

Evaluating the Effectiveness of Visualization Techniques for Schematic Diagrams in Maintenance Tasks

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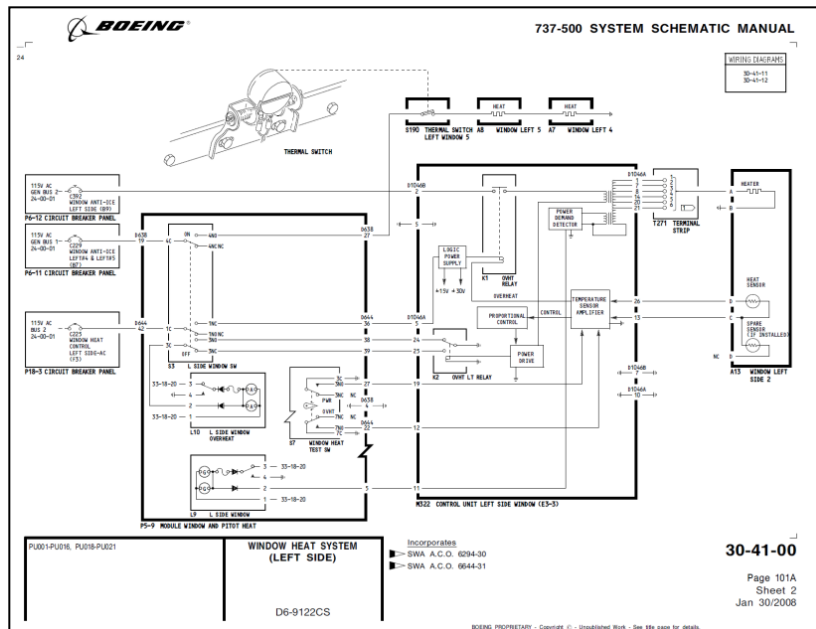
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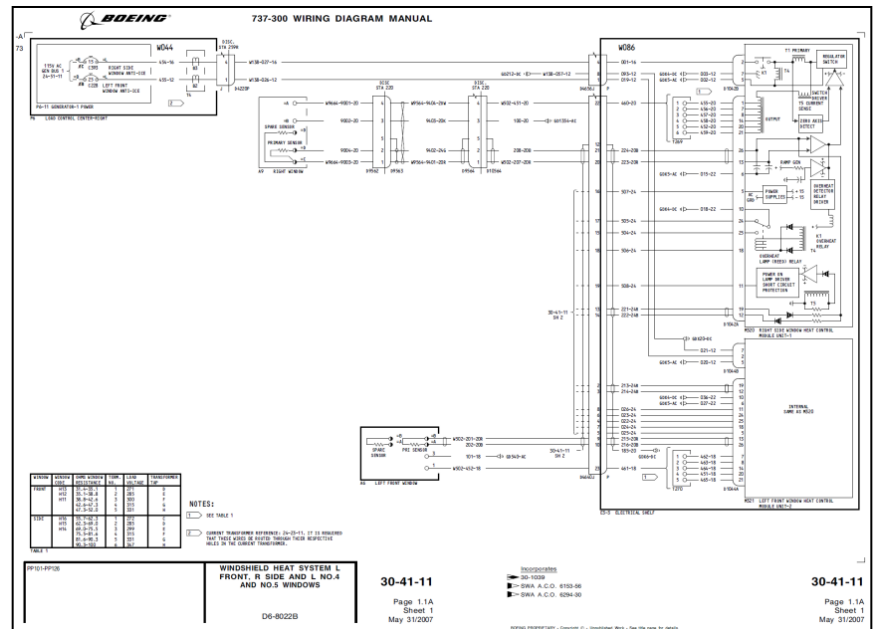
³Air Force Research Laboratory

Introduction (1/3)

- Technical documents in maintenance tasks
 - Maintenance Manuals
 - Schematic diagrams
 - Wiring diagrams



<Schematic diagram>



<Wiring diagram>

Introduction (2/3)

- Finding diagrams and components

- Understanding component operations,
- Hypothesizing causes of the fault

Maintenance manual

Schematic diagram

Schematic diagram

Wiring diagram

- Testing
- Marking component status

- Highlighting components and connections
- Tracing circuit

<Analyzing schematic and wiring diagrams in maintenance tasks>

Introduction (3/3)

- Finding diagrams
- Finding components

- Understanding component operations,
- Getting clues for the fault, and
- Hypothesizing

- Technicians suffer from**
- 1. preserving their analysis**
 - 2. doing repetitive work across diagrams**

Contextual information of the components can easily be lost.

- Highlighting components and connections
- Tracing circuit

- Testing
- Marking component status

<Analyzing schematic and wiring diagrams in maintenance tasks>

Schematic Diagram Visualization System

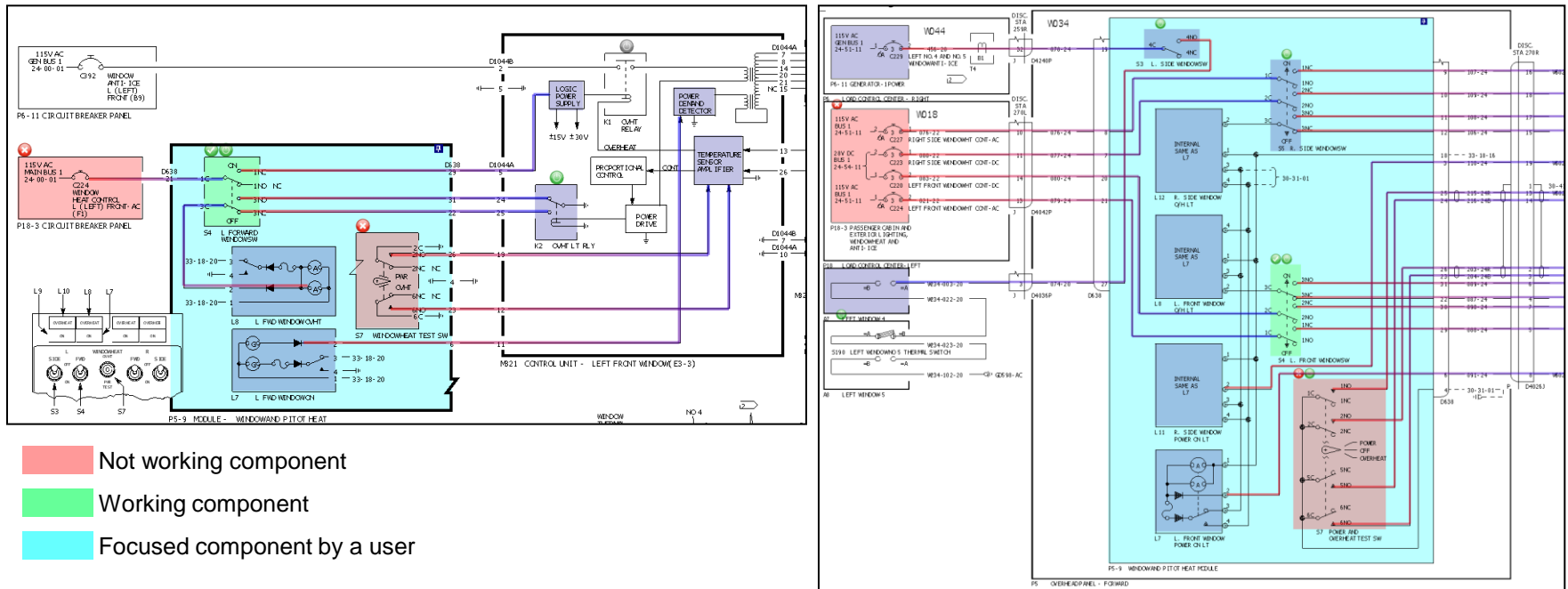
- An interactive **context-preserving** visualization system for technical diagrams
- A **practical system** for technicians' training and maintenance tasks using interactive visualization techniques
 - Preserving users' interactions across diagrams
 - Providing seamless visualization
- Expected users
 - People who already have technical diagram analysis skills

