Can LiDAR Point Clouds effectively contribute to Safer Apron Operations?

- Results of an experimental controller-in-the-loop study -

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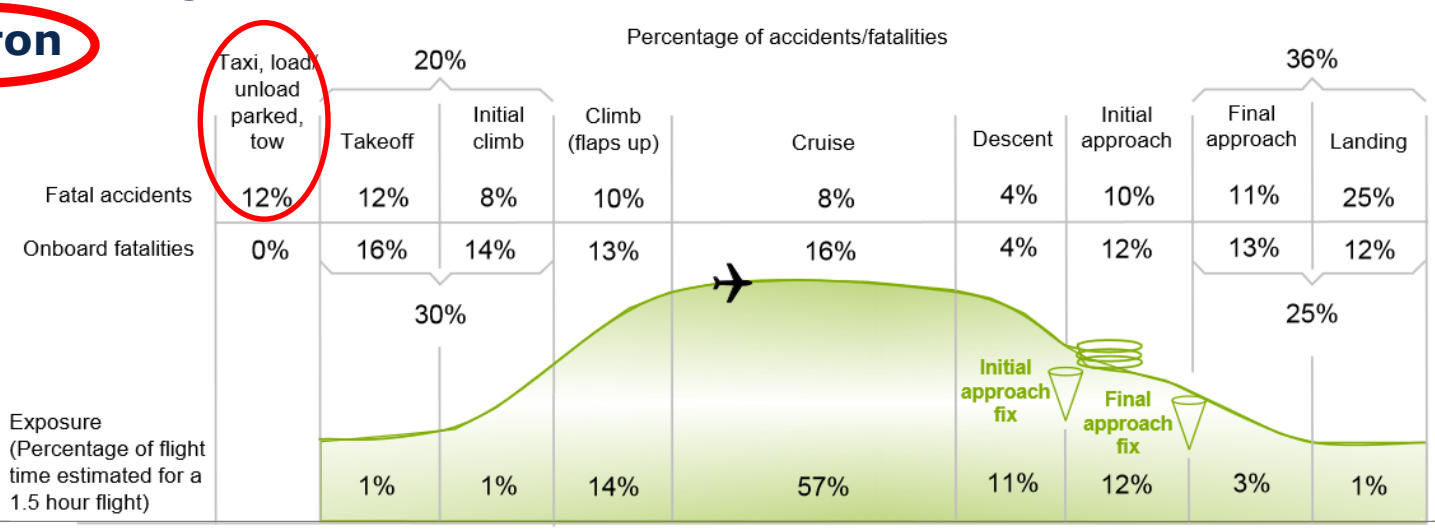
Agenda

- Introduction to LiDAR sensing for Apron Surveillance
- Background to the experimental CITL Study
- Experimental Design
- Experimental Setup
- Experimental Results
- Conclusion & Outlook

The Need for Risk Mitigation

- future aviation and ATM concepts call for improved safety targets (e.g. SESAR, ICAO GANP)
- the contribution of **airport surface operations** to risks is substantial (injuries to human health and damage to material)
- areas affected by surface operations:
  - manoeuvring area
  - **apron**



Source: Boeing Statsum

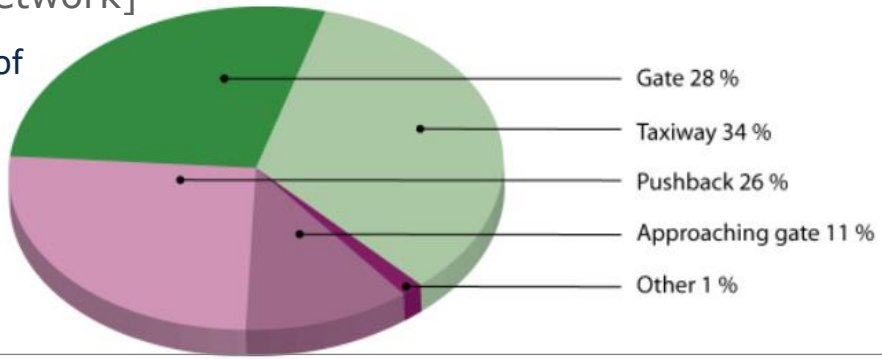
The Apron – Is there a Safety Problem?

