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ENGINEERING THE FUTURE: ADDRESSING SYSTEM COMPLEXITY IN HIGH-TECH EQUIPMENT

Prof. dr. Benny Akesson | INSIDE Connect 2025

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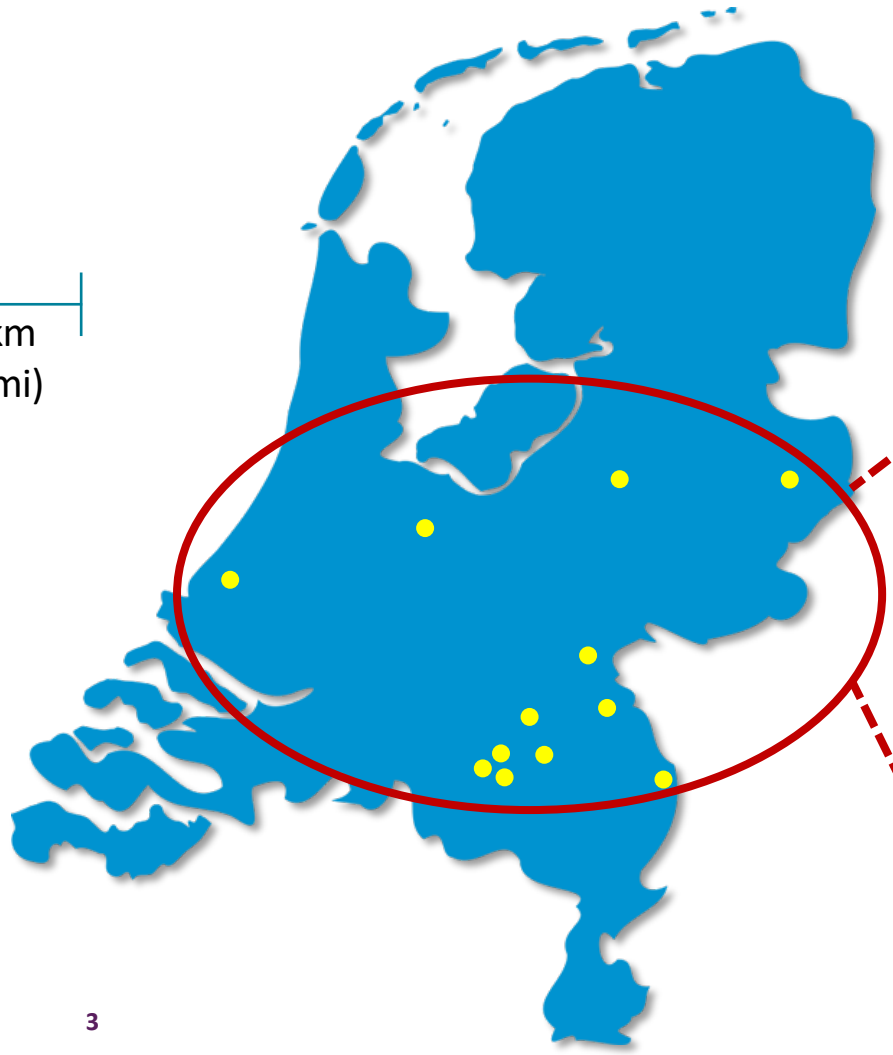
THE DUTCH HIGH-TECH EQUIPMENT INDUSTRY



SYSTEM COMPLEXITY IS INCREASING!

Five technological and market trends drive increasing complexity in high-tech equipment:

1. **Additional functionality**
   - Number of interfaces and lines of code are **rapidly increasing**
2. **Mass customization**
   - Increased customization of systems at design time to the point where **each system is unique**
3. **Long life-times**
   - Systems operate for decades and need to **continuously evolve** after deployment
4. **Increasing autonomy**
   - Systems acting autonomously with **little or no human interaction**
5. **Systems of systems**
   - Interconnected systems of which **nobody is in complete control**