System Design: Tabletop Exercise

- Tabletop exercise
 - Performed by one exercise leader and three expert technicians simulating a real world problem
 - To analyze system requirements and key tasks, and to develop scenarios for evaluation study
- Scenario
 - Finding two fault errors (Boeing 737 aircraft)
 - A short in the wiring leading from the power supply to the window heater
 - A bent pin in the P5-9 component
- Procedure
 - Technicians diagnosed the issues using printed manuals
 - The exercise leader provided information as they proceed through their steps
 - All the actions taken by all technicians were recorded

SDViz: Schematic Diagram Visualization System (1/2)

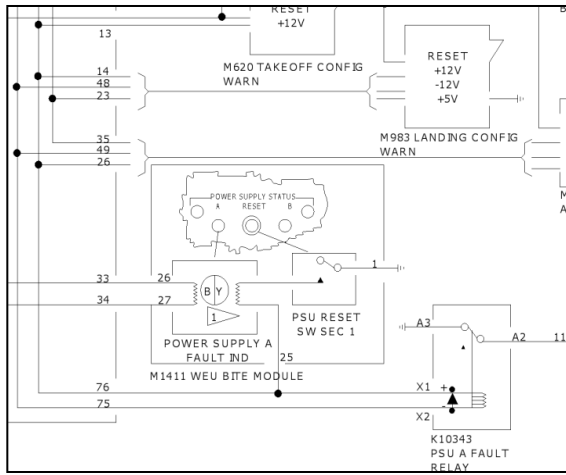
- Highlighting components (component status and users' interaction) and links
- Highlighting preservation among related diagrams



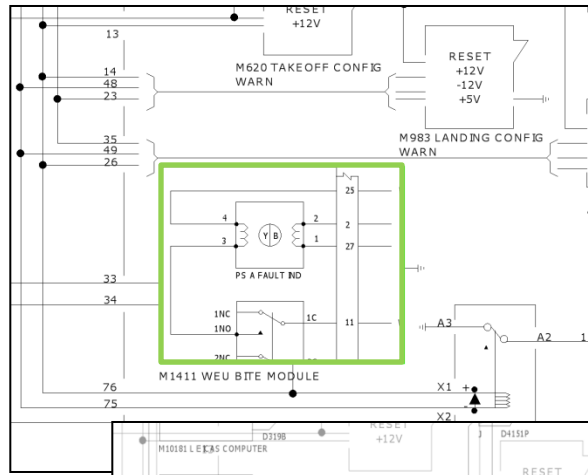
<Highlighting preservation between related diagrams>

SDViz: Schematic Diagram Visualization System (2/2)

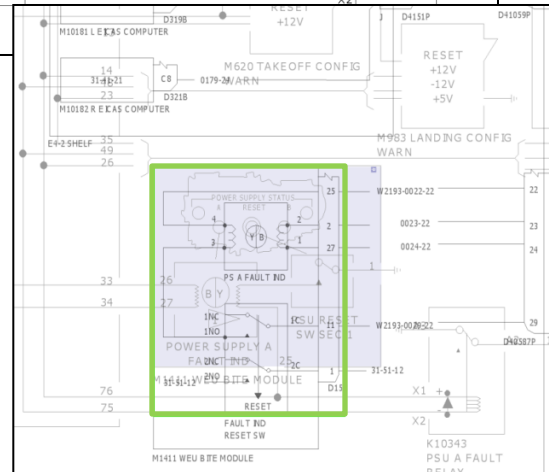
- Inter-diagram navigation preserving spatial information



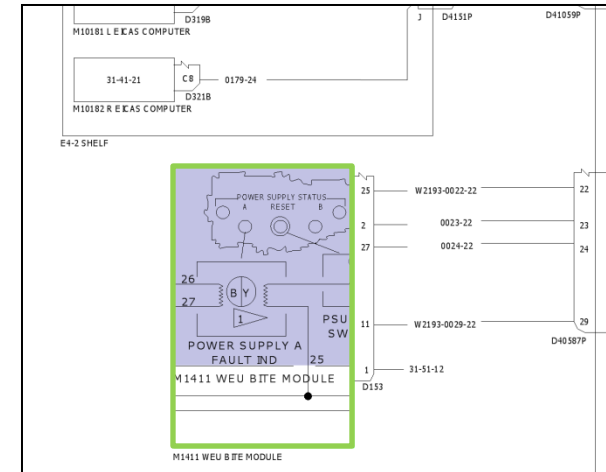
1. Schematic diagram



2. Finding the same component in the related diagram using a relational lens



3. Blending from SD to WD



4. Wiring diagram

Goal

- Evaluating the effectiveness of context preserving visualization techniques for maintenance tasks
- Effectiveness
 - Ability to enhance user's understanding of technical diagrams
 - Ability to reduce task completion time and to improve accuracy
 - by maintaining contextual information between related schematic and wiring diagrams

Related Work

- Cognitive design principles
 - [Heiser et al., 2003] Cognitive design principles for visualizations: Revealing and instantiating.
 - [Agrawala et al., 2003] Designing effective step-by-step assembly instructions.
 - [Heiser et al., 2004] Identification and validation of cognitive design principles for automated generation of assembly instructions.
- Cognitive analysis for maintenance
 - [Barnard et al., 2006] Mental models of users of aircraft maintenance documentation.
 - [Barnard and Reiss, 2006] User-centered innovation of electronic documentation for maintenance.
- Evaluation of effectiveness (or usability)
 - [Ferwerda et al., 2002], [Scholtz, 2006], [North, 2006], [Plaisant et al., 2008], [Greenberg and Buxton, 2008]

Evaluation Study Design (1/2)

- Evaluation study
 - Quantitative evaluation study
 - Qualitative field evaluation study

- Data
 - Training
 - Schematic and wiring diagrams for the Warning Electronics Unit Power Supply (Boeing 757 aircraft)
 - Actual experiments
 - Schematic and wiring diagrams for the Window Heat System (Boeing 737 aircraft)

Evaluation Study Design: Procedure (2/2)

1. Pre-questionnaire
 - To collect information of subjects' background knowledge and experience
2. Training session
 - To be familiarized with the system functionality
 - Training instruction and videos, users' manual
3. Pre-test
 - To decide subjects' ability to use the system functionality and re-training
4. Actual experiments
 - Perform repeated trials and tasks randomized using a magic square
 - Record time and mouse clicks for analysis
5. Post-questionnaire
 - To collect qualitative feedback

