The comments received from the referees on the Ph.D. thesis of Ms. Rijurekha Sen are enclosed herewith.

The referees generally spend considerable amount of their valuable time in assessing the work and it is felt that the quality of work would be materially enhanced, if the recommendation and suggestions of the external examiners are accepted and incorporated whenever feasible and possible.

You are requested to kindly go through the reports carefully and send us your detailed response jointly with co-supervisor, if any/ individually for each point of criticism raised by the two referees. A suitably modified version of the thesis should be presented at the time of defence viva-voce examination.

If the reports do not have any point of criticism (eg. (a) or (b)), you may recommend holding of the defence straightway. In case of (c) / (d) / (e), on receiving your report, it will be sent to the internal examiner for his perusal and after receipt of his comments the report will be put up to Convener, PGAPEE for approval.

However, if there are certain suggestions in the reports the arrangements for holding of defence can be initiated only after receiving a detailed reply to the suggestions and a clear assurance from the supervisor that the modifications agreed to, in his comments have been carried out. It may please be noted that, after approval of Convener, PGAPEE, you will be communicated the details about Board of Examiners, to whom you may contact to fix up the date & time of defence, which may be communicated to this office for further necessary action.

It may also be noted that any communication, pertaining to evaluation of thesis, with the external examiners should be made through Academic Office only.

Dy./Asstt. Registrar (Academic)

To:

1. Prof. Bhaskar Raman , Computer Science & Engineering (supervisor)
1. Name of the candidate: Ms. Rijurekha Sen
2. Name of the Department/Center: Computer Science & Engineering
3. Name of the Supervisor/Co-Supervisor: Prof. Bhaskar Raman
4. Thesis Title: Different Sensing Modalities for Traffic Monitoring in Developing Regions.
5. Name of the examiner, his/her designation and address: Vikram Srinivasan, Researcher, Member of Technical Staff Bell Labs Research, India., Manyata Embassy Business Park, Silver Oak-Wing A., Outer Ring Road, Nagavara, Bangalore-56004.

6. Recommendation of the examiner (Mark appropriate box)
   a) The thesis be accepted
   b) The thesis be accepted after clarification of the minor points listed in the report at the time of viva-voce
   c) The thesis be accepted after minor modifications/revision as suggested. After modification, the thesis need not be referred to me again
   d) The thesis requires major modifications/revision. The Nature of the modifications required are indicated. It is recommended that the revised thesis be referred again by an external examiner
   e) The thesis be rejected

Date: 8/13

(Signature of Examiner)
7. Detailed report on the thesis: (Comment on the salient features of the work reported in the thesis and the basis of the recommendations - use additional sheets, if necessary.)

See attached

8. Questions to be asked to the candidate at the time of the viva-voce examination.
(use additional sheets, if necessary.)

See attached

(Signature of Examiner)
1. You seem to be implicitly assuming that the vehicle starts and stops honking only when it is between the 2 sensors. This seems to result in your formula \( d1f1 = d2f2 \) for example on page 52. But this is not necessary. If the vehicle starts honking before it reaches R1, then for some duration the frequency will be \( f2 \) for R1. Similarly if it continues honking after it passes R2, for some duration both will see frequency \( f1 \).

2. In my high school days, I’d learnt that the speed of sound was 330m/s. I looked up Wikipedia and it gives a number of about 340m/s at 20 degrees C. Other sources say 330m/s. It appears that sound gets faster with age 😊 Since, there are so many different values available in literature, I would suggest giving a citation to where you’ve picked your number from.

3. On page 56, why do you need N to be a power of 2? Is it because you are using the FFT and FFT implements the Cooley-Tukey algorithm (essentially the radix 2/4 algorithm)? If so there are implementations which don’t need a power of 2 and there are numerous open source implementations for this.

4. At what granularity are you trying to get speed estimates? 3.69 standard deviation with a mean of 14.16 means the speed estimates are not really close!

5. Secn 3.8: Is the 10Kmph characteristic that of Mumbai/the particular road that you look at?

6. What if user behavior changes? In Bangalore people don’t honk as much anymore when stuck in traffic for example.

7. Define fill rate.

8. Your observation on having traffic dependent signalling is unwarranted. This is already implemented world over (including several cities in India where it is done manually by traffic cops).

9. One major issue with using honks is that the inter sensor distance has to be 20-30m. In your own estimate the cost per sensor is around $160. While you account for a simple weather proof casing, you don’t account for the cost of a ruggedized, weather proof, dust proof enclosure sensor that can work in all types of environment. Next you need to account for the cost of manual labour to deploy the sensors + the cost for the leasing rights to deploy the sensor on lampposts (e.g., in Mumbai a lot of the traffic lights are operated by Reliance power) and the cost to draw power to the sensor (battery will only work for short durations). Based on my experience, all this will easily put the cost per sensor in the $300-400 range. Assuming you want to cover all of Mumbai (around 2000Km), you will need to deploy 5 sensors per Km and the the cost for covering Mumbai will be $20Million! Not sure if this is a cheap solution!

