Research on the accuracy and reliability for distance based measurement and determination of tariff for KMP: Management Summary

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Building Capital Limited

RESEARCH ON THE ACCURACY AND RELIABILITY FOR DISTANCE BASED MEASUREMENT AND DETERMINATION OF TARIFF FOR KMP:
Management Summary

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Client: **The Ministry of Transport, Public Works and Water Management, Netherlands ("the Ministry")**
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CONTENTS

1 SUMMARY

Consideration of how the existing requirements in respect of distance accuracy might be interpreted within a real-life scheme deployment support the opinion that GNSS-based OBUs may already be able to meet the requirements. The research demonstrates that accurate measurement of distance travelled (with an error of less than 1%) is achievable with currently available mixes of GNSS and additional sensors. Solutions which rely solely on GNSS achieve distance errors of between 1.2 and 4.5%. Short urban journeys are more challenging but distance measurement errors of less than 1% are still achievable. Distance measurement accuracy is largely unaffected by open water and foliage for all technologies tested. While GNSS-only solutions do exhibit increased distance errors due to tunnels, interference from electromagnetic radiation and sources of multi-path effects (e.g. high reflective buildings), additional sensors are shown to reduce these errors to below 1%.

Positional accuracy of less than 5m was regularly achieved by GNSS-only and enhanced solutions. Driving under heavy foliage and near sources of multi-path effects increases positional errors more consistently and for more of the technologies under consideration than sources of EM radiation and open stretches of water appear to do.

In the vast majority of cases, entry and exit times to charge zones were within a small number of seconds of the actual time of crossing the boundary, with the majority of zones correctly identified within 60 seconds of the time the vehicle actually crossed the boundary.

The OBU supplier community has demonstrated an enthusiasm to participate in Dutch Road Pricing.

2 INTRODUCTION

The Dutch Government intends to introduce road pricing. The envisaged end goal is distance-based charging for all vehicles on all roads, with tariffs that depend on location, time and environmental characteristics of the vehicle.

The scope of this research project is to examine the achievable accuracy of distance measurement and the accuracy of determining the applicable tariff in various scenarios for differentiation by time and place. The boundary condition is that the technologies used should allow a robust low-cost solution. Specifically, this research was asked to address six research objectives:

1. What overall level of accuracy of the calculated distance travelled can be achieved with low-cost GNSS-based solutions available today, preferably from different suppliers? Certain specific problem areas relating to short journeys and start conditions are to be addressed.
2. To what extent does differentiation by location (i.e. charging different rates for driving on specific sections of road) affect the accuracy/reliability of the systems?
3. What is the effect of specific conditions (building density, electromagnetic radiation, foliage etc) on accuracy and what solutions are available to mitigate these?
4. What (combinations of) technologies are likely to fulfil the draft requirements of the KMP from an accuracy and reliability perspective, and what are the cost implications?
5. How should the overall requirements on system accuracy/reliability be formulated to ensure a high probability of accurate monthly charges for all participants?

6. Assuming an open market for on board equipment, the investigation should provide some input for a certification framework on the aspect of accuracy and reliability.

This final report presents the findings of the research on all six of the research objectives.

3 APPROACH

Eleven supplier OBUs, providing a range of innovations and solutions, were selected for on-road trials on the basis of an objective assessment of OBU supplier responses to a questionnaire. One further representative OBU was supplied by the research team (number 12 in the list below) and included in the research. A Septentrio Galileo receiver was also installed in one of the test vehicles (number 13 in the list below) to provide the European Space Agency (ESA) development team with driven data for their own research purposes – the data from this OBU was not included in the analysis for the Ministry research project.

1. Blaupunkt GmbH
2. Efkon AG
3. Fela Management AG
4. GMV Aerospace and Defence SA
5. mm-lab GmbH
6. Princip A.S.
7. Siemens AG
8. Stok Nederland B.V.
9. Strategic Mapping Inc.
10. Technolution B.V.
11. Traffilog Ltd
12. Building Capital Ltd
13. ESA

In the interests of commercial confidentiality and to focus the attention on the technologies involved (rather than the specific suppliers who provided these examples), all results in this report are anonymised.

The OBU supplier community exhibited a reassuringly high level of desire to participate in and a commitment to the success of the research project, especially given the challenging timescales (both to respond to the initial questionnaire and then to prepare for the on-road trials). A mix of prototype and more established technologies were offered, some of which were dedicated Road Pricing solutions, while others were adapted vehicle tracking solutions.

Three test vehicles (identical make and model) were each fitted with highly accurate location and distance measurement equipment (to generate the “truth” data based on the actual vehicle trajectories, rather than relying on data from pre-surveyed routes) and three or four OBUs under test.

A schedule of seven test routes was developed which are both representative of overall driving behaviour and contain features and conditions expected to challenge the technologies in terms of distance and location (and hence charging) accuracy with a view to developing an understanding of how innovations in OBU design and operation cope with these features and behaviours. The resulting routes, which ranged in length from 35km to 130km, included dense urban driving, tunnels, underground car-parks and tree-lined routes.