Quantitative Evaluation Study (1/2)

- Subjects
 - 49 subjects who had taken undergraduate level circuit courses
 - Graduate students in Electrical and Computer Engineering at Purdue University
 - Experimental group vs. control group

Quantitative Evaluation Study (2/2)

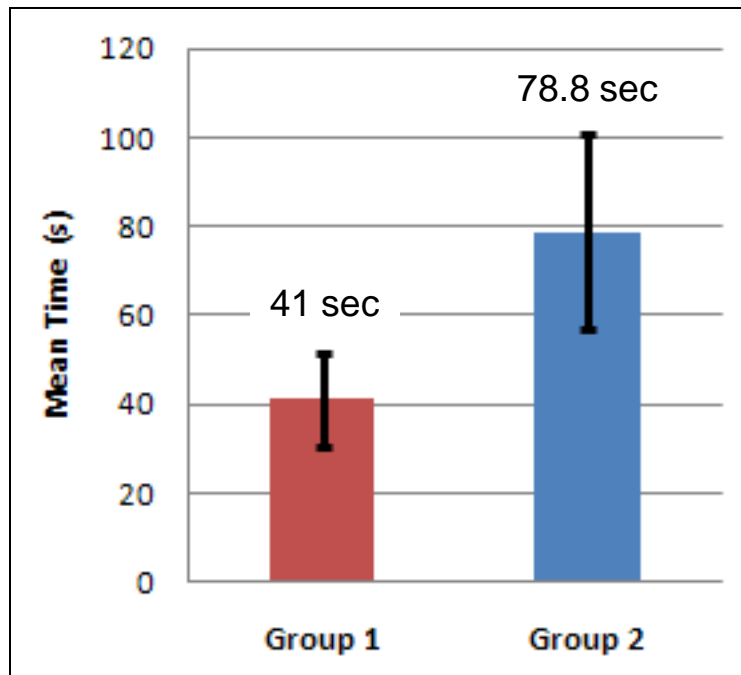
- Task
 - Task 1
 - To evaluate the effectiveness of highlighting components and connections in schematic diagrams
 - Task 2
 - To evaluate the effectiveness of maintaining contextual information through highlighting and spatial information
 - Task 3
 - To evaluate the effectiveness of a lens method providing contextual information

Quantitative Evaluation Study:

Task 1 (1/4)

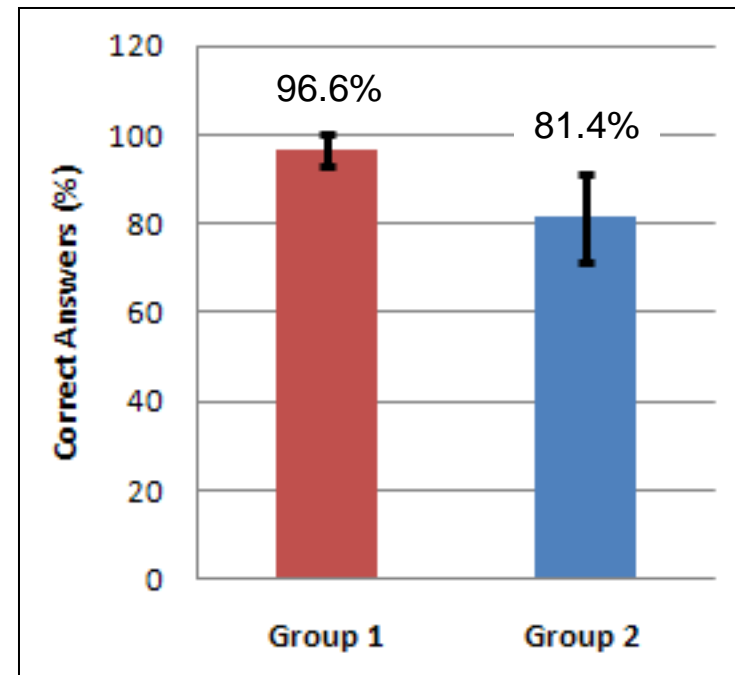
- Goal
 - To evaluate the effectiveness of highlighting components and connections in technical diagrams
- Scenario
 - Subjects are asked to find the 115V AC power source connected to a given component
- Groups
 - Group 1: experimental group with highlighting components and connections
 - Group 2: control group with no highlighting

Quantitative Evaluation Study: Task 1 (4/4)



Task completion mean time

p -value = 0.0118



Mean accuracy

p -value = 0.0335

- Group 1 is significantly faster and more accurate.

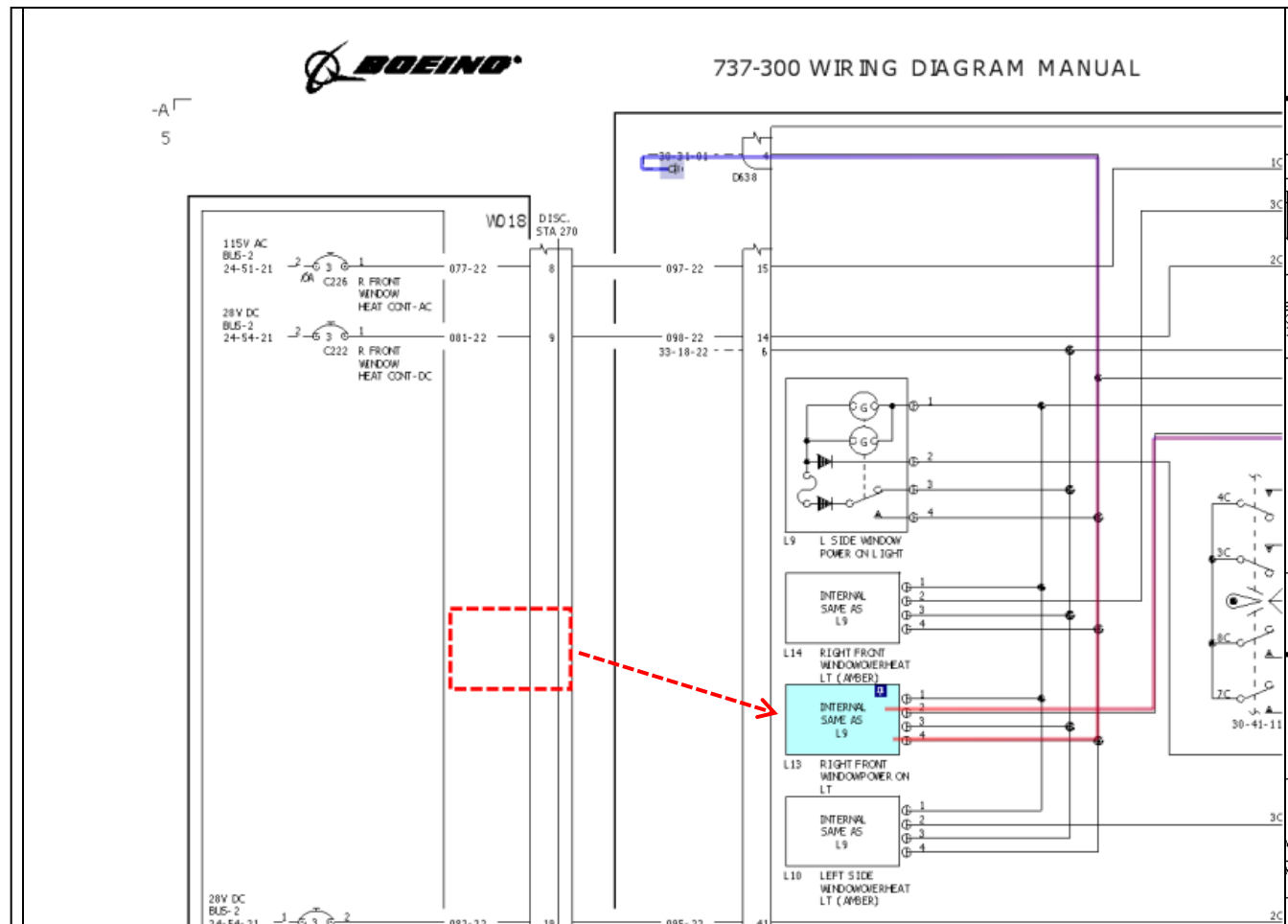
Quantitative Evaluation Study:

Task 2 (1/6)

- Goal
 - To evaluate the effectiveness of maintaining highlighting and spatial information between related schematic and wiring diagrams
- Scenario
 - Given a component in a schematic diagram, subjects are asked to find the same component in the related wiring diagram in order to find a specific pin number connected to the component
- Groups
 - Group 1: highlighting preservation
 - Group 2: highlighting and spatial information preservation
 - Group 3: nothing
 - Group 4: spatial information preservation

Quantitative Evaluation Study: Task 2 (2/6)

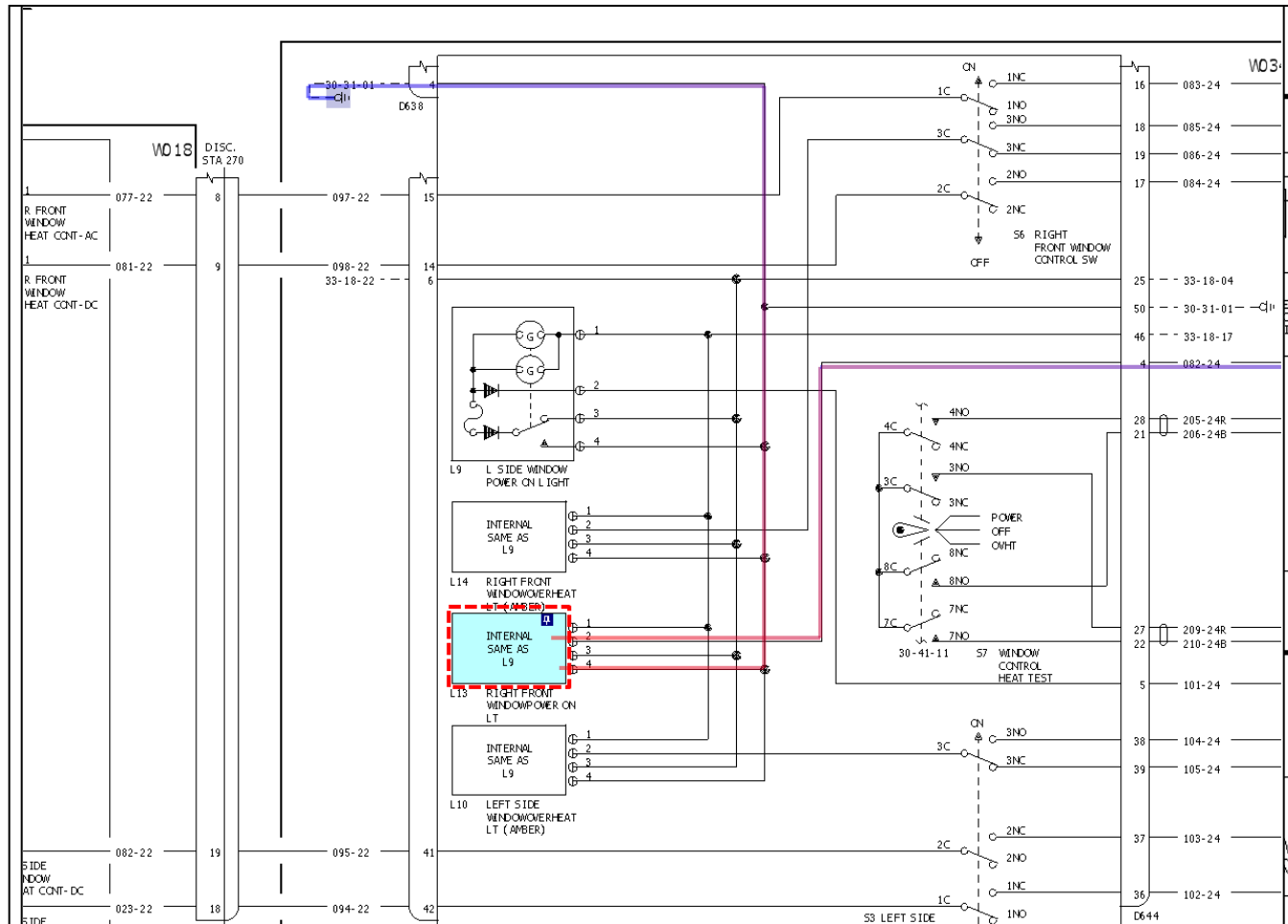
See highlighting preserved between related diagrams



Group 1: highlighting preservation

Quantitative Evaluation Study: Task 2 (3/6)