- common problem: incomplete/not publicly accessible reporting of safety relevant occurrences on the apron
- available statistics indicate the **apron to account for a significant share of the total risk** in aviation:
  - probability of apron personnel at US airports to be fatally/severely injured: 0.47×10E-6 per aircraft departure [NTSB]
  - 5 of 41 recorded ground occurrences at Australian airports FOD-related [ATSB]
  - US fatal accident rate during pushback : 2.12×10E-8 [NTSB, AIDS, ATADS]
  - ≈ $6.8 million total costs of material damage resulting from ground handling accidents [Global Aviation Safety Network]

Sources: airdisaster.com

aviationpics.de

Distribution of Australian Ground occurrences by location (except from the RWY)

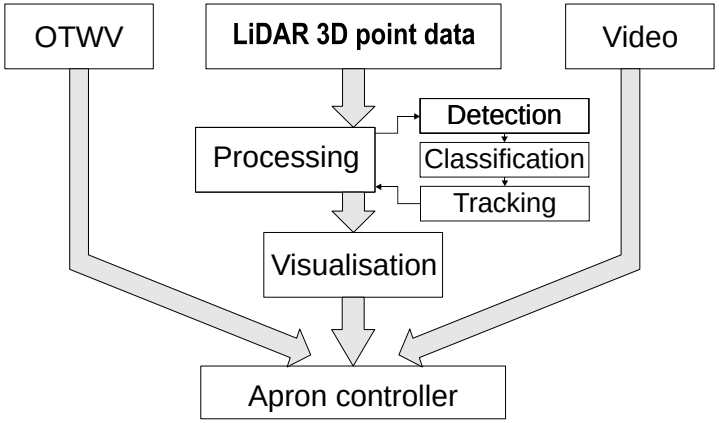


Source: ATSB, Transport Safety Report AR-2009-042, 2010

Risk Mitigation by LiDAR-based Surveillance

Overarching Risk Assessment

- identify and mitigate the risk of incidents and accidents on the airport apron
  - by improving the **Situational Awareness** of the responsible controller
  - through the provision of processed **LiDAR 3D point data.**
- Eurocontrol SAM used as methodological framework



Basic Functions	Relevant Target Objects	State of Movement
Detection	All objects that are not part of the static apron scenery	stationary & in motion
Classification	Aircraft (AC), ground vehicles (GV), pedestrians (PED), turnaround equipment (EQ), FOD	stationary & in motion
Instance Recognition	AC: e.g. Airbus 319-100, Boeing 737-700; GV: e.g. follow me, fuel truck	stationary & in motion
Tracking	All objects from line “Classification”, all object types from line “Instance Recognition”	in motion

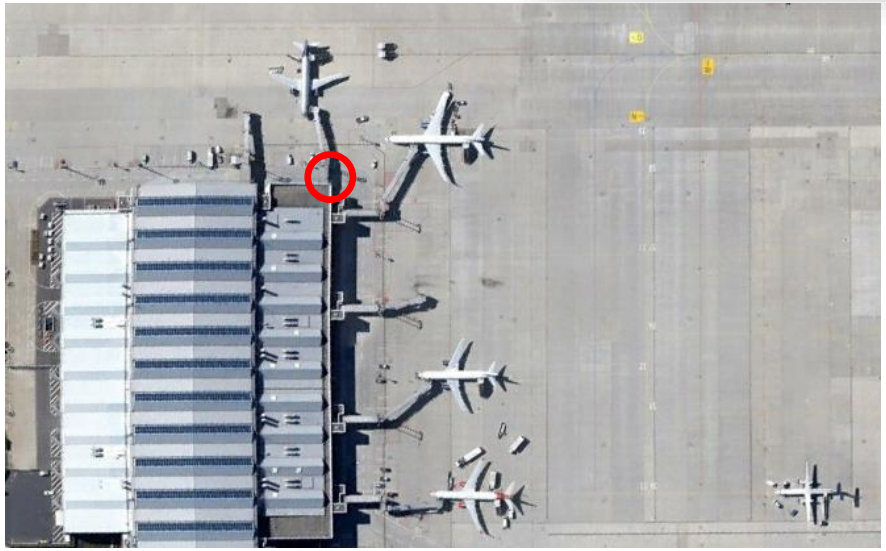
Basic requirements for a LiDAR system (sensor & data processing techniques) for apron surveillance

