GMAR
GNSS Metering Association
for Road User Charging

PROGRESS REPORT:

GPAF
GMAR Performance Analysis Framework

Bern Grush, Skymeter

acknowledging
Joaquín Cosmen-Schortmann, GMV and Carl Hamilton, Centre for Transport Studies, Royal Institute of Technology

- Problem
- Current progress
- Proposed solution
- Examples
GMAR’s GPAF

- GMAR
  - GNSS Metering Association for Road user charging
- GPAF
  - GMAR Performance Assessment Framework
- Authors
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  - Sam Storm von Leuoven, NLR (Nationaal Lucht- en Ruimtevaartlaboratorium)
About GMAR

The GNSS Metering Association for Road User Charging (GMAR) was established to create the GMAR Performance Analysis Framework (GPAF) to quantifiably address performance issues related to road-use metering. Experts from Britain, Canada, Belgium, France, Germany, Netherlands, Spain, and Sweden have drafted a body of criteria, characterizations, tests and analyses specific to Charging Reliability. The measurement criteria are related only to charging data as opposed to distance or other accuracy metrics. Hence, GPAF analysis is independent of on-board technology, algorithms, processing or interconnection to vehicular systems.

GMAR

GMAR Standard Performance Definitions For GNSS Road Use Metering


Click here to download GMAR Standard Performance Definitions

GPAF Current Draft

This first draft of the GPAF standard addresses Charging Reliability. A second draft scheduled for early Fall 2009 will incorporate feedback from advisers. A third draft to follow that will address Security including a component to protect road users (privacy) and another to protect the operator (tamper protection).

Click here to Download the GPAF Draft

GPAF Status and Overview

Provides a brief overview of GMAR's purpose and metrics.

Click here to download GPAF Overview
Problem
What is status of GNSS tolling?

- Interoperable ETC systems based on GNSS
  - the most flexible and cost efficient technology
  - EU and others are working on implementations
  - Dutch ABvM is an ambitious example

- International effort to standardize and legislate
  - E.g.: EETS Directive and ISO 17575
What’s missing?

- Are all those efforts sufficient for ensuring a successful implementation?
  - Acquisition, Certification, Interoperability, Cost Control
  - SLA, KPI, QoS, etc
- Are the interests of all stakeholders well protected with the current level of standardization?
- No to both questions
The GPAF Initiative

- GNSS-based ETC systems require Performance Metrics and a Test Framework to guarantee:
  - The interest of all stakeholders are protected: e.g., acceptable level of charging errors derived from GNSS positioning errors
  - A procurement framework: What minimum performance must systems provide?
  - Validation and Certification of the system: How can this performance be demonstrated?
  - Interoperability among systems: How can we ensure **reliable charging** performance regardless of system specifics?
Performance Metrics
(Summary Requirement)

- Uniform framework for performance assessment of GNSS based road user charging systems
  - Quantifiable
  - Testable
- Make comparison between the systems possible, relevant, and economically achievable
  - Acquisition
  - SLA negotiation/enforcement
  - Performance monitoring
  - Compare across examiners and cities
Proposed Solution
How metrics can be established

- **Performance Metrics** are defined to:
  - Cover all road charging schemes
  - Protect user and toll charger
  - Be technology independent
  - Focus on charging performance, not position accuracy
  - Prepare for system validation & certification

- **Define:**
  - Relative "Accepted Charging Error Interval":
  - **Charging Availability**
    - Error interval to protect toll charger
  - **Charging Integrity**:
    - Overcharge limit very near 0 error to protect user

*Accuracy, Continuity, Integrity, Availability re GNSS signal is inadequate*
Discrete Schemes

Event Matrix

<table>
<thead>
<tr>
<th>Charging event takes place</th>
<th>System detects charging event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes: Correct Recognition</td>
</tr>
<tr>
<td></td>
<td>No: Missed Recognition (Undercharging)</td>
</tr>
<tr>
<td>No</td>
<td>Yes: False Recognition (Overcharging)</td>
</tr>
<tr>
<td></td>
<td>No: Correct Rejection</td>
</tr>
</tbody>
</table>
Continuous: Ideal vs actual

A
Correct Charge
Wide, unbiased error

B
narrow, unbiased error

C
Error biased, charge too low

D
Error biased, charge too high
Continuous Schemes

Charging Integrity:
Accumulated Probability in this interval

Accepted Charging Error Interval

0 error

Charging Availability:
Accumulated Probability in this interval
## Continuous vs Discrete schema