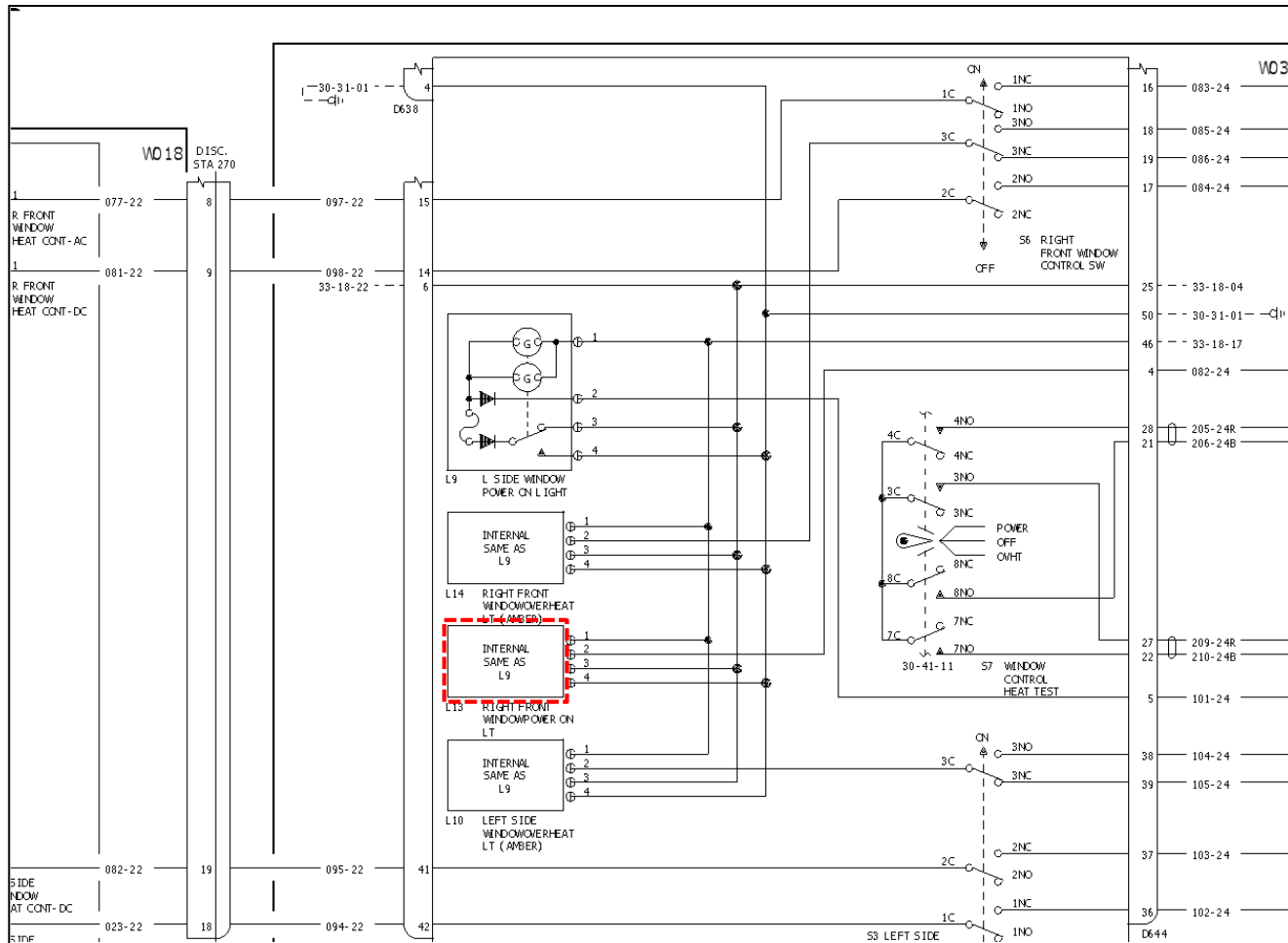
See highlighting and spatial information preserved between related diagrams



Group 2: highlighting and spatial information preservation

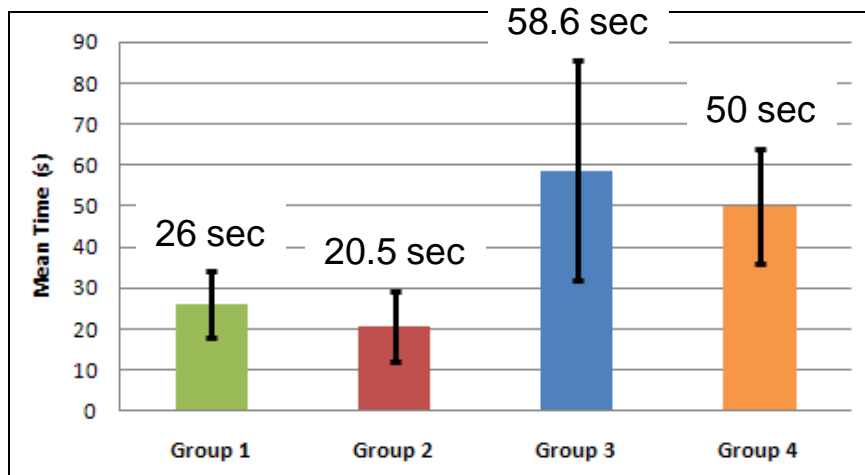
Quantitative Evaluation Study: Task 2 (5/6)

See spatial information preserved between related diagrams



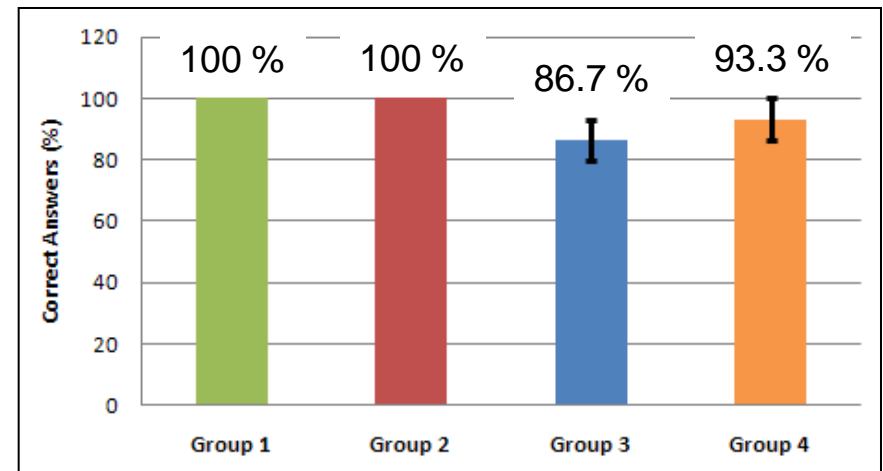
Group 4: spatial information preservation

Quantitative Evaluation Study: Task 2 (6/6)



Task completion mean time

p -value = 0.0448



Mean accuracy

p -value = 0.2611

- Group 1 and 2 are significantly faster.
- Group 4 is not significant. Users easily fail to notice the spatial cue preserved.