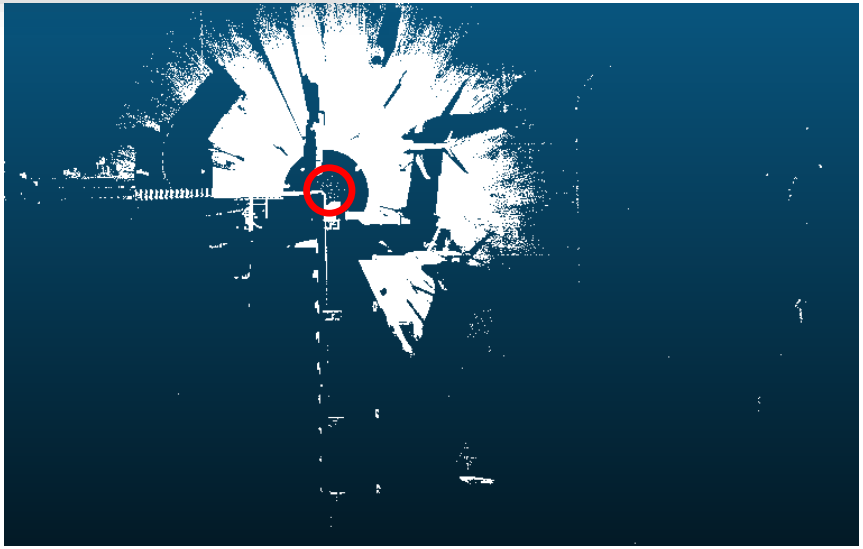
LiDAR-based concept for apron surveillance, see [“LiDAR Performance Requirements and Optimized Sensor Positioning for Point Cloud-based Risk Mitigation at Airport Aprons”, ICRAT 2014]

A particular challenge: Processing LiDAR 3D Point Data

LiDAR Neptec OPAL 360 at Dresden airport

Source: Google Earth, 2015

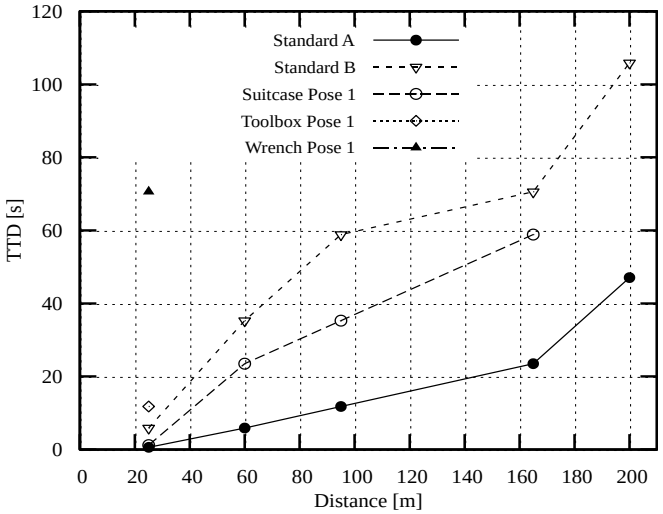




Processing (I) - Object Detection Technique

- ✓ the developed detection technique is fully functional and real-time capable
- ✓ detection performance quantified for several test objects and environmental conditions within several field trials, see [„Performance Evaluation of LiDAR Point Clouds towards Automated FOD Detection on Airport Apron“, ATACCS 2015]

Temporary GUI displaying real-time detection results



Time to detection (TTD) over distance for selected test objects

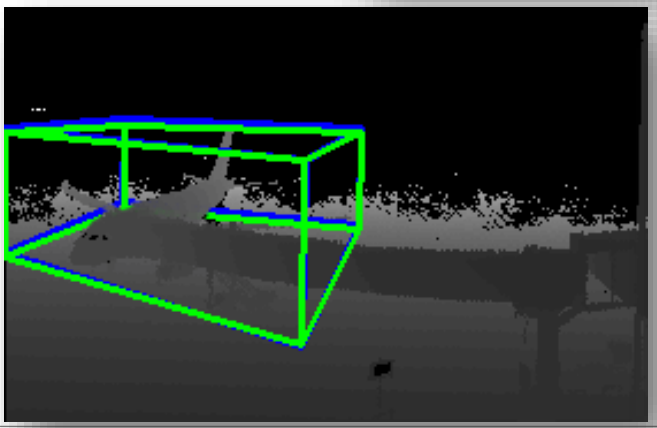
Processing (II) - Object Classification Technique