Charge zones - segments and areas - were also arbitrarily devised as a fair (i.e. solution-independent) test of the ability of the suppliers’ solutions to operate under such conditions.

The routes, tests and analysis were designed to create equally challenging situations for all envisaged technologies and thus not favour one particular technique over other approaches. The test vehicles were driven around the test routes in convoy, over a period of 4 weeks. Each route was repeated a number of times to ensure the results are statistically significant, with each test vehicle covering approximately 5,000km.

4 RESULTS AND CONCLUSIONS

Five of the OBU suppliers were able to supply distance measurement results using 'raw' GNSS data only. All twelve supplied one or more sets of data where different combinations of technologies were used to enhance the GNSS data. These combinations ("technology mixes") included additional sensors and alternative approaches to processing and fusing the data.

Nine of the technology mixes were able to achieve less than 1% absolute distance error on average over all of the distance driven during the four week period, with **four of these achieving less than 1% distance error on average for each individual route driven**. Hence, a distance charging error of less than 1% was **comfortably achievable by a significant number of Participants' prototype** systems over the particularly **challenging routes** devised by the Research Authority. **Operation of production systems over normal routes is expected to exhibit further performance improvement. None of these systems employed map-matching**.

Of the nine technology mixes which achieved less than 1% absolute distance error on average over all of the distance driven, five of these also achieved less than 1% absolute distance error on average for all derived short journeys of 1 and 2 km. These five all used an odometer input.

The best performance in terms of accurate distance measurement was achieved by OBUs with a connection to the vehicle odometer, either by means of the CAN bus or a Vehicle Speed Sensor (VSS) signal. No OBU achieved the required accuracy on all routes without an odometer input, although some came close. The Den Haag Centrum route proved to be consistently difficult for OBUs without an odometer input. This route contains many challenging features including underground car-parks, tunnels and congested driving conditions.

A connection to the vehicle clearly enables overall charging distance error, and charging distance error in TTFF (Time To First Fix) scenarios, to be minimised to the extent that **the risk of operation outside the required accuracy parameter is negligible**. This wheel-speed / distance input also provides for **significant resilience to fraud** in respect of charging distance accuracy.

However, **despite these benefits of wheel-speed / distance inputs, there is a significantly increased installation complexity and cost**. The full implications of this may be a subject for further research.

The research supports the view that a €100 production OBU is feasible. This was corroborated by both the trials participants and examination of the components comprising a typical OBU.

Whilst this research trial was not specifically devised to evaluate GNSS-only systems (i.e. without wheel-speed / distance sensor connection to the vehicle, but possibly including on-board sensors like gyroscopes or accelerometers), **a number of GNSS-only systems exhibited very promising performance**. The best performing GNSS-only solution achieved 1.2% overall distance error, and this was significantly affected by its performance on the Den Haag Centrum route (4.1% distance error) which contains many challenging features including underground car-parks, tunnels and congested driving conditions. Taking account of the prototype nature of the systems being evaluated, elimination of "outlier" data points from the results brought another GNSS-only system within the 1% error target. All GNSS-only technologies achieved distance errors of less than 5% (in the range of 1.2 – 4.5%).

The performance of prototype and demonstrator systems may be reasonably expected to be below or on par with more robust production counterparts, and so the Ministry might consider the opportunity for this natural process of refinement to yield a GNSS-only based compliant OBU within the deployment timescales required, given implementation of working TTFF enhancement, but clearly without any necessity for dependence upon Galileo.

Indeed, consideration of how the existing requirements in respect of distance accuracy might be interpreted within a real-life scheme deployment support the opinion that **GNSS-based OBUs may already be able to meet the requirements**.

Most of the technologies exhibited higher distance accuracy on rural and motorway routes compared with high-density urban routes. The Den Haag Centrum route proved the most challenging in terms of distance accuracy, although, the research shows that technology exists to achieve the required accuracy even under these difficult circumstances.

In the vast majority of cases, **entry and exit times were recorded which were within a small number of seconds of the actual time of crossing the zone boundary**. It can therefore be concluded that correct temporal identification of zone boundary crossing is not an issue. The analysis suggests that a **60 second time buffer appears to include the majority of correctly identified zones** – increasing this time buffer further does not significantly increase the number of correctly identified zones.

The charge segment location which appears to cause the greatest challenge for distance measurement accuracy has its boundaries at either end of the Maas Tunnel in Rotterdam. Over half of the technology mixes achieved large distance errors, only those OBUs which incorporated additional sensors achieved less than 1% measured distance error. The measured distance errors for the other segments and the two charge areas were comparable with those described above.

Two sites were included in the routes as a test of the impact of Electromagnetic (EM) radiation on OBU performance. The first is on the N210 between the Gerbrandy tower in IJsselstein (used for directional radio services and for FM- and TV-broadcasting) and the Lopik medium wave transmitter. The second site is the KNMI mast at Cabauw. **Neither EM site demonstrated any negative impact on the number of satellites in view** when compared with the adjacent 'open sky' control sites. **Positional errors in the vicinity of the site on the N210 increased for half of the GNSS-only OBUs by a factor in the range of 0.3 to 0.5, with the other half seemingly unaffected**.