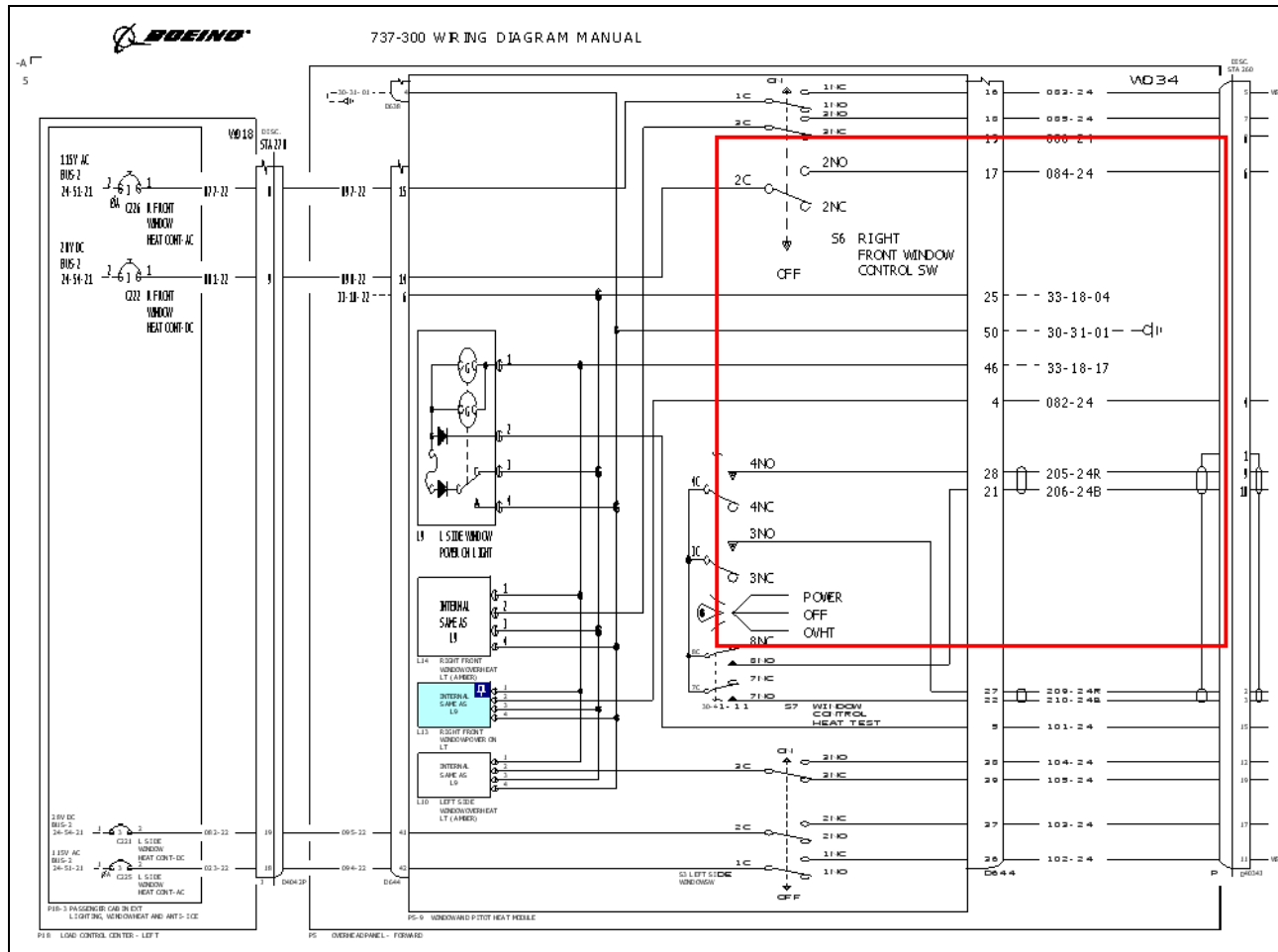
Quantitative Evaluation Study:

Task 3 (1/4)

- Goal
 - To evaluate the effectiveness of contextual information in a single diagram by using a lens method
- Scenario
 - Given a component in a schematic diagram, subjects are asked to find a specific pin number connected to the component by using distortion viewing
- Groups
 - Group 1: experimental group with a rectangular fisheye lens
 - Group 2: control group with a magic lens

Quantitative Evaluation Study: Task 3 (2/4)

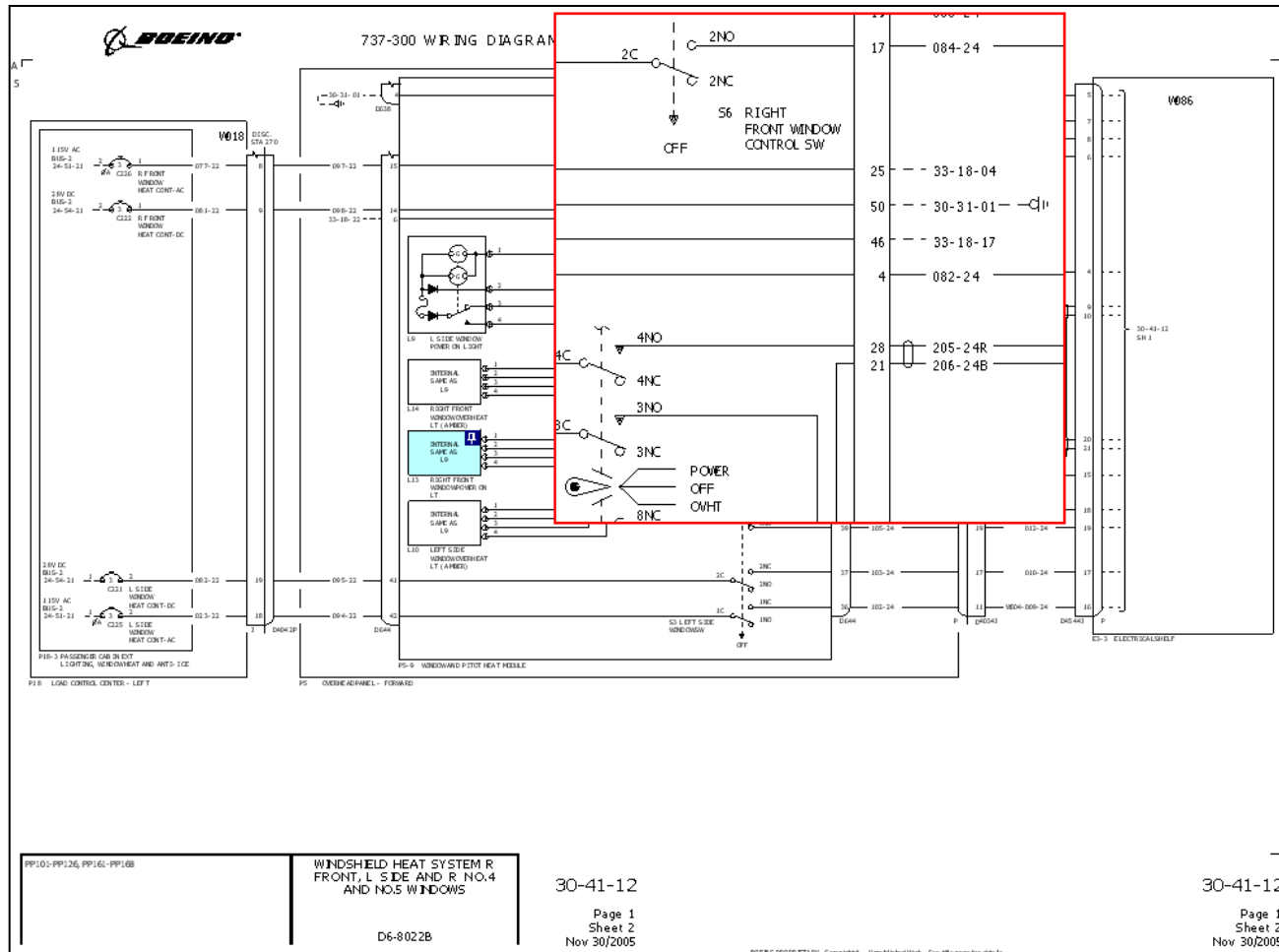
Rectangular fisheye lens without occlusions



Experimental group (Group 1)