10. I don’t understand why you want to have only sensing at R1, by how much are you actually reducing the cost by ignoring a computation element and transmission element in R1? I don’t think you are reducing the cost by much.

11. Is it legal to transmit on the FM band between R1 and R2?
12. You make detailed propagation delay experiments over FM. Why? Why is propagation delay over FM any different from any other frequency band, they all travel at the speed of light, which is constant.

Chapter 4:

1. A major concern with this chapter and the rest of thesis is that you don’t have a clear grip on state of the art ITS solutions, their costs and drawbacks. You have done a very preliminary study in Chapter 2. You argue for deploying 3 pairs of sensors (supposedly at $200 per pair - I think the costs will be higher if you include proper ruggedized casing with appropriate ratings, power supply draw etc). The cost of an inductive loop based sensor is not that different compared to your system of 3 pairs of sensors ($500-1000). The disadvantage of course is that you have to dig up the road and maintenance costs can be high. Inductive loop based sensors are used the world over to control traffic sensors based on queue sizes - and at a cost comparable to yours. My main concern with this thesis so far, is that you have done only a very preliminary study of existing ITS solutions and dived into different point problems without a clear understanding of the relative merits with respect to the state of the art.

2. You come up with a heuristic for classifying the state by using the count metric and seeing whether the freeflow count metric or the congestion count metric is higher. This is completely arbitrary. If you wanted to design a statistically valid test with a given false positive/false negative thresholds, you may come up with some thresholding policies.

3. You say that using RSSI is better than LQI or PRR is non intuitive I don’t understand why? Isn’t using the RSSI metric intuitively a better way?

4. How does your classification method react to changes in the environment (e.g., some road construction that goes on for few months, road widening which improves the road conditions etc.)?

5. Finally I really don’t see why this is a better cheaper alternative compared to inductive loop sensors for measuring queue length/traffic. Inductive loop sensors will also work in conditions where traffic doesn’t follow lane discipline and doesn’t seem much more expensive. This has to be explained more clearly in this chapter.

6. Personally, I would hesitate to characterize mapunity folks as practitioners in the field, while they are doing some good work on providing traffic information, I am not sure if they are trained ITS experts.

Chapter 5:

1. I found this chapter the most interesting of all. I think the idea of using low cost traffic cameras to come up with accurate estimates of speed is interesting and particularly challenging in Indian road conditions. The idea of using this to plot the fundamental traffic characteristic curves very interesting.
2. However, I found the discussion on people changing their travel times very flaky. I was expecting a more detailed analysis on the impact of say x% of commuters changing their travel time from a congested time to a less congested time. I did not see this at all. Also the interview with commuters and their skepticism about changing travel time and their experience of congestion is highly flaky and not believable at all. In the worst case it is clear that travelling at mid-night instead of 9:30AM will result in free commute. I am surprised that commuters questioned the impact of changing commute time. I am very skeptical of your interview methodology. Also I don’t see the point of a detailed measurement study on different days from 8AM -11AM to show that commute times are different. Of course it is! If it was congested all the time, there is something wrong with human behavior. All roads, anywhere in the world have congested and un congested durations.
INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY

REFEREE'S REPORT ON PH.D THESIS
(Confidential)

<table>
<thead>
<tr>
<th>1. Name of the candidate</th>
<th>Ms. Riju Rekha Sen</th>
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</thead>
<tbody>
<tr>
<td>2. Name of the Department/Center</td>
<td>Computer Science &amp; Engineering</td>
</tr>
<tr>
<td>3. Name of the Supervisor</td>
<td>Prof. Bhaskar Raman</td>
</tr>
<tr>
<td>Co-Supervisor</td>
<td>Prof.</td>
</tr>
<tr>
<td>5. Name of the examiner, his/her designation and address</td>
<td>Prof. Ramesh Govindan, Professor of Computer Science, University of Southern California, MC 2905, 3710 S. McClintock Ave, RTH 412, Los Angeles, CA 90089-2905.</td>
</tr>
</tbody>
</table>

6. Recommendation of the examiner (Mark appropriate box)
   a) The thesis be accepted
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   e) The thesis be rejected
7. **Detailed report on the thesis:** (Comment on the salient features of the work reported in the thesis and the basis of the recommendations - use additional sheets, if necessary.)

   Please see attached sheet.

8. **Questions to be asked to the candidate at the time of the viva-voce examination.**
   (use additional sheets, if necessary.)

   None.

   (Signature of Examiner)
* 2013-06-04 Tue 15:36* Rijurekha Sen thesis

Overall, I find the thesis documented to be very well written and the work itself to be very meticulous and an exemplary piece of experimental computer science research. As such, I would recommend the thesis be accepted towards the requirements for the Doctor of Philosophy degree at your institution. Below, I list several suggestions for improving the clarity of the presentation; these are minor changes to the document and the thesis need not be referred back to me again.