As expected, **fewer satellites were in view (one less satellite on average) in areas with overhanging dense foliage** when compared with the adjacent 'open sky control' sites. The Aerdenhout route had significant foliage cover over a part of the route. **This foliage had no discernable effect on the measurement of driven distance**. This is consistent with expectations for modern high-sensitivity GNSS chipsets. A measurement of numbers of satellites in view only drops by 5 - 10% for all but one technology mix - that one case being an OBU with a previous generation GNSS chipset of lower sensitivity where the number of satellites seen drops by nearly 50%. **Positional errors under foliage doubled for**

approximately 50% of the technology mixes however driven distance errors were largely unaffected.

As expected, **fewer satellites were in view in areas expected to exhibit multi-path effects** when compared with the adjacent 'open sky control' sites. In the case of both sites chosen for their expected multi-path effects, there is a small drop in the number of satellites in view of up to about 25% for technologies based on current GNSS chipsets, with those using a previous generation GNSS chipset which is expected to be less tolerant of multi-path reflections showing a drop of up to 35%. Of the two sites, **the ING building in Rotterdam had the most apparent impact on positional error** for the vast majority of technology mixes (with increases of a factor of between 0.3 to 14 times over the 'open sky' error). **Six of the technologies achieved less than 1% distance error for both multi-path sites**. These used different mixes of technologies with none relying on GNSS only.

Although positional error in the vicinity of water does appear to double in the cases of 50% of the technology mixes, the resulting errors are all less than 10m. The **driven distance errors are less than 1% in almost every case** (including solutions relying solely on GNSS data for distance determination) which provides firm evidence that the presence of open water does not have a detrimental effect on distance accuracy.

Accurate measurement of driven distance through a tunnel was feasible for about half of the OBUs, both those with or without an odometer input. This was however not the case when a segment start/end point was within the tunnel, as for the Maas Tunnel segment.

Nearly half of all technology mixes (both GNSS only and enhanced with additional sensors and processes) exhibited average positional errors of less than 5m in open sky conditions at various locations.

The ABvM requirement for accuracy is expressed in terms of billing accuracy, with 99% of bills having a maximum billing error of 1%, and only 0.1% of bills over charging. In effect, this means that the vast majority (>99%) of bills need to be between 99% and 100% of the correct charge. To measure this, a number of Case Studies were created where the driven distance accuracy data in various on-road scenarios was used to construct monthly bills for three different user profiles (broadly, a typical low, medium and high mileage driver). These demonstrate high levels of billing accuracy for high mileage drivers, with OBUs both with and without an odometer connection regularly able to achieve bills in the range 99-100% of the correct charge. The Case Studies also suggest that it will be most difficult to achieve the required billing accuracy for low mileage drivers. A number of scheme designs and bill calculation techniques are suggested which can be deployed to overcome these specific sources of inaccuracy.

The Ministry is considering a number of possible system architectures for the KMP project. The research considers the certification implications for 3 candidate Operational models. The various bodies involved in the certification process are identified and roles described.

Given that the billing accuracy desired is crucially dependant on the accurate measure of driven distance, the potential sources of error are identified. Depending on the Operational model chosen, some or all of these sources of error will need to be targeted during the certification process.

The main functional blocks for the charging and billing function are identified and the options for interfaces where charging accuracy can be tested are determined. These are the potential test points where compliance can be verified by the certification system. The choice of certification test points will depend on the selected Operational model.

The implications of different OBU client and Back Office server architectures on the certification process are discussed.
Certification is also strongly advisable for the quality processes in operation at the equipment manufacturing premises and for the operational processes within the Back Offices. It is essential that sufficiently robust processes are in place to assure accuracy and consistency of billing, and hence the whole system being defensible in arbitration.

The requirements for a certified test house are also discussed, as well as ensuring a statistical basis for testing.

Finally the testing process itself is discussed. After defining the concept of a generalised journey and how it may be used to measure charge accuracy and reliability, test methodologies for both an OBU and a Back Office are proposed. The OBU test is based on the concept of test routes which will be driven by an instrumented test vehicle, allowing a certified test house to accredit an OBU design as providing sufficient accuracy to be used in the road charging system. The development activities leading to the approval of one or more Test House by a Certification Body are discussed and the scale of the effort in performing a compliance test on an OBU is estimated. An automated journey synthesiser approach is proposed for checking the accuracy of Back Office billing functions.

The Research Authority recommends that the Ministry should **consider a development phase in the build up to a national scheme by implementing a scalable demonstrator project**. This would allow all the functional, operational and performance characteristics or all entities which comprise an end-to-end distance based road charging scheme to be animated and for specifications and certification processes to be developed. This would provide the basis of specifications for a future procurement phase.