Validation of GNSS-based high-precision velocity estimation for outdoor sports

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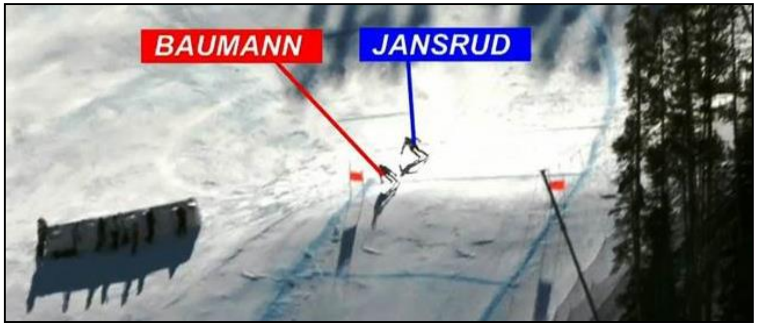
Introduction

- Outdoor **sports** and **surveying** are faced to **similar challenges**
  - precise timing
  - positioning
  - velocity estimation
- In sports were the **path length** is **equal** for each athlete **velocity** is usually determined using **photocells** systems
- Trajectory and instantaneous velocity are necessary for **performance analysis** and **research**

http://www.leica-geosystem.com

http://www.all-athletics.com/



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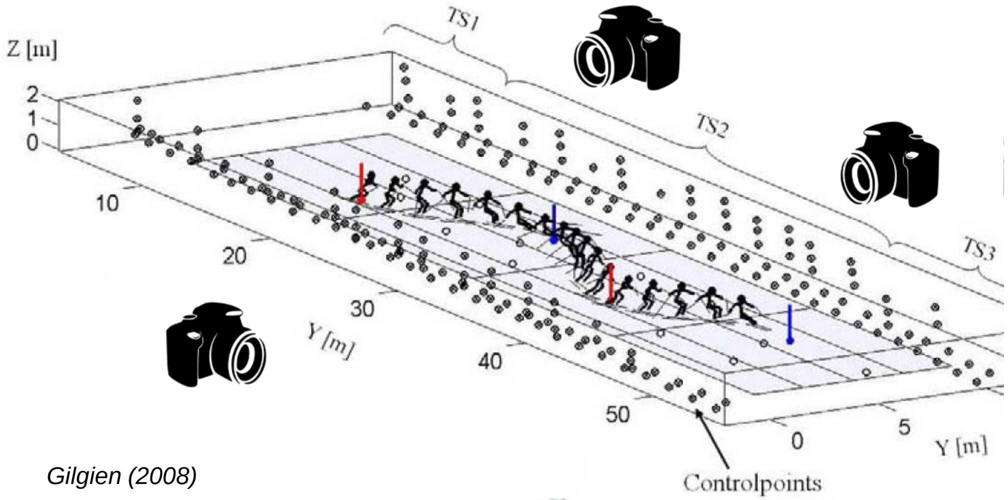
Introduction

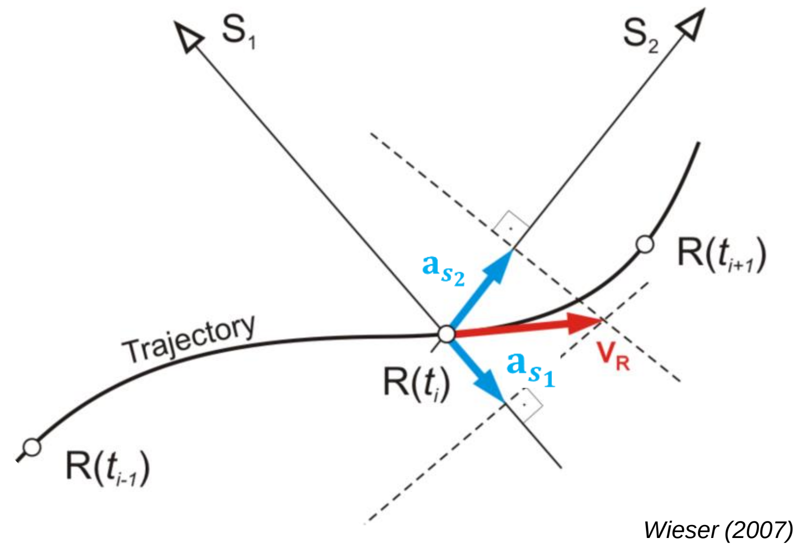
- **Photogrammetric systems** are applied to reconstruct the body dynamic.
- Sports over large spatial volumes apply **GNSS**
- Goal: **assessment of the accuracy of velocity GNSS measurement**



