, you already now should plan for that. In this case the traffic volume don´t plan to increases. The first reason for that is, the ramp meter itself reduce the flow because the travel time be longer. Instead more vehicles want to choose Kållered junction. The second reason is the introduction of congestion taxes in 2013, make more people become to use public transport instead of own cars. It may be reasonable to assume that the amount of traffic on the junction will be relatively unchanged, which means that the ramp meter should work.

Overall, this makes ramp metering to be a good to use at the northbound on-ramp.

3.7.3 Klareberg junction

During afternoon, rush hour problems occur on E6 northbound all the way from Göteborg up to Kungälv. Traffic flows with reduced speed up to the Jordfall junction, but the slowest part is from the Klareberg junction and upstream. Queues occur on the freeway in level with the northbound on-ramp in Klareberg junction and go upstream. Although traffic problems remain even north of the junction, the speed increases significantly after the ramp. Of that reason the negative impact of the ramp is clearly visible. The problems are worst from approximately 16:00 and one hour ahead. A traffic measurement was going from 14:30 to 17:00 and showed the amount of traffic on the junction was 440 vehicles per hour during this period. During the max load; 16:05 to 16:20, the traffic flow was 750 vehicles per hour. A traffic flow of 750 vehicles per hour is a high volume, but it is still below the limit of what is acceptable for one lane. Figure 3.6 shows examples of the situation at the northbound ramp on a weekday afternoon.

Figure 3.6 Klareberg junction close to the northbound on-ramp.

One of the reasons that the ramp creates problems for the freeway is that the traffic on the ramp comes very irregular. Up to approximately 12 vehicles can come together, then none at all, since new collection vehicles. A large proportion of traffic that uses the junction comes from the road Norrleden. On the Norrleden it is many traffic signals, making the traffic collected in this way. Hence, ramp metering in this case be very good. The general aim of ramp metering on this site is to release on car per green time and do it so quick so all vehicles has been released before the next wave of vehicles came. Otherwise, the queues will be longer and longer.

The ramp is very long, so there is no risk you cannot store both the queue and have enough with space for the acceleration after the signal. Since the ramp goes uphill toward the freeway, it is necessary to ensure that the acceleration distance is long enough. The time before the next green period must also be substantially extended when a heavy vehicle driving on the highway. Otherwise light vehicles reach the heavy vehicle before it enters the freeway and you will partially lose the benefit of the ramp meter. Although the ramp is long, you must avoid placing the signal further back than is absolutely necessary. A long acceleration distance makes you must extend the time any more for the heavy vehicles and the risk also increase a fast car reach more slowly car. Due to the rush hour, the traffic flows more slowly on the freeway than the normal speed. Of that reason it is not necessary that the vehicles have enough stretch to reach the normal speed.

As in the case of Lindome junction flow the flow I relatively high. During the max period you must release the vehicles every 4.8 seconds. Measurements have shown that the heavy traffic represents about 5% of traffic. We estimated that it is appropriate that the time between green periods increase by 250% and that time must be done in 60% of cases (because they are relatively often the heavy vehicles comes after each other). The formula becomes (sekunder = seconds)

$$t = \frac{4{,}8}{0{,}05(3{,}5 \cdot 0{,}6 - 1) + 1} = 4{,}55\ sekunder \qquad (2.8)$$

During the maximum flow therefore need to release one vehicle every 4.55 seconds. This is fairly common and can possibly cause problems at the beginning before users have learned the rhythm of the signal. When the drivers have become skilled they know when it's time to drive by studying how often the vehicles in front are running out. The driver is ready to run immediately when the signal turns green. Therefore the short time do not expect to cause a problem, at least not when the drivers has been skilled a short period after the installation of the ramp meter equipment.

It is hoped that the waiting time at the signal should not be particularly long. Is there a risk that people choose other ways to avoid the ramp? A big part of the traffic on the ramp has come from the road Hisingsleden from the area around Älvsborg Bridge and Torslanda. Maybe some drivers will run Lundbyleden / E6 instead. Maybe some will run from Säve along Kongahälla Road to Rödbo junction close Kungälv. Perhaps some will choose to turn off just before Klareberg junction and choose to run Ellesbo Road north to Kungälv. These three alternatives road are the most are essentially alternative ways one can imagine that people will choose to avoid the ramp. Provided that the waiting time is kept short, however, it is not expected to pose a significant shift to happen. A slight increase in other ways deemed not pose a problem.

