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# A Framework on Early Decoupling Level Metric Assessment based on NLP4RE

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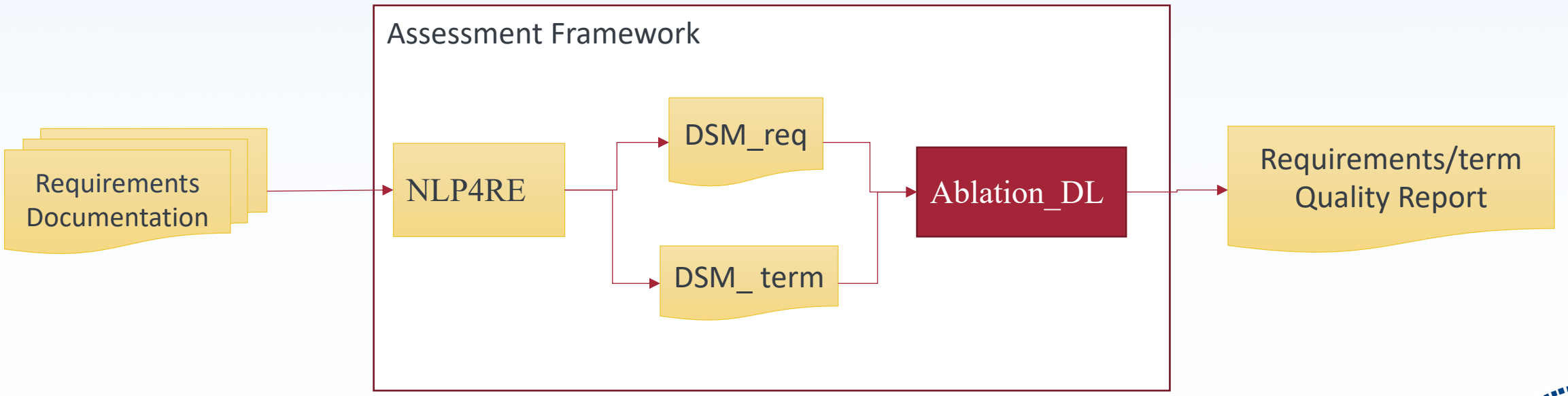
20 YEARS

# Modularity: Importance and Challenges

- System modularity is important. A modular system will:
  - Be easier to manage.
  - It can be developed in parallel.
  - Be easier to maintain and upgrade.
- However, modularity is challenge to achieve in real-life applications.
  - It is hard to measure and evaluate a modularity of complex systems
  - There is no method for early assessment of system modularity

# Our Framework: Early Assessment of Modular Structure

- The framework is built upon existing techniques, NLP4RE, and the Decoupling Level (DL) metric.
- We proposed a new procedure called Ablation_DL based on the DL metric.



# Natural Language Processing for Requirements Engineering (NLP4RE)

## What is NLP4RE?

- Work of NLP4RE builds on prior research by Systems Engineering Research Center (SERC) [1,2].
- Natural language processing applications
- Identify dependencies between system requirements & key terms

## Input:

- The natural language description of system requirements.

## Output:

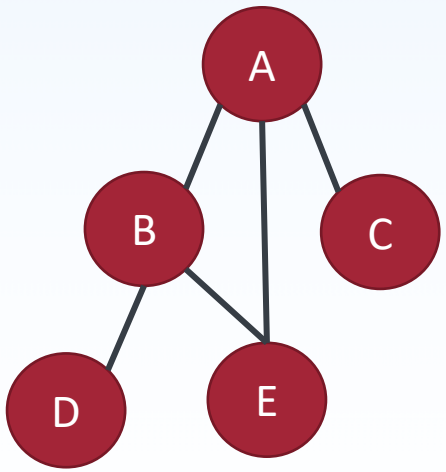
- Dependencies among system requirements and its key terms

[1] Vierlboeck, M., Dunbar, D., & Nilchiani, R. (2022, April). Natural Language Processing to Extract Contextual Structure from Requirements. In 2022 IEEE International Systems Conference (SysCon) (pp. 1-8). IEEE.
[2] Vierlboeck, M., Lipizzi, C., & Nilchiani, R. (2022). Natural Language in Requirements Engineering for Structure Inference--An Integrative Review. arXiv preprint arXiv:2202.05065.