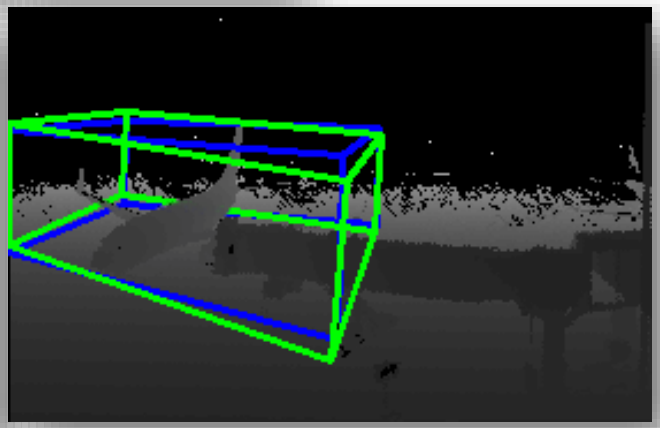
- ✓ the developed classification technique has successfully undergone a proof of concept study, see [“Introducing LiDAR Point Cloud-based Object Classification towards Safer Apron Operations”, ESAVS 2016]
- ○ but is still of restricted functionality (missing real-time capability, limited number of aircraft models etc.)

Left: **A319-100**

Right: **B737-700**

Green Box: **Estimated position**
Blue Box: **True positon**



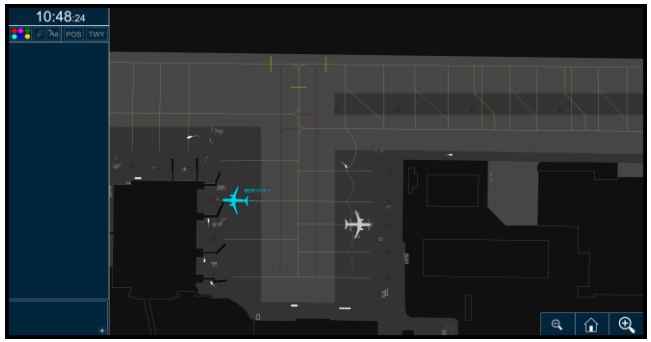


Measurement quality
(static aircraft)

Aircraft type	Angular Error	Translational Error
A319-100	1.159°	0.868m
B737-700	3.701°	0.534m

Methodological Background to this CITL Study

- Recently performed Risk Assessment on apron safety
  - ✓ hazard & cause analyses conducted
  - ✓ risk mitigation concept based on LiDAR sensing developed, among others:
    - LiDAR 3D point data processing (in progress!)
    - data visualization concept for apron controller working position (CWP)



LiDAR GUI for the apron CWP

- **Open Issue: Concept evaluation**
  - central research question:
    “If and to what extent a LiDAR support at the apron CWP will reduce risks for apron operations”?
  - method: experimental controller-in-the-loop (CITL) study to evaluate selected metrics representing the achieved safety level

Experimental Design (I)

- **control condition:** Common Apron CWP → Configuration 1
- **experimental conditions:** LiDAR Apron CWP with
  - Performance Level “Real Time” → Configuration 2
  - Performance Level “Case Study” → Configuration 3
- **test persons:** 18 subjects, two groups

	Control Condition	Experimental Condition
group 1	Configuration 1	Configuration 2
group 2	Configuration 1	Configuration 3

Groups of subjects

Performance Level	Time Delay Detection	Time Delay Classification	Time Delay Tracking
Real Time	All objects: 0.5s	All objects: 0.5s	All objects: 0.5s
Case Study	AC: 2s GV/EQ: 10s PED: 25s FOD: 50s	AC: 2s GV/EQ: 10s PED: 25s FOD: 50s	No tracking

Definition of LiDAR performance levels

AC = Aircraft GV = Ground Vehicle EQ = Equipment
PED = Pedestrian FOD = Foreign Object Debries

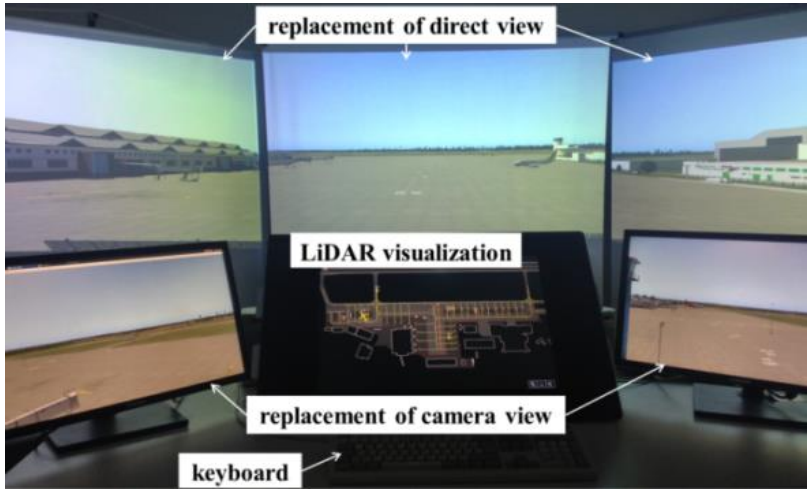
Experimental Design (II)