Since traffic volume is already relatively high at the ramp, you must make a forecast of its development. If traffic volume exceeds 900 vehicles per hour is necessary to have two lanes before the signal to make it possible to release all traffic. If traffic volume is growing strongly, it is probably better to build a third lane north of Klareberg junction all the way up to Jordfall junction and make it possible for the ramp to continue as an own lane along E6. Even now, the usage along E6 between these junctions is very high, so the speed is already now falling in rush hour, from 110 km/h to maybe 50 – 80 km/h.

Between Klareberg junction and Bräcke junction (north of Älvsborg Bridge) there are two routes that take about the same to travel. The first one is E6/Lundbyleden and the second one is Hisingsleden. Although Lundbyleden is a generally higher standard, the Swedish Transport Administration wishes more people will choose Hisingsleden to reduce the traffic in the more central areas. To make Hisingsleden more attractive, the long-term plan is to rebuild the road from the current two-lane road with traffic signals to freeway. In addition, a new link between Hisingsleden and Öckeröleden will be built (southeast of Volvo´s holdings), the so-called Halvor Link. Both these things will make Hisingsleden more attractive compared to Lundbyleden and this makes the flow on the ramp in Klareberg junction will increase in the future. None of this rebuilding will be maked in the next few years, so the traffic growth will not happened the coming years. If the ramp meter will be installed, this would only be a temporary solution in a few years, because in the future the traffic volume will be too high.

This means that it is not sure ramp metering is a good solution on this site. An installation of ramp meter will reduces the queues on E6 upstream the ramp, but an installation will increase the travel time if you come from Hisingsleden. This would bring Hisingsleden less attractive, the opposite of what the Swedish Transport Administration wants. This is another reason why the ramp meter only will be a temporally solution.

Overall, one can therefore say that ramp meter is not a long term solution to use on this site, but can be a good solution in the short term before the flows on the ramp will increase.

4 Result

The purpose of this work is to develop better computational models for combining measurement data for the creation of flow and speed diagrams, and increasing understanding of ramp meters and investigate if there are places in the Göteborg area in which this might be appropriate.

4.1 Algorithms

Many different algorithms were developed and tested. After many tests it was found that the so-called Stockholm model worked best. Figure 4.1 shows how the black line calculated with the Stockholm model follow the lines from the days very well.