<table>
<thead>
<tr>
<th>Continuous</th>
<th>Discrete</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Charging Availability</strong></td>
<td>The probability that for a predefined <em>trip</em>, the <em>Relative Charging Error</em> is within the <em>Accepted Charging Error Interval</em>. This is the probability that the <em>toll charger</em> is getting sufficiently paid for road usage, AND that there is an acceptably low level of over charging.</td>
</tr>
<tr>
<td><strong>Charging Integrity</strong></td>
<td>The probability that for a predefined <em>trip</em>, the <em>Relative Charging Error</em> is below the upper bound of the <em>Accepted Charging Error Interval</em>. This is the probability that the <em>user</em> is paying no more than required.</td>
</tr>
</tbody>
</table>
Define four test tracks for which you know the correct charge

- **Easy**: Urban residential streets, little or no foliage.
- **Medium**: Buildings 10 stories+, heavy foliage
- **Hard**: Deep in the central core highest buildings
- **Long**: Starts or ends in difficult signal circumstances; mimics a typical suburban-to-city automotive commute
Examination: Nuisance variables

- Time of Day x 2
- Weather x 2
- Vehicle Height x 2
- Metalized windshield coating x 2

- Not included:
  - Electrical interference
# Examination matrix

<table>
<thead>
<tr>
<th>Nuisance Treatments</th>
<th>Path Error Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EASY (5km)</td>
</tr>
<tr>
<td></td>
<td>MEDIUM (5km)</td>
</tr>
<tr>
<td></td>
<td>HARD (5km)</td>
</tr>
<tr>
<td></td>
<td>LONG (15km)</td>
</tr>
<tr>
<td>0000</td>
<td>% charge error</td>
</tr>
<tr>
<td>0001</td>
<td>% charge error</td>
</tr>
<tr>
<td>0010</td>
<td>% charge error</td>
</tr>
<tr>
<td>0011</td>
<td>% charge error</td>
</tr>
<tr>
<td>0100</td>
<td>% charge error</td>
</tr>
<tr>
<td>0101</td>
<td>% charge error</td>
</tr>
<tr>
<td>0110</td>
<td>% charge error</td>
</tr>
<tr>
<td>0111</td>
<td>% charge error</td>
</tr>
<tr>
<td>1000</td>
<td>% charge error</td>
</tr>
<tr>
<td>1001</td>
<td>% charge error</td>
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<tr>
<td>1010</td>
<td>% charge error</td>
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<td>1011</td>
<td>% charge error</td>
</tr>
<tr>
<td>1100</td>
<td>% charge error</td>
</tr>
<tr>
<td>1101</td>
<td>% charge error</td>
</tr>
<tr>
<td>1110</td>
<td>% charge error</td>
</tr>
<tr>
<td>1111</td>
<td>% charge error</td>
</tr>
</tbody>
</table>

- Ephemeris
- Precipitation
- Antenna height
- Windshield coatings
64 treatments per matrix run (480 km)

Can drop variables (page 30)

Can run matrix N times to achieve required statistical reliability
Mixed type schemes
(continuous with discrete aspects)

- Factors affecting the reliability measurement
  - Zone boundary locations
  - Tariff time spans
  - Charging level differences

- These require additional specifications for the test runs
  - Parallel charge zones / roads
  - Controlled testing charge levels
Current Progress
Charging Performance proposal for new work item (NWI) accepted by ISO/CEN

- Proposed Title
  - Electronic fee collection - Charging performance metrics and examination framework

- Submitted by Spain

- Accepted by
  - Austria, Czech Rep, Finland, France, Netherlands, Portugal, Slovenia, Sweden, Switzerland, UK

- 3 comments
  - Consider DSRC
  - Consider invoicing and collection
  - Use existing GMAR work as starting basis.

- Adopted as new work item
Highlights of transfer to ISO/CEN process

- Charging Reliability
  - Charging Integrity
  - Charging Availability
  - Examination Framework
  - Reliability Analysis
Next steps

- Work plan for ISO/CEN TC278/WG1/SG5
  - By end-Feb 2010
- Focus on Charging Performance
- Expect 1 year until DTS
- Later:
  - Reevaluate whether GMAR will return to Privacy and Tamper
  - ISO/CEN is also working on these issues, possibly making GMAR’s work redundant.
One Meter. One Bill.


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A Few Examples
Charging Reliability
Without the Clutter

- AVI and GNSS both work on limited access highways
- But what about inside our cities?
- Should we solve the signal problem or put up with the clutter?
Non-Line-of-Sight Multipath

Non-line-of-sight multipath can easily and severely offset a position estimate.