# Design Structure Matrix

## What is DSM?

- A square matrix that represents the dependency relations between the design elements, which are requirements and terms in the context of our study.




Requirements/Terms
Dependency Relationships

| | A | B | C | D | E |
|---|---|---|---|---|---|
| A | 0 | 1 | 1 | 0 | 1 |
| B | 1 | 0 | 0 | 1 | 1 |
| C | 1 | 0 | 0 | 0 | 0 |
| D | 0 | 1 | 0 | 0 | 0 |
| E | 1 | 1 | 0 | 0 | 0 |

Design Structure Matrix

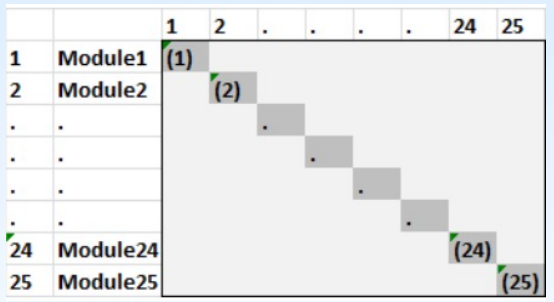
# Decoupling Level:

- Decoupling Level (DL) is a metric introduced by Mo et al. [1] to measure to what level a system is decoupled into small and manageable modules.
- The DL metric of a system can be calculated based on the DSM (Design Structure Matrix).
  - The DL value ranges from 0 to 1.
  - With higher DL values indicating a higher level of modularity in the system.
  - Empirical observation shows that a system is easier to maintain and modify when it has a higher DL value.

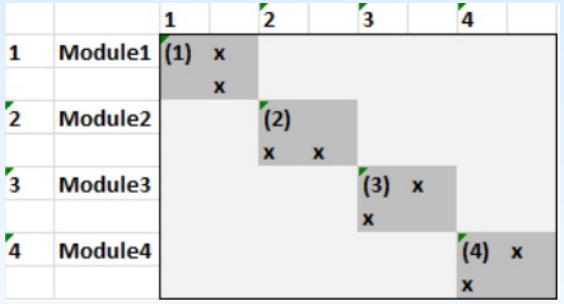
[1] Mo, R., Cai, Y., Kazman, R., Xiao, L., & Feng, Q. (2016). Decoupling Level: A New Metric for Architectural Maintenance Complexity. 2016 IEEE/ACM 38th International Conference on Software Engineering (ICSE), 499-510. doi: 10.1145/2884781.2884825.

# Decoupling Level (DL) Interpretation Examples

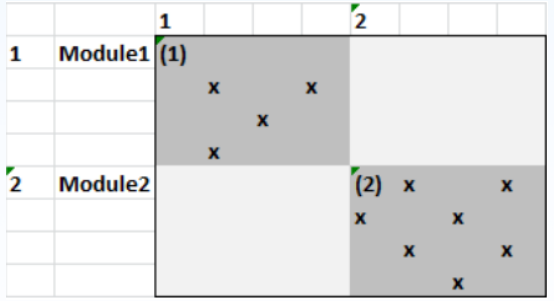
- Here are some examples from Mo et al. [1] to illustrate the rationale of DL based on a DSM with 100 elements:
  - (a) 100 files are decoupled into 25 modules, each having 4 elements : DL = 100%(1.00)
  - (b) 100 files are decoupled into 4 modules, each having 25 elements : DL = 50%(0.50)
  - (c) 100 files are decoupled into 2 modules, each having 50 elements : DL = 41%(0.41)
  - (d) 100 files are decoupled into 1 module with 100 elements : DL = 35%(0.35)



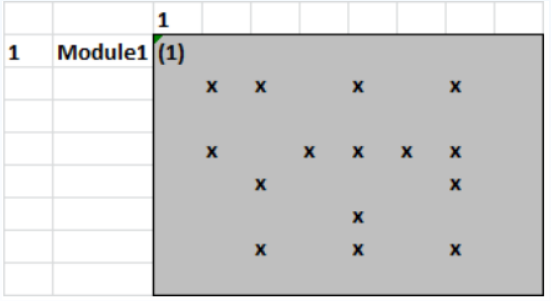

(a) DL = 100%(1.00)




(b) DL = 50%(0.50)