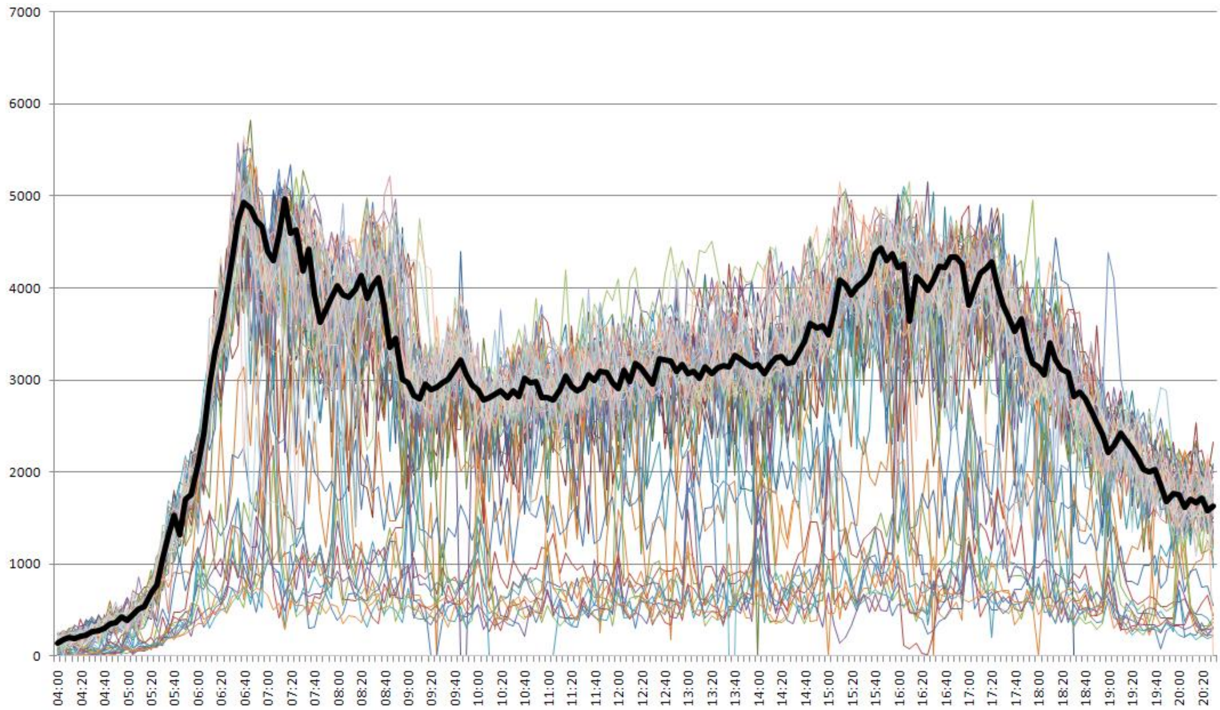

Figure 4.1 Flows from all days together with the black line calculated with the Stockholm model. The flow is expressed in vehicles per hour.

The weighted flow calculated by the Stockholm model was used to determine the different congestion tax levels for Göteborg. Figure 4.2 illustrates the relationship between the weighted curves from different sites together with the proposed tax levels.

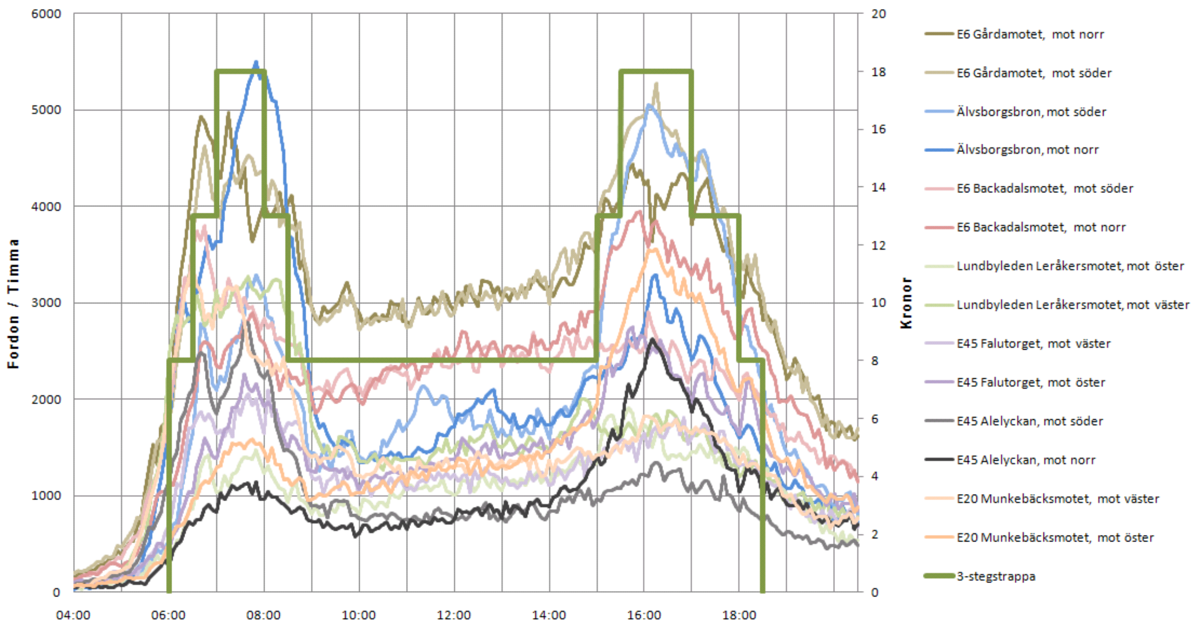

Figure 4.2 *Flows from some sites together with the suggested tax rates with three levels. The flows are calculated with the Stockholm mode. This diagram was included in the report by the Swedish Transport Administration about the Congestion taxes, published in February 2010.*

4.2 Ramp meter

A general overview of ramp meters is included in the work. This increased the general knowledge of ramp meter. In addition, own proposal on detection points and suggested algorithms is included. Even a formula which takes into account the extended time for heavy vehicles between green periods was developed. See Section 3.4 for the proposed placement of the loop rates and related algorithm. See Section 3.6 for the formula that takes into account the extension of time for heavy vehicles.

