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# **STPA as a Tool for Safe and Efficient Implementation of New Battery Technologies in Industrial Vehicles**

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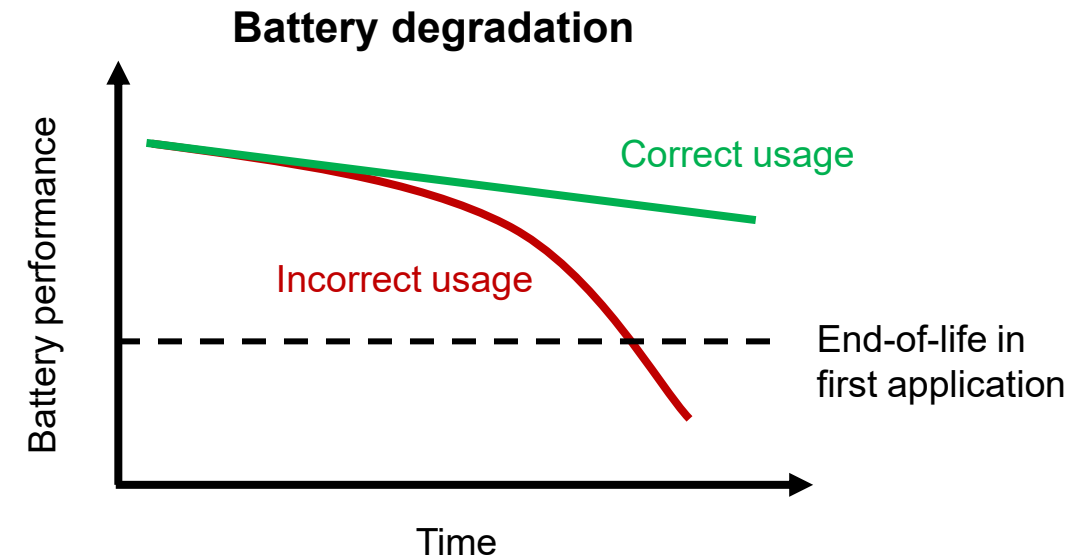
# Introduction

System under analysis:

- Lithium-ion powered forklifts and operation of them in an industrial environment

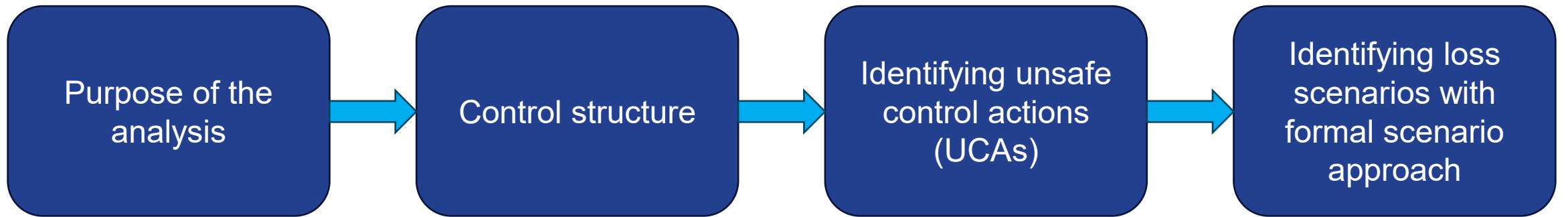
Goals of the study:

- Identify ways to prevent lithium-ion battery degradation
- Identify what information human controller needs to receive and process to sustain efficient use of forklifts.