(c) DL = 41%(0.41)




(d) DL = 35%(0.35)

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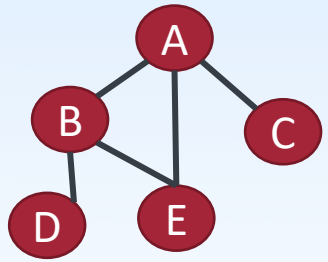
# Ablation_DL Procedure

- **What is the purpose?**
  - To evaluate the impact of each single design element on the modularity of the entire system.
- **How does it work?**
  1. Input: Design Structure Matrix (DSM)
  2. Calculate DL value, record as Origin_DL.
  3. Remove one design element (e.g., E) from the DSM
  4. Calculate new DL, record as New_DL
  5. Calculate delta = Origin_DL - New_DL.

In this example, **delta** represents the impact of the design element E on the modularity of the system's requirements.

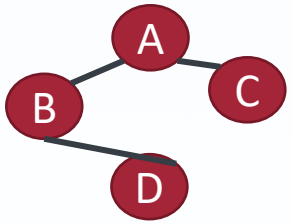
- For each design element:
  - If **DL_delta** < 0: this element is a **coupler** since there is a **negative** impact on the modular structure (removing it will **increase** the decoupling level).
  - If **DL_delta** > 0: this element is a **decoupler** since there is a **positive** impact on the modular structure (removing it will **decrease** the decoupling level).




| | A | B | C | D | E |
|---|---|---|---|---|---|
| A | 0 | 1 | 1 | 0 | 1 |
| B | 1 | 0 | 0 | 1 | 1 |
| C | 1 | 0 | 0 | 0 | 0 |
| D | 0 | 1 | 0 | 0 | 0 |
| E | 1 | 1 | 0 | 0 | 0 |

DL value: **Origin_DL**

Remove E




| | A | B | C | D |
|---|---|---|---|---|
| A | 0 | 1 | 1 | 0 |
| B | 1 | 0 | 0 | 1 |
| C | 1 | 0 | 0 | 0 |
| D | 0 | 1 | 0 | 0 |

DL value: **New_DL**

# Case Study on Unmanned Aircraft System (UAS)

- We conducted a case study based on the Unmanned Aircraft System (UAS), a project from the Systems Engineering Research Center (SERC).
- We capture the DSMs of the UAS at two levels based on the NLP4RE:
  - a requirement-level DSM (70 requirements)
  - a term-level DSM (245 key terms).
- We applied our Ablation_DL  procedure to quantitatively evaluate and rank the contributions of different design elements to the modular structure of the UAS system.