Gilgien (2008)

GNSS velocity computation

- The Doppler shift f_d of the GNSS signals is proportional to the relative velocity between satellite $\mathbf{v}_s$ and receiver $\mathbf{v}_r$
- Highly precise Doppler observables are obtained as time-derivative of the carrier phase Φ
- The observations are processed kinematically in an Extended Kalman Filter (EKF) using a MATLAB-based GNSS post-processing software.



Wieser (2007)

$$f_d(t_i) := \frac{\Phi(t_{i+1}) - \Phi(t_{i-1})}{2\Delta t} \approx f_0 \cdot \frac{v(t_i)}{c}$$

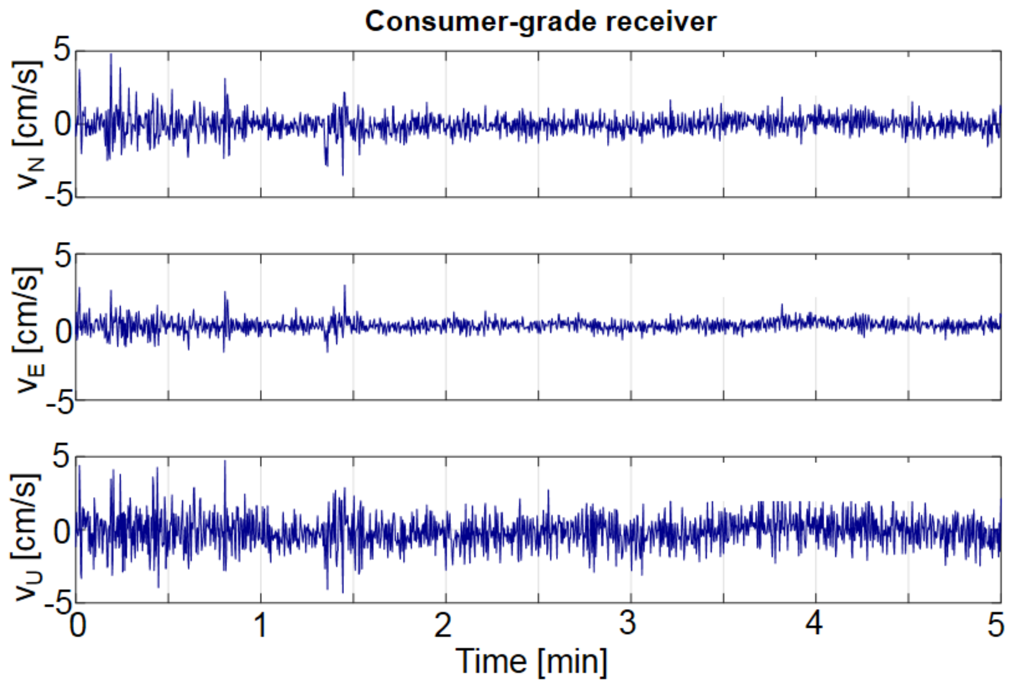
$$f_d^{obs} - f_d^{sat} = \frac{1}{\lambda}\mathbf{a}^T \boldsymbol{v}_r - f_0 \dot{b}_r + \varepsilon$$

GNSS velocity computation

- Many effects will affect a static receiver like a kinematic one
- The level of random observation noise is expected to be higher
- Static test as an indication of the accuracy