# Methods





# Purpose of the analysis

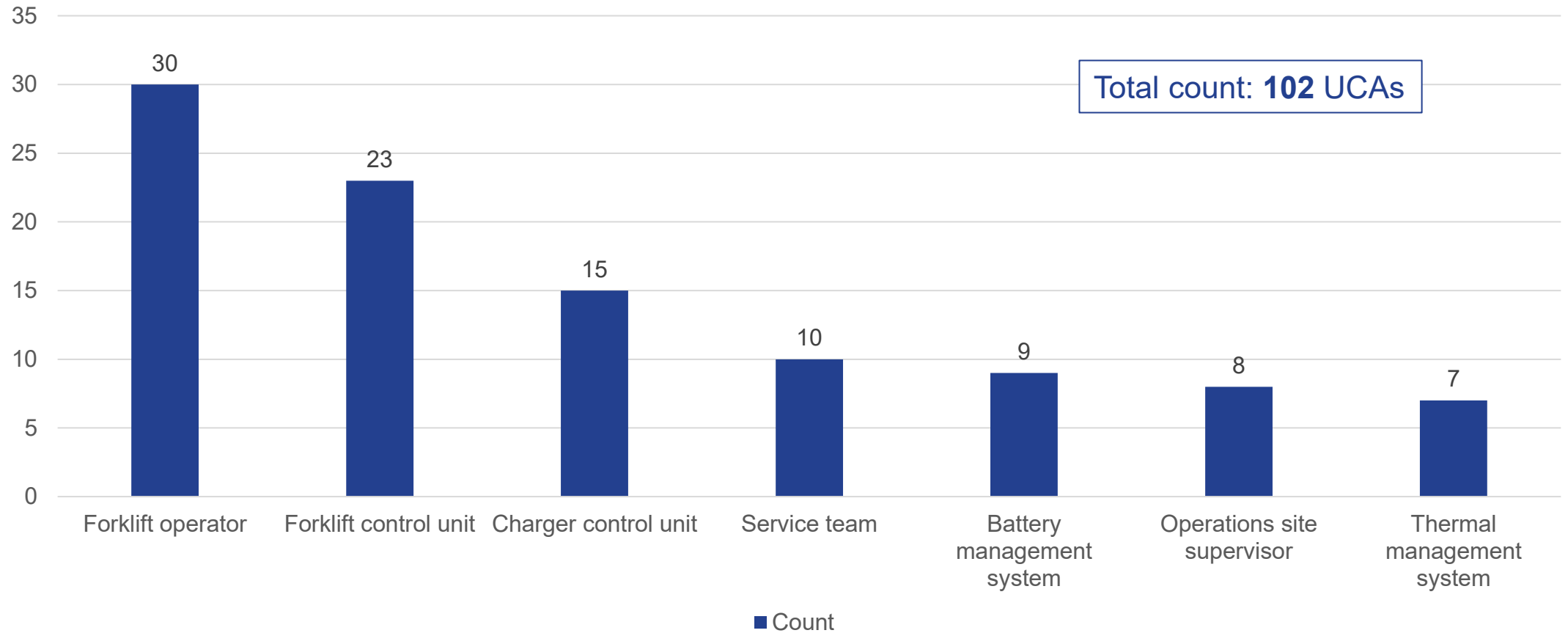
ID	Description of loss
L1	Loss of life or injury
L2	Loss of or damage to forklift or nearby objects
L3	Loss of battery or battery lifespan
L4	Loss of user satisfaction
L5	Environmental loss

ID	Description of hazard
H1	Humans, forklift or nearby objects are exposed to hazardous materials or phenomena [L1, L2, L3, L4, L5]
H2	Conditions accelerating battery degradation [L3, L4, L5]
	<b>Temperature:</b>
H2.1	Battery temperature is not on an optimal level specific to battery chemistry during charging and discharging and during rest periods
	<b>Current:</b>
H2.2	Battery discharging rate is not optimal to battery chemistry
H2.3	Battery charging rate is greater than 1C
H2.4	Battery charging and discharging rates are not symmetric
	<b>Cell voltages and depth of discharge:</b>
H2.5	Battery cell voltages are not kept on optimal level for the used battery chemistry
H2.6	Battery is at rest at low or high cell voltage level
H2.7	Battery cell voltages are not balanced
H3	Operational use of forklift is not enabled [L4]
H4	The operational life of the forklift is not maintained [L1, L2, L3, L4, L5]
H5	Inefficient use of resources [L4, L5]