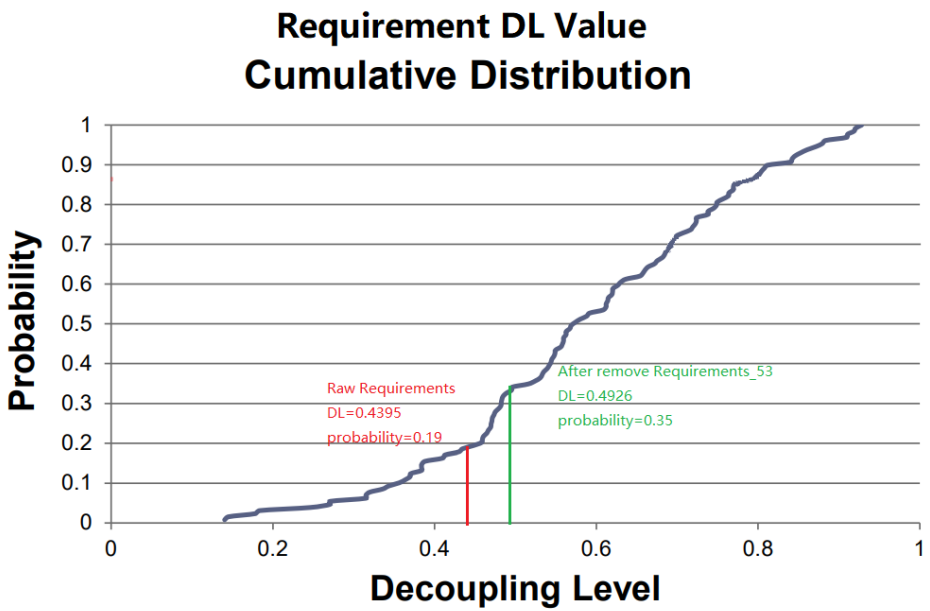
# RQs in Case Study of the UAS

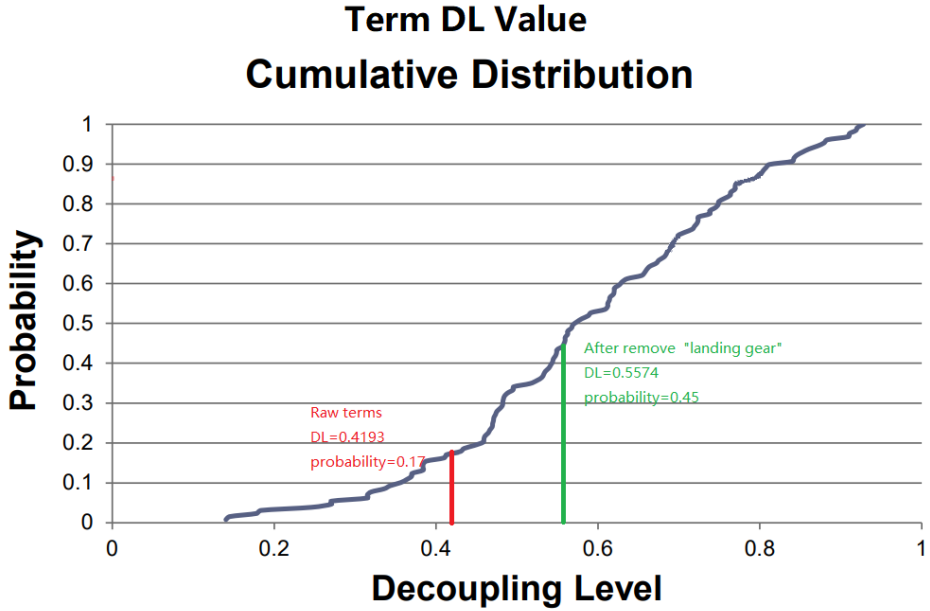
- RQ1: How is the DL metric of the UAS system compared to the "health chart" of DL metrics?
- RQ2: How do the different requirements in the UAS system contribute to the DL metric?
- RQ3: How do the different design terms in the UAS system contribute to the DL metric?
- RQ4: Why some requirements/terms have a decoupling/coupling effect to the UAS system?

# RQ1: How is the DL metric of the UAS system compared to the "health chart" of DL metrics

"Health chart": generated from the DL values of 129 software systems [1].

- UAS DL is at the 20 percentile, more coupling than 80% of software projects studied prior.
- Our ablation procedure identified requirement #53 as the most coupling requirement, removing it could improve the DL by over 5%.
- DSM_term shows consistent observations with DSM_req.