An investigation was also made to see which locations in Göteborg area that may be interesting for ramp meters. Close to the Göta Tunnel on E45 signals for ramp meters are already installed. One signal on the westbound on-ramp at Järntorget and one signal on the eastbound on-ramp at Lilla Bommen. In the current situation, none of these signals are in use. After analyzing the situation at the respective sites, a need of the signals may not be seen. In the westbound direction at Järntorget queue never occurs. In eastbound direction at Lilla Bommen queue arises due to capacity problems at Gullberg junction, but the on-ramp at Lilla Bommen continues as own lanes eastbound. Of that reason there is no need of ramp meters to improve the possibility for vehicles to change lane from the ramp to the road. Ramp meters could be used to reduce the traffic from local roads, thereby reducing the total traffic on the E45 east of Lilla Bommen, but this would cause more problems at the local road network than it would benefit users who come from the Göta tunnel. In addition, the traffic problems that would arise at the local road network also cause problems for travelers in other directions than to the Gullberg junction, for example traffic to the Göta Tunnel and traffic to the Götalv Bridge.

Two other locations were also studied, the northbound on-ramp in Lindome junction and the northbound on-ramp in Klareberg junction. It was known that both of these ramps have negative impact on the flow on the freeway. Many of the criterias for ramp meter is appropriate for both sites, but since traffic on the Klareberg junction in a few years is expected to increase sharply, it is no long-term solution to install a ramp meter. When traffic volume has increased to the future expected levels, the signals cannot release the traffic fast enough. Instead, other solutions must be taken, such as broadening the E6 northbound between Klareberg junction and Jordfall junction to three lanes. Lindome junction met all the criterias and ramp meter would get positive effects, mainly by the travel times along E6/E20 between Kungsbacka and Kållered would decrease.

5 Discussion

5.1 Algorithms

The calculation models that were developed are constructed specially for the Swedish Transport Administration database. The special measurement errors and other characteristics of the database are the models designed for. When the copy of the algorithm from Stockholm tried to be used together with this database, the answer was totally wrong. This was probably due to input data from Göteborg contained more error than it did in Stockholm and the model was therefore need to be equipped with additional filters which removed the incorrect data. Of this reason the algorithms is not generally. However, the different components in the models are more general, but not the full models.

When charts were developed for the congestion project it was very important to check the sensitivity of the analysis. If a small changes has made the outcome had been totally different, the model would not be good enough to decide the different tax levels. Therefore a lot of measurements were did, other measurement periods than autumn 2007, many measuring sites and also other models than the Stockholm model, for example the model for different percentile levels. The results of this showed that the result was almost exact the same, that means the models are not sensitivity.

5.2 Ramp meter

The proposals of the detection point locations and algorithms should apply generally. The algorithms are generally and allow the constants to be used with different values. Different sites can use different values for the constants. When knowledge about ramp meter was collected, web pages from many parts of the world were visited. The overall picture was that the installation and regulatory requirements for ramp meters looks the same all over the world.

The analyses of suitable sites in the Göteborg area were made by using criterias for when ramp meters is appropriate to use. Similary criteras are used in many countries. Therefore the criterias is generally and can be used in many countries. The final assessment of which of the suggested sites that area appropriate for using ramp meter, may be different depending on the person who takes the decision. Since both the Klareberg junction and Lindome junction on most items meet the criterias, individual assessments can give different outcomes.

In connection with my work on the Swedish Transport Administration it has been discussons if the ramp meters can be installed on any of these sites. When it was clear that it was no long term solution at Klareberg junction, the focus was on the Lindome junction. In the first half of June 2010 two measures sites is installed on E6/E20 at Lindome junction. The results give us better knowledge about the flows and speeds. If the results of the measurement are successful, the investigation will continue and can result in a future ramp meter on the northbound on-ramp.

6 Summary

Probably no one has mad models for the Swedish Transport database in this way before. When it was necessary with some type of models, many models were created and tested. In the end, the so-called Stockholms model was used to decide the different tax levels.