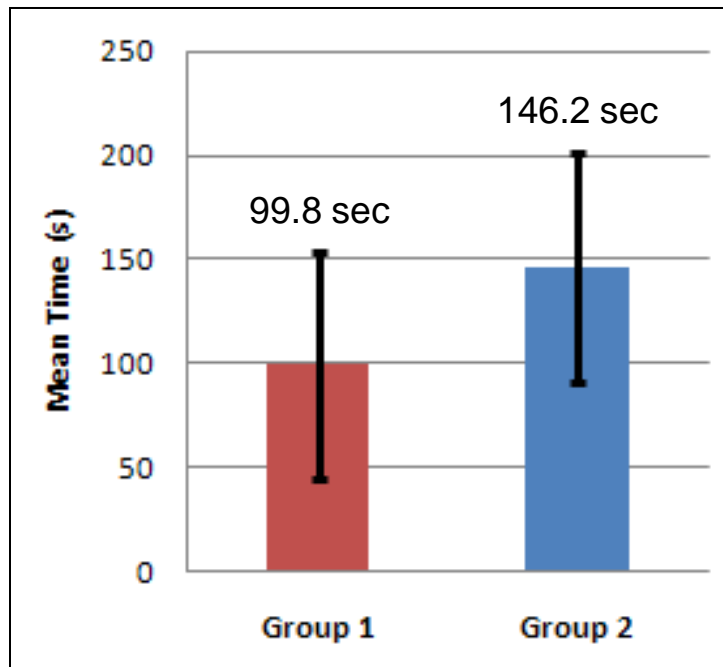
Quantitative Evaluation Study: Task 3 (3/4)

Magic lens with occlusions



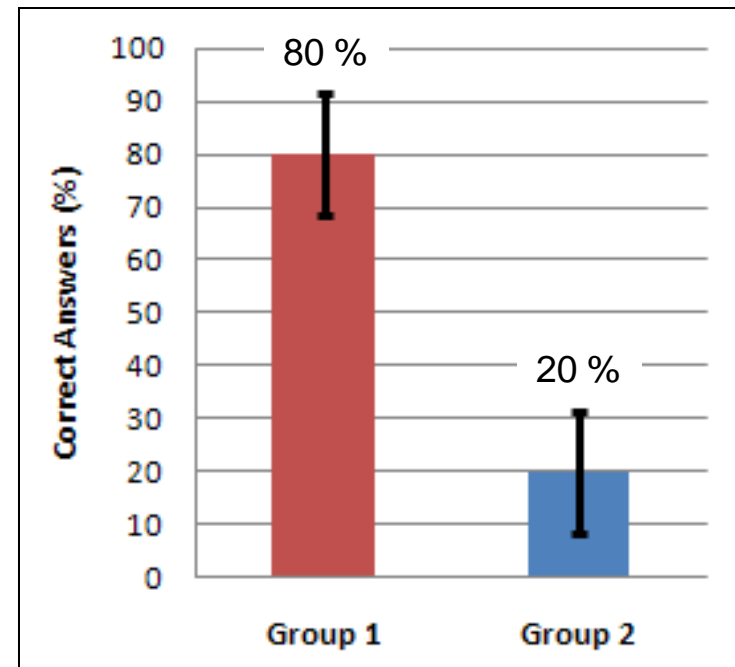
Control group (Group 2)

Quantitative Evaluation Study: Task 3 (4/4)



Task completion mean time

p -value = 0.3166



Mean accuracy

p -value = 0.013

- Group 1 is significantly accurate.
- Due to unfamiliarity, subjects preferred to use neither fisheye lens nor magic lens.

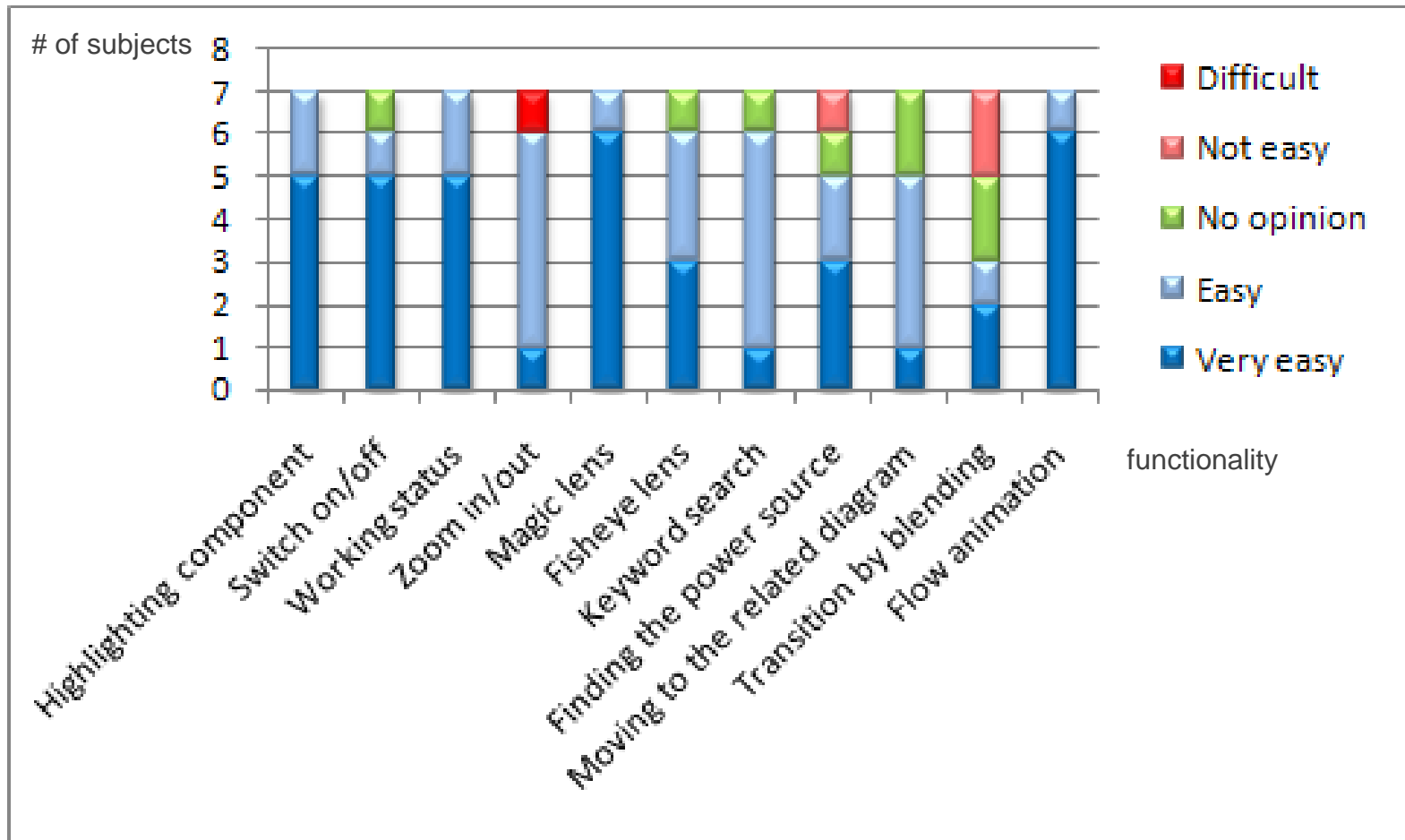
Qualitative Field Evaluation Study (1/2)

- Goal
 - To evaluate the effectiveness of our visualization system for schematic diagrams
- Scenario
 - Tabletop exercise scenario: supposes the malfunctioning of a window heater in a Boeing 737 aircraft. (Voltage is not indicated when the left side window control switch has been turned on.)
 - Subjects are asked to troubleshoot this problem.
- Post-questionnaire (Group 1 only)
 - Usability: how easy to use
 - Usefulness: how useful to solve real, practical problems