Chapter 1:

The introductory chapter is well written. I might suggest adding a paragraph at the end of this chapter summarizing future work that arises from this dissertation.

Chapter 2:

Some minor comments. The first paragraph can be shortened a little bit, since it is not necessarily to
exhaustively list the different kinds of backgrounds required in order to make the point that publications are found in different venues.

In section 2.2.2, since the discussion of mobile sensors is about a page and a half long, it might help to move the discussion of how mobile sensing is complementary to the approaches discussed in the thesis *before* discussing the specifics of mobile sensors.

One line of related work worth including is that which uses OBD-II readings to get car speed etc. This can be used in a crowd-sourced fashion (see the GreenGPS or CarMA papers in Sensys).

Also, I'd recommend putting Section 2.3 on Indian organizations involved in smart transportation is better off as an appendix?

Chapter 3:

In section 3.2.4, it might be good to separate out the software that you used (e.g., Praat etc.) from what you
actually did (audio format conversion, computation of the spectrogram etc.). In some sense, the latter is more important for your problem, since there are many possible tools that can be used to accomplish these tasks.

In section 3.2.5, it would be good to specify the target synchronization requirement (i.e., what level of time synchronization is sufficient in order to perform the various algorithms that you use such as honk matching). Often, it is possible to derive the synchronization requirements either from the sampling rate or from the time granularity at which your algorithm makes decisions.

Also, in the same section, it appears that you do not consider clock drift? Is it worth adding a brief description of why you think clock drift is not important for your application?

Section 3.4.5: "..form an arithmetic progression series": it's not clear what you mean here, i.e., whether this is an empirical
observation from your data, or you are referring to the fact that the honks have higher-order harmonics which are multiples of the fundamental frequency?

Section 3.5: "Amplitude difference...detect it earlier...": I didn't understand why an amplitude difference could result in one of the recorders detecting the honk *earlier* than another: is this time difference due to propagation delays or is it due to computational time differences in the same algorithm at the two different nodes.

Section 3.6: How do you distinguish between a Doppler shift of a single car's honk and two different stationary cars with slightly different frequencies (e.g., identical model cars with honk frequencies that differ slightly as a result of manufacturing differences). This is a theoretical issue, and I'm not sure how practical this concern is, but if you have thought about it it might be worth documenting it.
Section 3.8.3: "...we arrive at the 2 metrics": Is there a physical intuition for this choice of metrics (i.e., why is the dividing line the 70th percentile and 10%)? Without this physical intuition, you might end up with very different thresholds for different roads (something you discuss later in your machine learning section). If there is no physical intuition, it might be worth acknowledging that at this point in the text and adding a forward pointer to the discussion section.

Page 75: "...presence of an impending fork". This is interesting. How does this placement issue for R1 affect the results you have discussed previously in the paper? (It may not, but it might be worth adding a few lines to discuss this).

Section 3.9.2: I buy that using an analog FM signal to communicate between the two nodes is convenient, but I'm wondering if, deploying these two nodes in a busy intersection is likely to introduce signal distortions in practice that may affect the
accuracy of your algorithms?

I liked the discussion in Section 3.11.

Chapter 4:

I generally liked the evaluation methodology in this chapter and the care with which ground truth has been obtained, as well as the careful empirical evaluation of each design choice for the system.

I have only two minor comments on this chapter:

- One is that the precise definition of queue length is never clearly articulated (or I may have missed it) until page 109.
- You might want to add a few sentences earlier in the text about using an array of transmitter receiver pairs and defining queue length by the binary level of congestion seen at each pair.

- Second, your discussion about localization and about how none of the previously proposed work in localization has been deployed seems to
suggest that your work is important because it has been deployed. However, as I understand it, you are not precisely localizing each node but rather simply ordering the transmitter receiver pairs (which I would argue is a simpler problem)? You might want to soften your claims and perhaps even not call what you're doing localization.

Chapter 5:

- first sentence: video processing is not a sensing modality :-)

- section 5.2.3: "to simplify this analysis": in what way does selecting frames with only one vehicle simplify the analysis? is it because your technique is limited only to such frames and is not robust to multiple vehicles per frame.

- in figure 5.12, the labels on the x-axis are missing. I presume they are the same as the labels on the y-axis but it would be good to add the missing labels.
- "stand-still traffic requires a large window...": I couldn't tell if
  this was a limitation of your approach, or merely that it would be
  too tedious to conduct an evaluation
standstill traffic. How *does*
your approach work with standstill traffic
  anyway?

- "...we use a window of size 30s": you claim
  that this will increase
the accuracy of your technique, but is that true? At what timescales
  do traffic densities change and is a 30s window in danger of
capturing density changes?

- page 155: in your speed calculations you
  seem to be implicitly
assuming that every frame of video is exactly
  1/30s apart, right? is
  this assumption correct in low-end cameras?