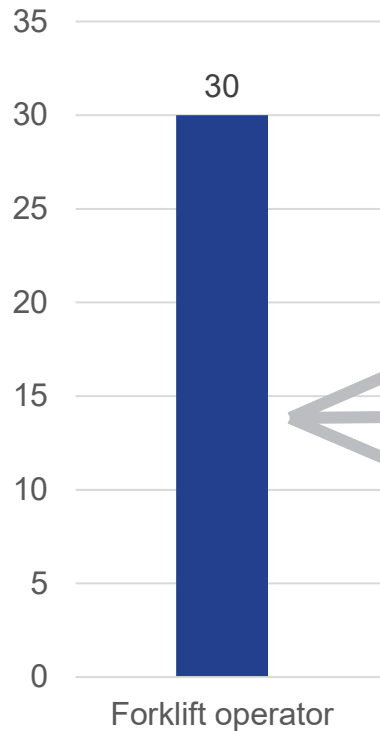


# UCAs per controller





# UCAs per controller



## Examples:

Forklift operator provides *Use the forklift* when battery temperature is below optimal operating temperature [H2.1]

Forklift operator provides *Use the forklift* without optimizing the operating SOC window [H2.5]

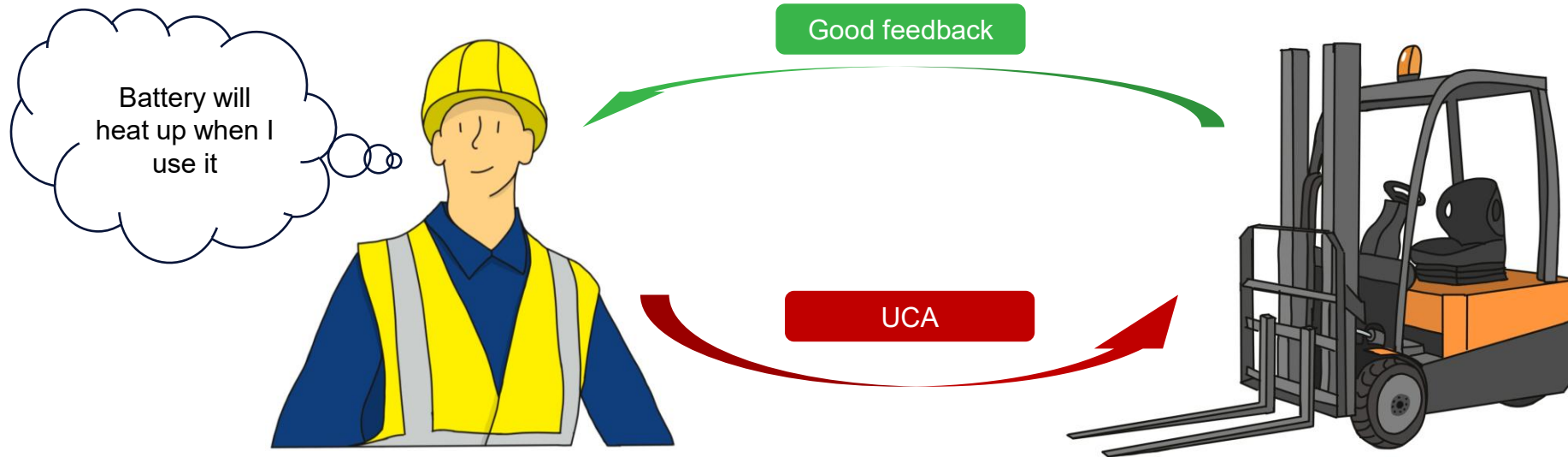
Forklift operator does not provide *Use the forklift* when there is transport order to fulfill [H3, H5]



# Forklift operator's unsafe mental models

- Formal scenario approach was used to prompt high-level loss scenario.
- Class 1 guides to unsafe mental models

Forklift operator provides Use the forklift when battery temperature is below optimal operating temperature. Forklift operator received feedback (or other inputs) that indicates battery temperature is below optimal operating temperature [H2.1].