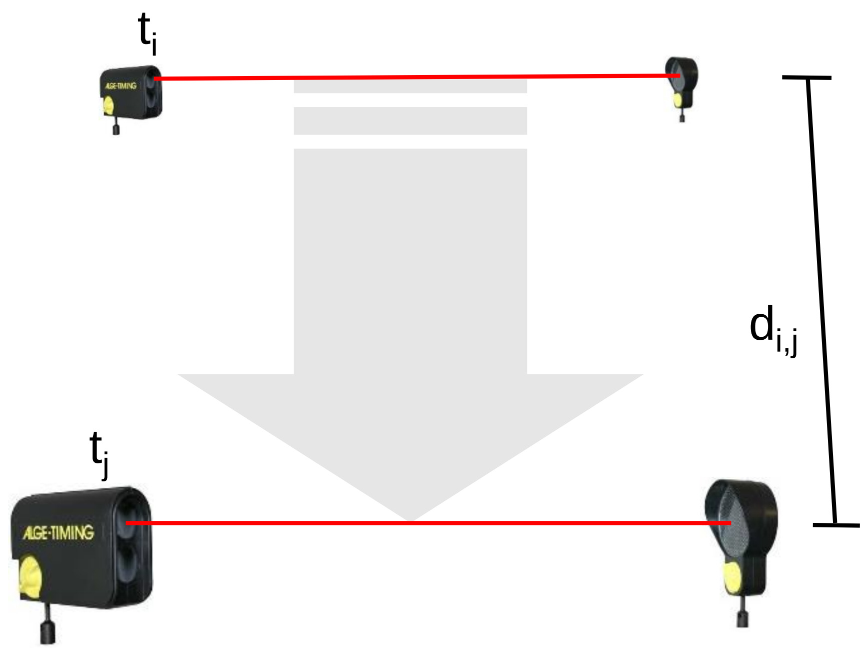
	σ_v [mm/s]
Geodetic receiver	3.5
Consumer-grade receiver	8.5

$$\sigma_{\bar{v},G} = \frac{1}{\sqrt{n}}\sigma_v$$



Reference system

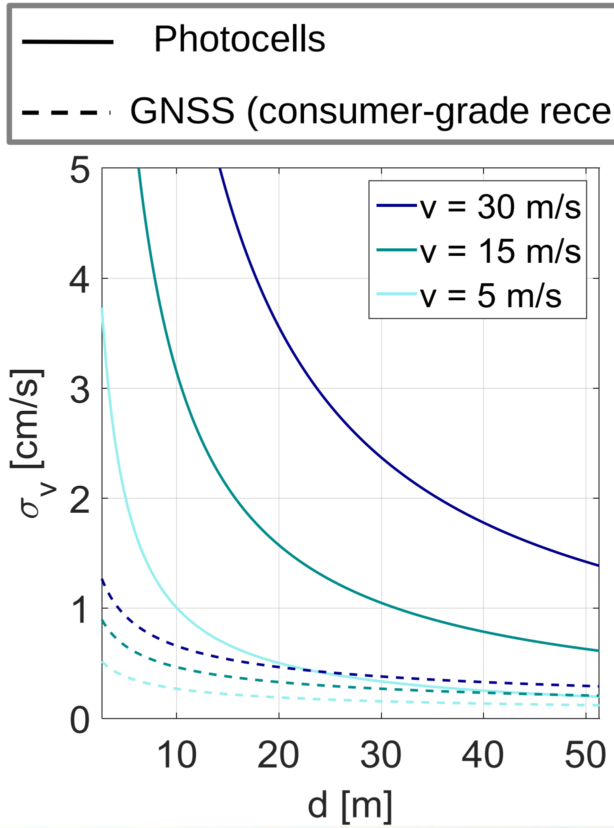
- Photocells as reference measurements for the experimental investigation



$$\bar{v}^{p}_{i,j} = \frac{d_{i,j}}{(t_j - t_i)}$$

$$\sigma_{\bar{v}^{p}_{i,j}} = \sqrt{\left(\frac{\partial \bar{v}^{p}_{i,j}}{\partial t_i}\right)^2 \cdot \sigma^2_{t_i} + \left(\frac{\partial \bar{v}^{p}_{i,j}}{\partial t_j}\right)^2 \cdot \sigma^2_{t_j} + \left(\frac{\partial \bar{v}^{p}_{i,j}}{\partial d_{i,j}}\right)^2 \cdot \sigma^2_{d_{i,j}}} = \frac{\bar{v}^{p}_{i,j}}{d_{i,j}} \sqrt{2 \cdot \left(\bar{v}^{p}_{i,j} \sigma_t\right)^2 + \sigma^2_{d_{i,j}}}$$