- **subjects’ tasks within the apron boundaries**
  - issuing clearances for aircraft and ground vehicles
  - recognition and reporting of emerging or already present hazardous situations
- **…for a total of 21 scenarios**
  - 4 standard scenarios
  - **17 hazard scenarios**:
    - ultimately result in hazardous situations
    - contain cause and hazard indicators **(visual cues)**

Hazard	Cause indicators	Hazard Indicators
Aircraft (AC) position misperceived	• Two or more taxiways in close proximity to each other • Short-term changes in the standard routing • Direct view to AC (partly) hidden by other objects	• AC overruns holding point without clearance • AC taxis on wrong taxiway

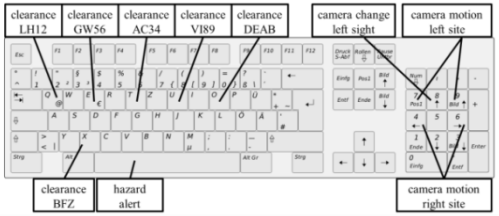
- **…under different environmental conditions** (CAVOK, CAT IIIa etc.)
- **dependent variables:**
  - primary variables: **Hazard Recognition Rate, Reaction times**
  - secondary variables: Situational awareness, workload, camera usage intensity

Experimental Setup

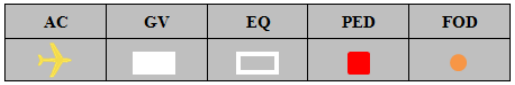


Experimental CWP at TU Dresden

LiDAR GUI at the experimental CWP



Keyboard Layout of experimental CWP



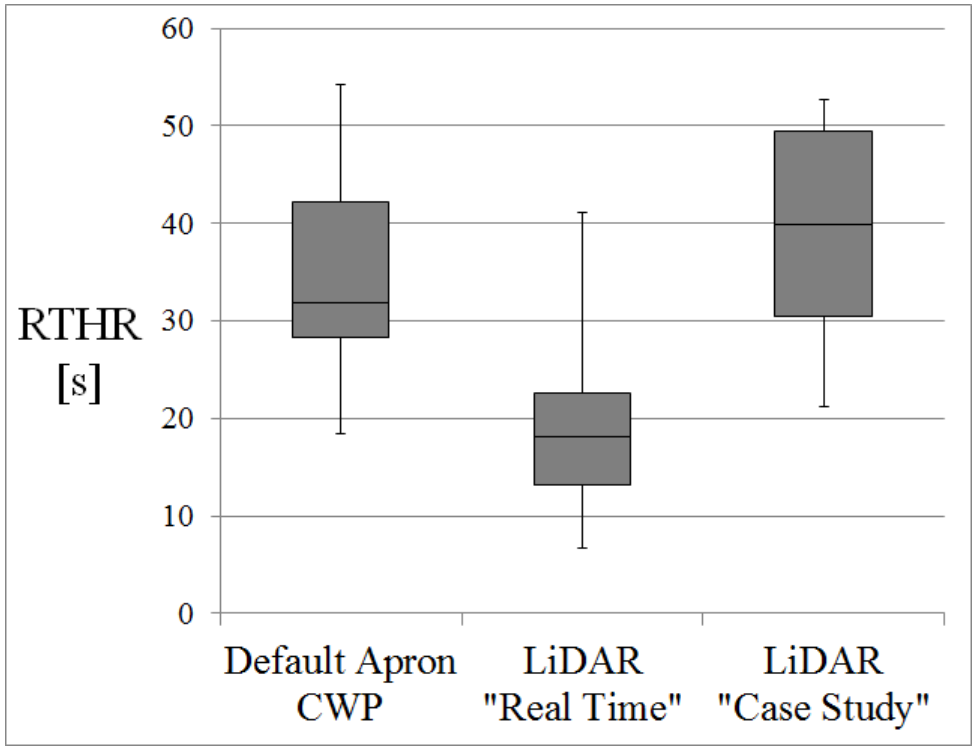
LiDAR GUI icons representing all potential target objects