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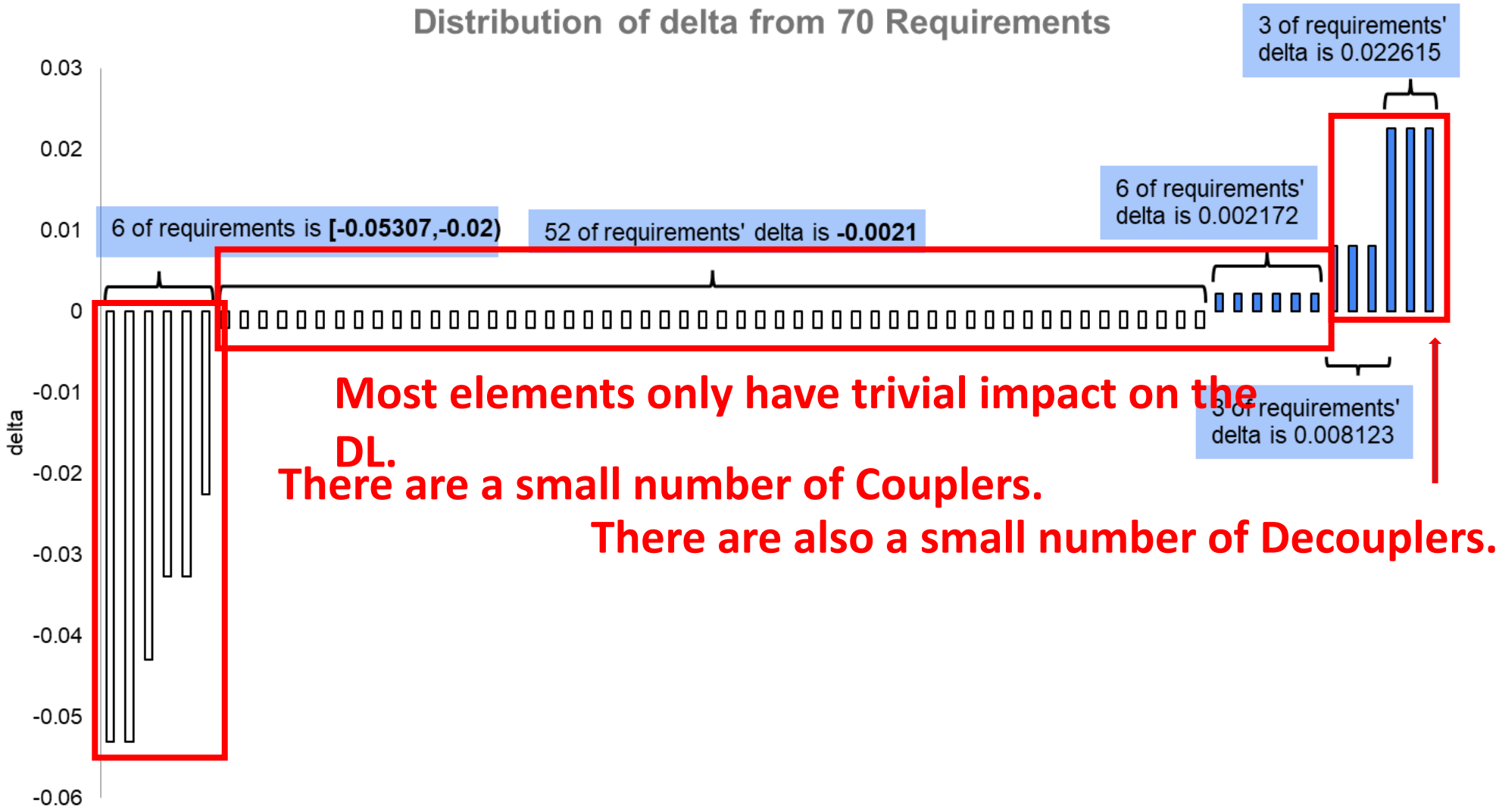
# RQ2: How do the different requirements in the UAS system contribute to the DL metric?