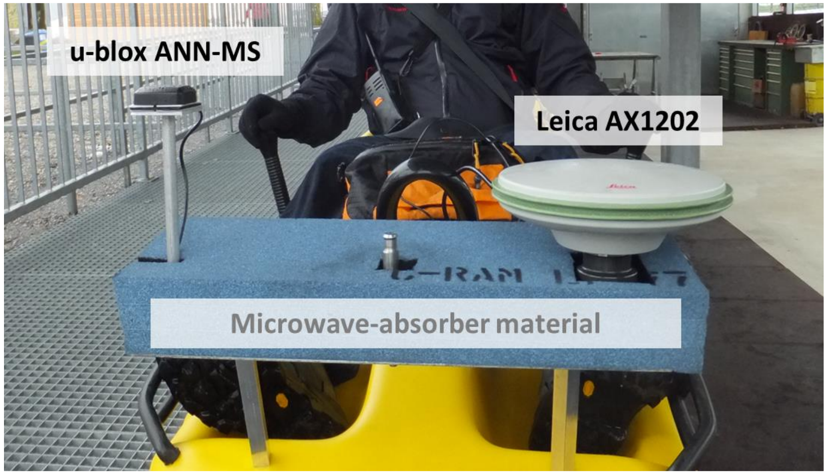
Comparison between the velocities estimated using GNSS and photocells



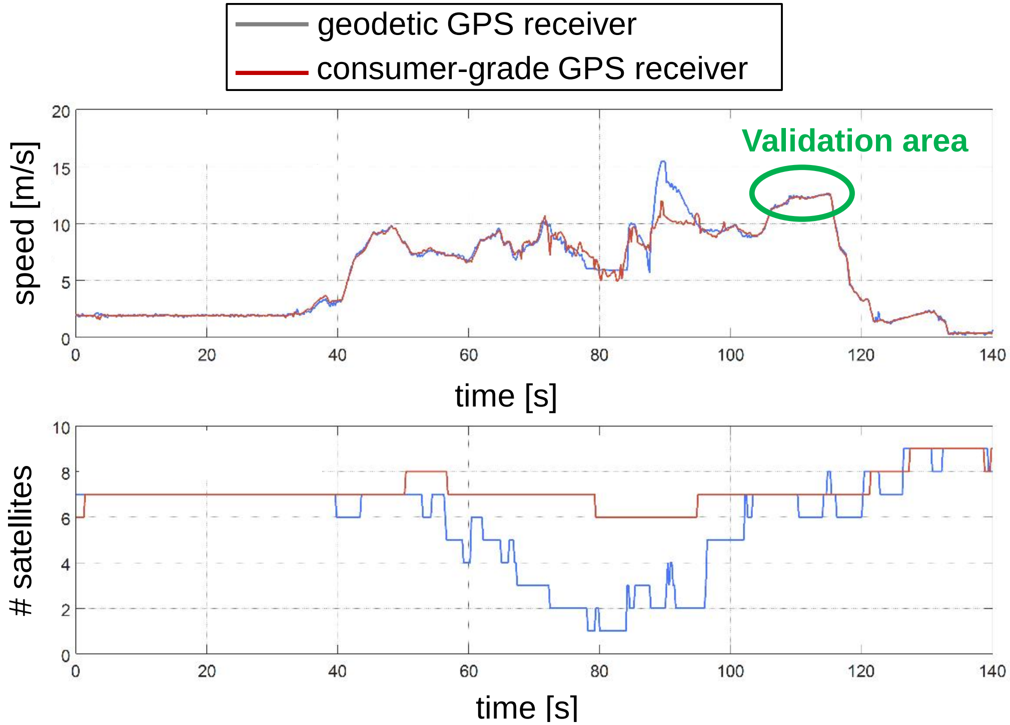
- Additional requirements:
  - The travelled distance with an accuracy of a few cm
  - Stable relation between the GNSS antenna and the part triggering the photocells
  - Repeatable experiment
  - Representative dynamic for outdoor sports (e.g. alpine skiing)

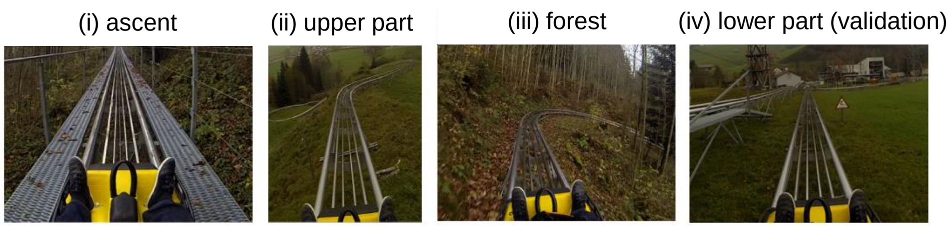
Kinematic test measurements

- 51.2 m, equipped with 9 photocells
- Distances between the photocells intervals from 3 m to 12 m
- 6 runs with average velocities varying from 45 km/h to 55 km/h
- 2 GNSS equipment
  - A geodetic GNSS receiver (Leica 1200) and antenna (Leica AS10)
  - A consumer-grade GNSS receiver (ublox EVK6T) and antenna (ANN-MS)