Results for the primary dependent variables

	Default Apron CWP (config. 1)	**LiDAR Apron CWP with “Real Time” (config. 2)**	**LiDAR Apron CWP with “Case Study” (config. 3)**
Number of recognized hazards (max. 17)	$\mu = 13{,}9$ $\sigma = 1{,}65$	$\mu = 16{,}8$ $\sigma = 0{,}42$	$\mu = 14{,}9$ $\sigma = 1{,}85$
Hazard Recognition Rate (HRR) [%]	81%	99%	88%

- significantly increased **HRR**s for both LiDAR configurations
- analysis by hazard groups: Highest HRR in FOD recognition for both LiDAR configurations (+33% “Real Time”, +24% “Case Study”)

Results for the primary dependent variables

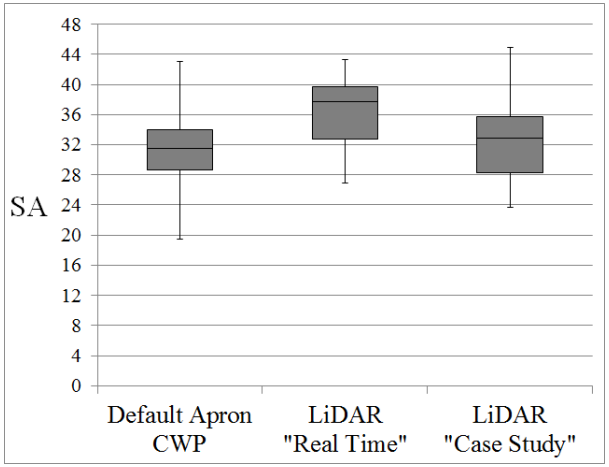


Reaction times for hazard recognition (RTHR)

- lowest RTHR for LiDAR configuration 2 “Real Time”(μ=19s)
- increased RTHR for LiDAR configuration 3 “Case Study” (μ=38s) compared to “Default Apron CWP” (μ=34s)

Results for the secondary dependent variables

Situational awareness
(SART scale:-14 is lowest, +46 is highest)



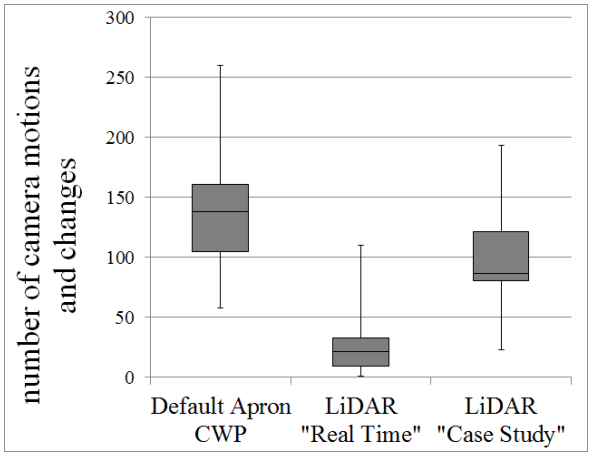
Workload
(ISA scale: 1 is highest, 5 is lowest)

	Default Apron CWP (config. 1)	LiDAR Apron CWP with “Real Time” (config. 2)	LiDAR Apron CWP with “Case Study” (config. 3)
WL	μ = 3,6 σ = 0,5	μ = 4,1 σ = 0,4	μ = 3,7 σ = 0,6

- LiDAR config. 2 “Real Time” with positive contributions on the subjects’ Situational awareness and Workload
- LiDAR config. 3 “Case Study” with marginal improvements compared to config. 1 “Default Apron CWP”

- LiDAR config. 2 “Real Time” with 75% less camera changes and motions compared to config. 1 “Default Apron CWP”
- LiDAR config. 3 “Case Study” with a smaller reduction (-24%) compared to config. 1 “Default Apron CWP”

Camera usage intensity



Summary & Outlook

Achievements

- ✓ the tested LiDAR system (both configurations) resulted in a enhanced apron controller`s capability to recognize hazards
- ✓ situational awareness and workload also tend to improve
- ✓ the benefits are highest for the LiDAR performance level “Real Time”

Next steps

- field trial of our LiDAR system at Dresden airport
- further development of the data processing techniques
- extension of the current LiDAR GUI by automated surveillance functions
- planning and undertaking of a 2nd experimental study with
  - new configurations based on a higher level of automation
  - adjustments for the experimental design and setup (“lessons learned” from the previous study)

Questions – opinions – suggestions?

Thank you.

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