The proposals for the location of detection points and design of algorithms for ramp meters are not unique. The suggested algorithm is in many ways similar with other algorithms. However, the analyses of suitable sites in the Göteborgg area can give value. Thanks to the work, the Swedish Transport Adminstration has launched further investigations on the Lindome junction northbound on-ramp, which in a first step let to a contractor make further measurements of flows and speed around Lindome junction.

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Appendix 1 Algorithm for the Stockholm model

When the calculation models were developed, many different algorithms were created and hence many different source codes. All source codes were written in Visual Basic which was running as macros in MS Excel, directly in the files that the database generates (with flows and speeds for every five minutes 24 hours per day for 15 weeks in autumn 2007). After testing of the different algorithms, the best algorithm for flow-time charts were the Stockholm model, where data are presented from 04:00 to 20:30. It was this algorithm that was used for generating the charts which was included in the report by the Swedish Transport Administration in February 2010. The source code of these algorithms is as follows:

```
antal = 15
antal = antal * 7
Range("G4").Select
ActiveSheet.Shapes.AddChart.Select
ActiveChart.ChartType = xlLine
y = 1
d = 1
For x = 1 To antal
If y < 6 Then
Namn = "Flöde " & d
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(d).Name = Namn
Namn = "'Data'!$D$" & (50 + (x - 1) * 288) & ":$D$" & (248 + (x - 1) * 288)
ActiveChart.SeriesCollection(d).Values = Namn
Dim m(1000,199) as Double
For z = 1 To 199
Namn = "$D$" & (50 + (x - 1) * 288 + z - 1)
m(d,z) = ActiveSheet.Range(Namn).Value
Next z
ActiveChart.SeriesCollection(d).Format.Line.Weight = 1
y = y + 1
d = d + 1
Else
If y > 6 Then
y = 1
Else
y = y + 1
End If
End If
Next x
For z = 1 To 199
m2 = 0
For z2 = 1 To d - 1
m2 = m2 + m(z2,z)
Namn = "$O$" & z2
ActiveSheet.Range(Namn).Value = m(z2,z)
Next z2
Namn = "O1:O" & (d - 1)
Range(Namn).Select
```

```
Activesheet.Sort.SortFields.Clear
Activesheet.Sort.SortFields.Add Key:=Range("O1"), _
SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With Activesheet.Sort
.SetRange Range(Namn)
.Header = xlNo
.MatchCase = False
.Orientation = xlTopToBottom
.SortMethod = xlPinYin
.Apply
End With
Dim medel as Double
Dim sd as Double
Dim undre as Double
Dim ovre as Double
Dim avstand_undre as Double
Dim avstand_ovre as Double
lagsta = 1
hogsta = d - 1
utanfor = 1
While utanfor = 1
nollor = 1
While nollor = 1
Namn = "O" & lagsta
If ActiveSheet.Range(Namn).Value = 0 Then
lagsta = lagsta + 1
Else
nollor = 0
End If
Wend
Namn = "I1"
Range(Namn).Select
Namn = "=Average(R[" & lagsta - 1 & "]C[6]:R[" & hogsta - 1 & "]C[6])"
ActiveCell.FormulaR1C1 = Namn
medel = ActiveCell.Value
sd = 2^(1/2) * medel^(1/2)
undre = medel - 2.807 * sd
ovre = medel + 2.807 * sd
utanfor = 0
Namn = "O" & lagsta
avstand_undre = undre - ActiveSheet.Range(Namn).Value
Namn = "O" & hogsta
avstand_ovre = ActiveSheet.Range(Namn).Value - ovre
If avstand_undre > avstand_ovre Then
If avstand_undre > 0 Then
lagsta = lagsta + 1
utanfor = 1
End If
Else
If avstand_ovre > 0 Then
hogsta = hogsta - 1
utanfor = 1
End If