Results and discussion



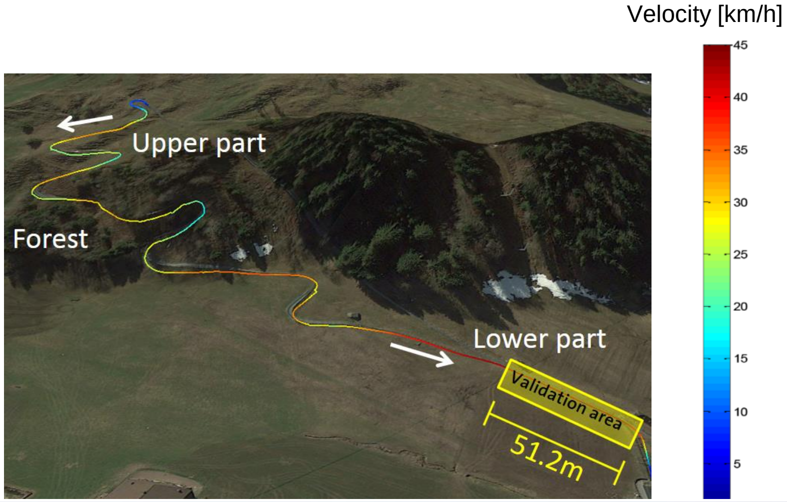


Geodetic receiver:

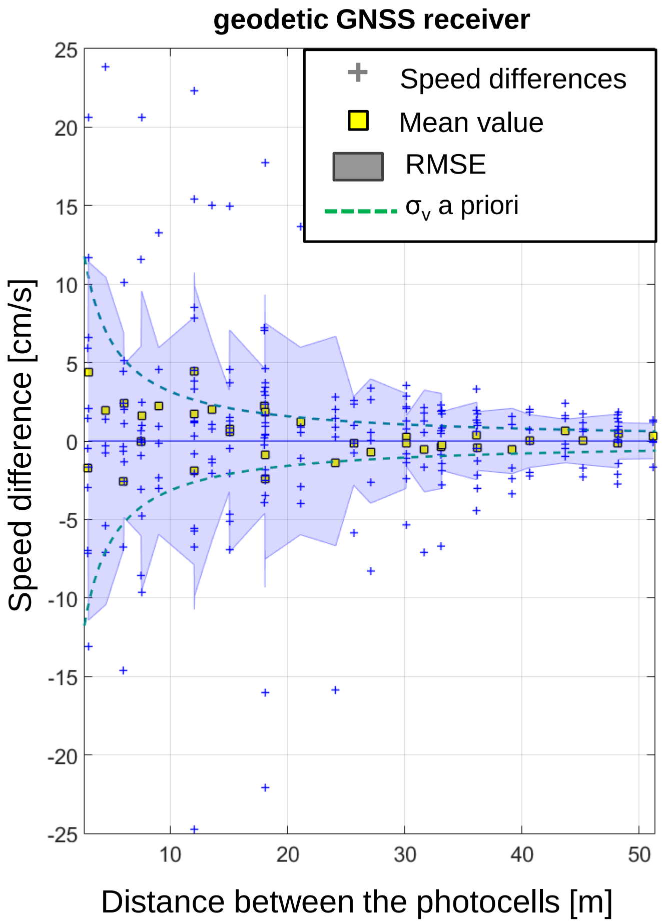
- optimized for quality

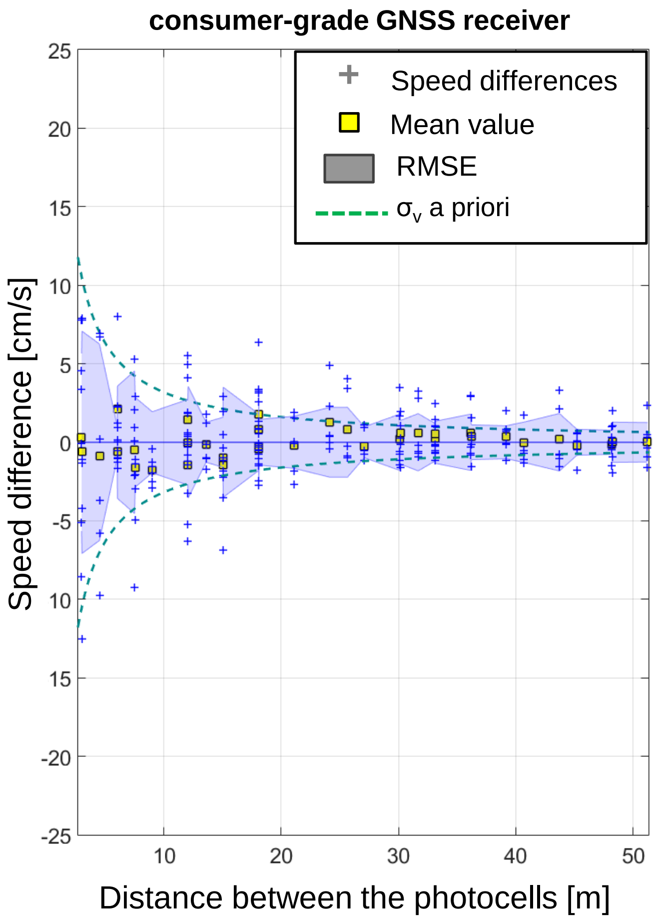
Consumer-grade receiver:

- fast signal acquisition
- tracking of weak signals



Results and discussion

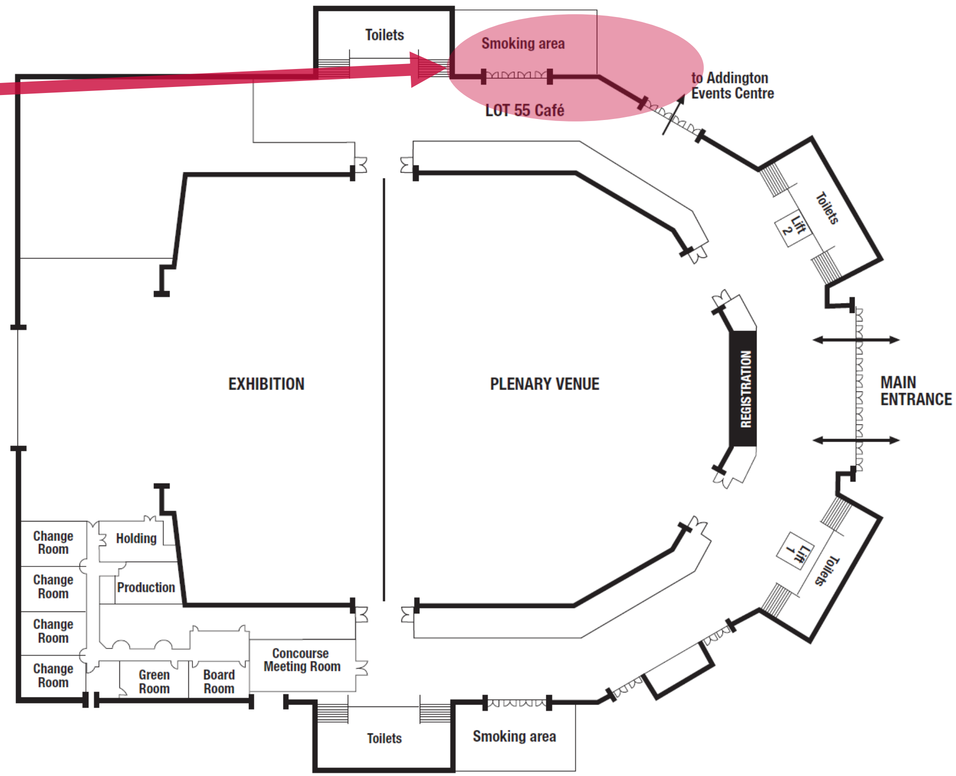




Conclusion

- Development of a method to **predict accuracies** for **velocity measurement** using GNSS and photocells
- An **empirical test** measurement on a **coaster track** compared both velocity measurement systems
- A precision better than **10 mm/s** can be obtained for the velocity estimated using a consumer-grade GNSS equipment

Swiss Reception



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