Line-of-sight multipath (the type typically addressed) is handled by correlators in the receiver.

A direct signal from this satellite never reaches the receiver.

Only these indirect signals reach the receiver, adding bias to the position estimate.
Mild Urban Canyon effect

Financial-grade GPS must be reliable, repeatable
Switching back and forth is due to alternating tall-then-short buildings
Financial-grade GPS vs Navigation GPS

Reliability

- Financial-grade GPS (blue)
- Navigation Grade GPS (red)
- Same receiver/antenna ensures data control during experiment
- Different positioning engines
3 overlapping runs, Financial-grade GPS

- 3 runs, identical route
- Positioning variability highly controlled even in the deepest canyon
- Same-trip = Same charge
Financial-grade GPS can deliver superior positional and statistical accuracy in dense "Urban Canyon".

Normal GPS - Red
- Max error (3 sigma): 100m
- Typical error (rms): 27m
- Mean error (50%): 2m

Financial Grade - Blue
- Max error (3 sigma): 18m
- Typical error (rms): 6m
- Mean error (50%): 1.5m

Seoul
Charging Reliability: Evidentiary Weight

FGPS integrity readings (blue), calculated every second, provide evidence of position to underpin a financial transaction.

GPS (red) has severe urban-canyon errors, especially if stationary; FGPS stays true.
Charging Reliability: Evidentiary Weight

Urban Canyon in perspective
Blue is Financial-grade GPS

Navigation Signals Bias:
Navigation-Grade GPS made a consistent error for over a kilometer, putting the vehicle on the wrong road and wrong price.

Navigation Signals Drift:
Car stopped here for light; but we solved this for parking applications.
Charging Reliability needs repeatability
Cisco comparison trials

40 of the same trip over a week...
Charging Reliability (route 3)
Cisco comparison trials

The Skymeter Price was derived using Skymeter’s Financial-grade GPS meter. Financial units are in Korean Won. exyz was one of the competitors for these runs. We do not have permission to disclose their name.
## Charging Reliability

[continuous scheme - all four Cisco routes]

<table>
<thead>
<tr>
<th>Route</th>
<th>Average Price</th>
<th>Min Price</th>
<th>Max Price</th>
<th>Consistency (STD %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$775</td>
<td>$756</td>
<td>$782</td>
<td>0.7%</td>
</tr>
<tr>
<td>2</td>
<td>$1,060</td>
<td>$1,037</td>
<td>$1,077</td>
<td>1.6%</td>
</tr>
<tr>
<td>3</td>
<td>$1,100</td>
<td>$1,097</td>
<td>$1,127</td>
<td>1.1%</td>
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<tr>
<td>4</td>
<td>$4,600</td>
<td>$4,592</td>
<td>$4,626</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

### Price Outside Cordons [KRW]

<table>
<thead>
<tr>
<th></th>
<th>TRUE</th>
<th>SMC</th>
<th>exyz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave</td>
<td>$769</td>
<td>-0.8%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Min</td>
<td>$756</td>
<td>-2.5%</td>
<td>-5.2%</td>
</tr>
<tr>
<td>Max</td>
<td>$782</td>
<td>0.9%</td>
<td>11.0%</td>
</tr>
</tbody>
</table>

### Price Inside Cordons [KRW]

<table>
<thead>
<tr>
<th></th>
<th>TRUE</th>
<th>SMC</th>
<th>exyz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave</td>
<td>$4,780</td>
<td>-0.9%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Min</td>
<td>$4,735</td>
<td>-5.2%</td>
<td>-2.5%</td>
</tr>
<tr>
<td>Max</td>
<td>$860</td>
<td>11.0%</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

### Total Price [KRW]

<table>
<thead>
<tr>
<th></th>
<th>TRUE</th>
<th>SMC</th>
<th>exyz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave</td>
<td>$5,649</td>
<td>-0.9%</td>
<td>3.6%</td>
</tr>
<tr>
<td>Min</td>
<td>$5,470</td>
<td>-2.3%</td>
<td>-2.8%</td>
</tr>
<tr>
<td>Max</td>
<td>$5,680</td>
<td>11.0%</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

### Error

- **Route 1**: Error 0.7% vs 4.25%
- **Route 2**: Error 1.4% vs 14.6%

---

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Visible everywhere

- Always on is the first requisite of Charging Reliability
- The addition of charge objects such as virtual gantries, road segments or a charging grid moves TDP errors well under 1%.

Data Courtesy of Caltrans
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