End If
```

```
Wend
Namn = "$Q$" & z
ActiveSheet.Range(Namn).Value = medel
Next z
ActiveSheet.ChartObjects("Diagram 1").Activate
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(d).Name = "Stockholmsmodellen"
Namn = "'Data'!$Q$1:$Q$199"
ActiveChart.SeriesCollection(d).Values = Namn
ActiveChart.SeriesCollection(d).Format.Line.Weight = 4
ActiveChart.SeriesCollection(d).Border.Color = RGB(0,0,0)
Range("M5").Select
ActiveCell.FormulaR1C1 = "4:00"
Range("M6").Select
ActiveCell.FormulaR1C1 = "4:05"
Range("M5:M6").Select
Selection.AutoFill Destination:=Range("M5:M203"), Type:=xlFillDefault
Range("M5:M203").Select
ActiveWindow.ScrollRow = 1
ActiveSheet.ChartObjects("Diagram 1").Activate
ActiveChart.SeriesCollection(1).XValues = "='Data'!$M$5:$M$203"
ActiveSheet.ChartObjects("Diagram 1").Activate
ActiveChart.Legend.Select
Selection.Delete
ActiveWindow.ScrollRow = 20
ActiveSheet.Shapes.AddChart.Select
ActiveChart.ChartType = xlLine
y = 1
d = 1
For x = 1 To antal
If y < 6 Then
Namn = "Hastighet " & d
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(d).Name = Namn
Namn = "'Data'!$E$" & (50 + (x - 1) * 288) & ":$E$" & (248 + (x - 1) * 288)
ActiveChart.SeriesCollection(d).Values = Namn
Dim n(1000,199) as Double
For z = 1 To 199
Namn = "$E$" & (50 + (x - 1) * 288 + z - 1)
n(d,z) = ActiveSheet.Range(Namn).Value
Next z
ActiveChart.SeriesCollection(d).Format.Line.Weight = 1
y = y + 1
d = d + 1
Else
If y > 6 Then
y = 1
Else
y = y + 1
End If
End If
Next x
For z = 1 To 199
m2 = 0
```

```
For z2 = 1 To d - 1
m2 = m2 + n(z2,z)
Namn = "$P$" & z2
ActiveSheet.Range(Namn).Value = n(z2,z)
Next z2
Namn = "P1:P" & (d - 1)
Range(Namn).Select
Activesheet.Sort.SortFields.Clear
Activesheet.Sort.SortFields.Add Key:=Range("P1"), _
SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With Activesheet.Sort
.SetRange Range(Namn)
.Header = xlNo
.MatchCase = False
.Orientation = xlTopToBottom
.SortMethod = xlPinYin
.Apply
End With
lagsta = 1
hogsta = d - 1
utanfor = 1
While utanfor = 1
nollor = 1
While nollor = 1
Namn = "P" & lagsta
If ActiveSheet.Range(Namn).Value = 0 Then
lagsta = lagsta + 1
Else
nollor = 0
End If
Wend
Namn = "J1"
Range(Namn).Select
Namn = "=Average(R[" & lagsta - 1 & "]C[6]:R[" & hogsta - 1 & "]C[6])"
ActiveCell.FormulaR1C1 = Namn
medel = ActiveCell.Value
sd = 2^(1/2) * medel^(1/2)
undre = medel - 2.807 * sd
ovre = medel + 2.807 * sd
utanfor = 0
Namn = "P" & lagsta
avstand_undre = undre - ActiveSheet.Range(Namn).Value
Namn = "P" & hogsta
avstand_ovre = ActiveSheet.Range(Namn).Value - ovre
If avstand_undre > avstand_ovre Then
If avstand_undre > 0 Then
lagsta = lagsta + 1
utanfor = 1
End If
Else
If avstand_ovre > 0 Then
hogsta = hogsta - 1
utanfor = 1
End If
```

```
End If
Wend
Namn = "$S$" & z
ActiveSheet.Range(Namn).Value = medel
Next z
ActiveSheet.ChartObjects("Diagram 2").Activate
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(d).Name = "Stockholmsmodellen"
Namn = "'Data'!$S$1:$S$199"
ActiveChart.SeriesCollection(d).Values = Namn
ActiveChart.SeriesCollection(d).Format.Line.Weight = 4
ActiveChart.SeriesCollection(d).Border.Color = RGB(0,0,0)
ActiveSheet.ChartObjects("Diagram 2").Activate
ActiveChart.SeriesCollection(1).XValues = "='Data'!$M$5:$M$203"
ActiveSheet.ChartObjects("Diagram 2").Activate
ActiveChart.Legend.Select
Selection.Delete
End Sub
```