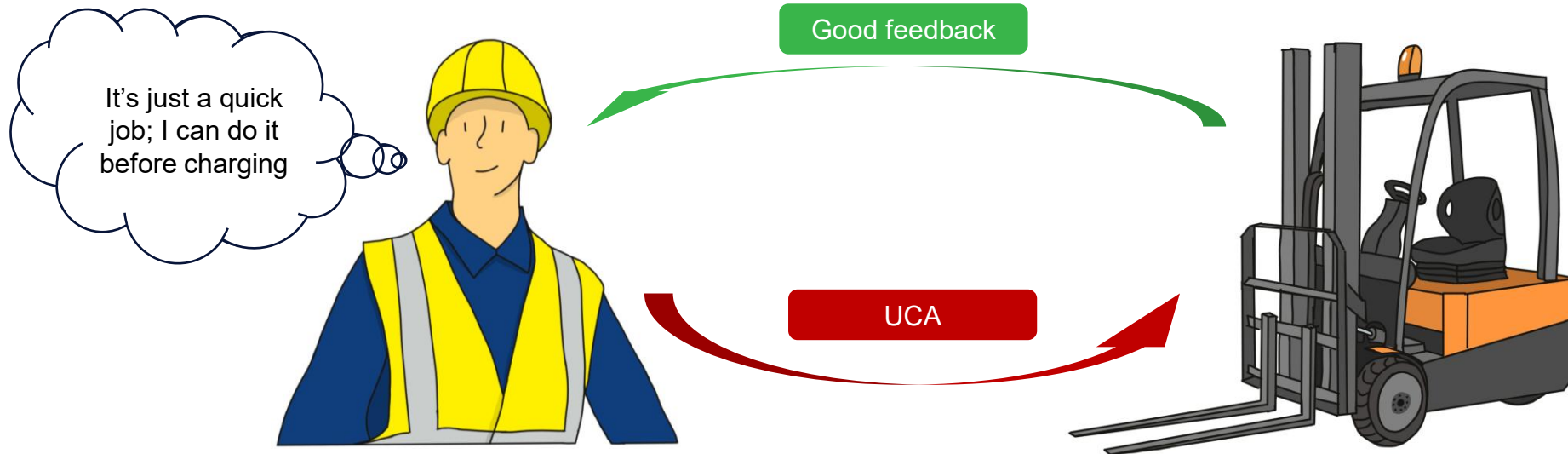




# Forklift operator's unsafe mental models

- Formal scenario approach was used to prompt high-level loss scenario.
- Class 1 guides to unsafe mental models

Forklift operator provides Use the forklift when battery operating SoC window is not optimized. Forklift operator received feedback (or other inputs) that indicates battery operating SoC window is not optimized [H2.5].