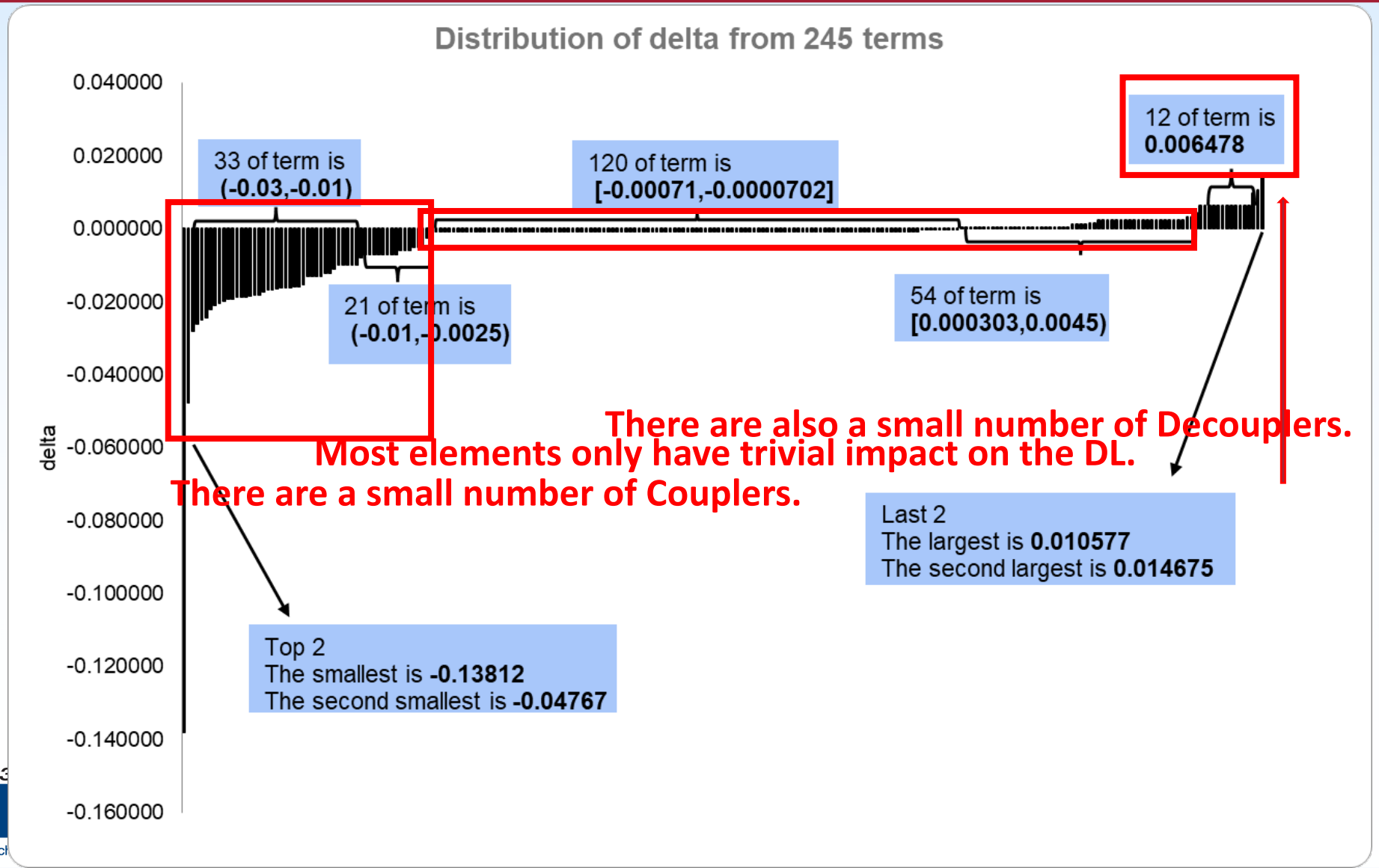



Most elements only have trivial impact on the DL.

There are a small number of Couplers.

There are also a small number of Decouplers.

# RQ3: How do the different design terms in the UAS system contribute to the DL metric?



# RQ4: Why some requirements/terms have a decoupling/coupling effect to the UAS system

## RQ4.1:Findings of requirements decoupling/coupling effect

- The most coupling system requirements are
  - Composed of longer and more descriptive requirements.
  - Contain frequent and central terms, such as “landing gear”
  - Have high connectivity.
- The most decoupling system requirements are
  - Are typically shorter. For example, Requirement #61 only have two entities
  - Contain rare terms, such as “landing energy absorption”
  - Have low connectivity.

| Requirement level | | | |
|---|---|---|---|
| Top 3 Coupling Requirement | | Top 3 Decoupling Requirement | |
| Requirement ID | Delta | Requirement ID | Delta |
| # 53 | -0.0531 | # 61 | 0.02262 |
| # 7 | -0.0531 | # 62 | 0.02262 |
| # 52 | -0.0429 | # 25 | 0.02262 |

# RQ4: Why some requirements/terms have a decoupling/coupling effect to the UAS system

## RQ4.2: Findings of terms decoupling/coupling effect

- The most coupling design terms
  - Have high connectivity.
- The most decoupling design terms
  - Typically composed of a compound noun
  - Have low connectivity.
- Have false positive connections in general terms like "time" and "inche“, should be analyzed manually after the Ablation_DL procedure.

| Term level | | | |
|---|---|---|---|
| Top 3 Coupling Term | | Top 3 Decoupling Term | |
| term name | Delta | term name | Delta |
| landing gear | -0.13812 | landing energy absorption | 0.014675 |
| time | -0.04767 | landing gear actuation | 0.010577 |
| inche | -0.02815 | single point non-structural failure | 0.009714 |

# Future Work

1. Verify Scalability and Transferability on different systems.
2. Generate recommendations directly using our Framework.

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# THANK YOU

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