Qualitative Field Evaluation Study (2/2)

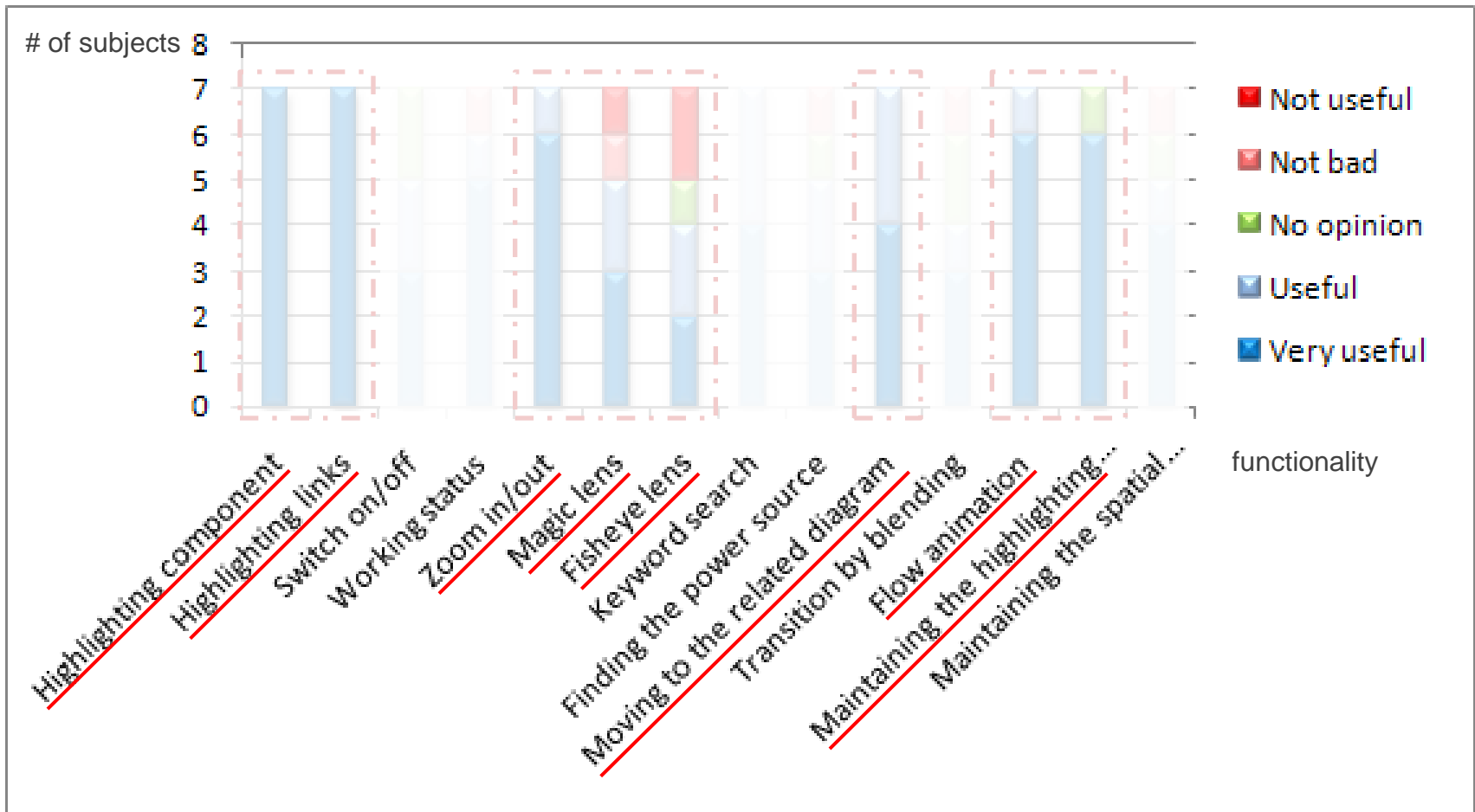
- Subjects
 - 10 senior students within Purdue University's Aviation Technology courses
 - Experience (6 months ~ more than 3 years) in the simulated troubleshooting of aircrafts using schematic and wiring diagrams
- Groups 1: experimental group, 7 subjects
 - Tutorial videos and prior training
 - Full functionality of our system
 - Any time access to the users' manual
- Group 2: control group, 3 subjects
 - PDF viewer with pan and zoom controls

Qualitative Field Evaluation Study: Usability



Usability for each function

Qualitative Field Evaluation Study: Usefulness



Usefulness for each function

Qualitative Field Evaluation Study: Result (2/2)

- Task completion time comparison
 - Group 1
 - 9 ~ 15 minutes
 - Most time was consumed to read maintenance manuals to understand the component operations
 - Group 2
 - 17 ~ 32 minutes
 - Most time was consumed to find related diagrams and components between the related diagrams

Conclusion

- Quantitative and qualitative studies
 - Evaluated the effectiveness of preserving contextual information between related diagrams
 - Designed based on the tabletop exercise by expert technicians
- Lessons we learned
 - Lesson 1: Context preservation provides a starting point for users' analysis when switching between related diagrams
 - Lesson 2: Preserving highlighting between related diagrams is significant in terms of time and accuracy
 - Lesson 3: Preserving spatial information between related diagrams can play an important role, but users easily lost information spatially preserved
 - Lesson 4: Although using rectangular fisheye lens was significantly accurate to find information in a large diagram, it may be less preferred by maintenance personnel due to unfamiliarity

Acknowledgements

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- We thank
 - the U.S. Air Force Research Laboratory Human Effectiveness Directorate and
 - the U.S. Department of Homeland Security's VACCINE Center.

Appendix 1:

Quantitative Evaluation Study: Result

Task	Time	Accuracy
1	significant ($p = 0.0118$)	significant ($p = 0.0335$)
2	significant ($p = 0.0448$)	not significant
3	not significant	significant (p -value = 0.013)

Summary of the results for our quantitative evaluation

Appendix 2:

Qualitative Evaluation Study: Result

Tool	Usability	Usefulness
Highlighting	100%	100%
Switch on/off	85%	71%
Working status	100%	85%
Magic lens	100%	71%
Fisheye lens	85%	57%
Finding power sources	71%	71%
Moving to the related diagram	71%	100%
Transition by blending	42%	57%
Flow animation	100%	100%
Maintaining the highlighting	-	85%
Maintaining the spatial information	-	71%

Summary of the results for our qualitative field evaluation

Appendix 3:

SDViz: Full Functionality

- Highlighting
 - Highlighting components and links
 - Mark component working status
 - Turn on/off switch components
- Inter-diagram navigation
 - Relational lens
 - Transition by blending
 - Tabbed view and tree view
 - Keyword searching
- Context preservation
 - Preserving highlighting, spatial information, working status, and switch status
- Single diagram navigation
 - Overview window
 - Zooming in/out
 - Magic lens
 - Rectangular fisheye lens
 - Jumping to the next connected component
 - Finding circuit breakers (power sources)
 - Flow animation