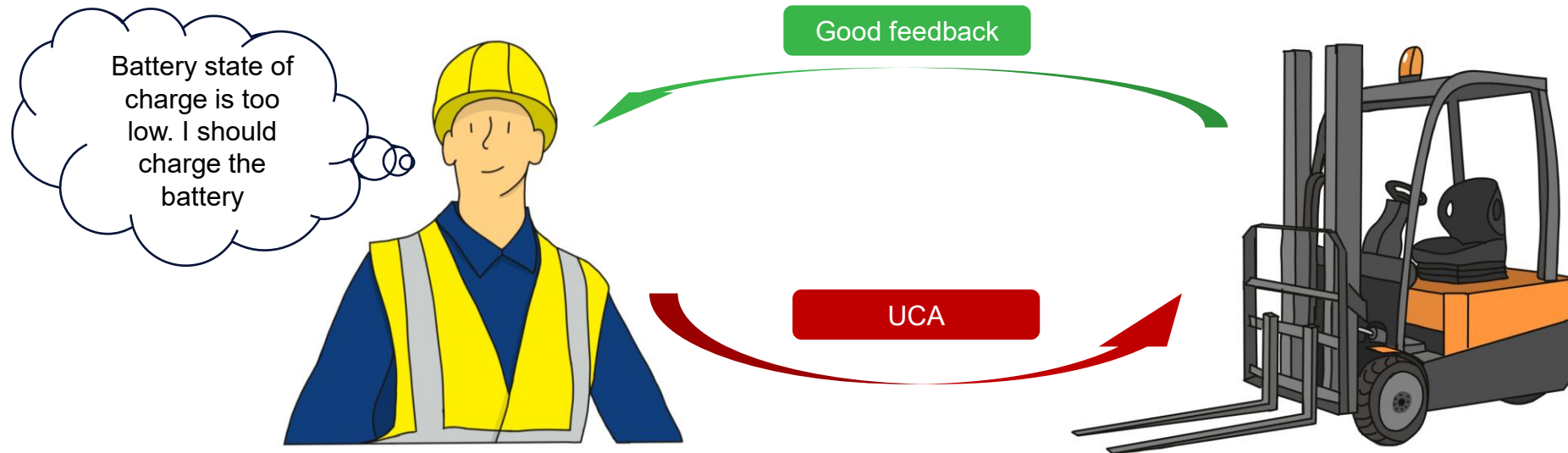




# Forklift operator's unsafe mental models

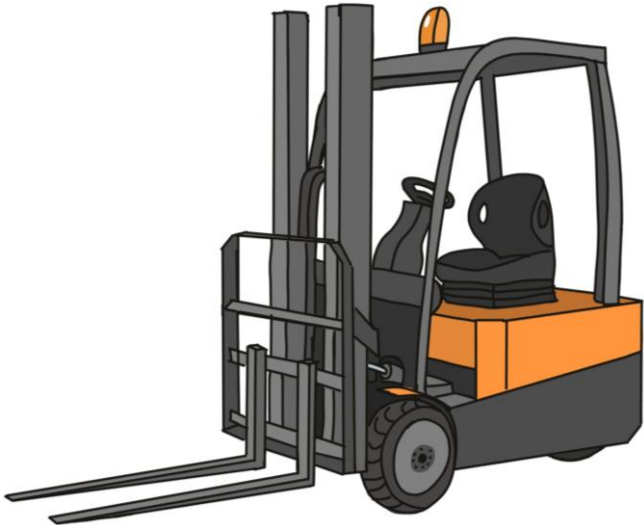
- Formal scenario approach was used to prompt high-level loss scenario.
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Forklift operator doesn't provide Use the forklift when there is transport order to fulfill. Forklift operator received feedback (or other inputs) that indicates there is transport order to fulfill [H3, H5].





# Recommendations for system operation



- Show optimal battery charge level range as 0-100% instead of the e.g. 20-80% that it actually is
- Show adequate battery information and instructions on how to preserve the battery



- Charges the battery to optimal charge level
- Has ability to time end of the charging just before start of the usage



- Mandatory user training
- ID card for activating the forklift for preventing unauthorized use
- Have a system that supports operator, gives transport orders, tells when to charge etc.



# Insights on the STPA process

- Completing all the STPA steps took about 5 months
  - I have mostly worked by myself and needed to learn both the system of interest and STPA method.
- Be brave to move forward in the analysis
  - I find the best way to learn the method was to conduct the analysis
- Formal scenario approach works well



# Conclusions

- STPA is a great tool for also other types of emergent properties than safety
- STPA shows the importance of system thinking when integrating new technologies into existing systems



# Thank You!

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Connect on LinkedIn:



DaRe-X – Lifecycle Data for Re-X circularity  
Decision number 195/31/2024