Leibbrandt, Wouter, et al.. "TNO-ESI–Systems Engineering Methodologies for Managing Complexity in the High-Tech Equipment Industry: Our Roadmap." INSIGHT 25.4 (2022)
Hendriks, T. and Azur, S. “Vision and Outlook for Systems Architecting and Systems Engineering in the High-tech Equipment Industry" TNO Report 2024 R10542, 2024

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MANAGING COMPLEXITY

Managing complexity in high-tech equipment is critical to successful development and deployment

- For a company, failure to manage complexity can lead to **errors**, **delays**, and **cost overruns**

Consequences of increasing complexity are visible in daily industrial practice

- Increasing development and maintenance **costs**
- Increasingly hard to **guarantee functional correctness** and **balance system qualities**
- Increasing **scarcity of experienced engineers**

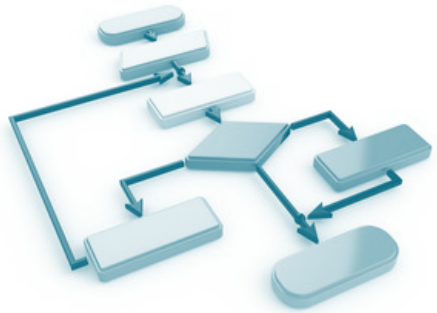
Hendriks, T. and Azur, S. “Vision and Outlook for Systems Architecting and Systems Engineering in the High-tech Equipment Industry" TNO Report 2024 R10542, 2024
B. Meier, M. Skelin, F. Beenker, and W. Leibbrandt, Eds., “HTSM Systems Engineering Roadmap.” 2020
A. van der Werf, et al. “Made in NL: The value of the Dutch high-tech manufacturing industry,” PricewaterhouseCoopers, 2024

METHODOLOGIES NEEDED

New methodologies and tools are required to **increase engineering productivity** and **address the shortage of experienced engineers** through

- **abstraction**, to hide unnecessary detail of increasingly complex systems
- **automation**, to increase engineering productivity
- **democratization** of engineering, to reduce dependency on experts

TNO-ESI is an organization that **orchestrates** the **innovation chain** for engineering methodologies in the Dutch high-tech eco-system and conducts **applied research to improve industrial practice**



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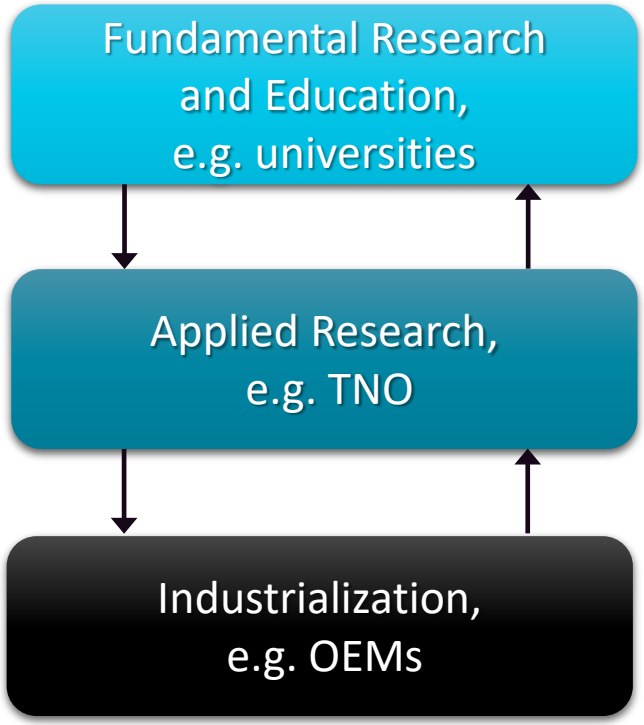
B. Meier, M. Skelin, F. Beenker, and W. Leibbrandt, Eds., “HTSM Systems Engineering Roadmap.” 2020

THE INNOVATION CHAIN

The path from ground-breaking research to industry impact often happens through an **innovation chain**

- **Universities:** Education and basic technology research
- **Applied Research Organizations:** Maturation and integration of research results and application/validation in industry context
- **Industry:** Industrialization of technology

It is important to **understand your role** in the innovation chain, and the roles of the other actors to work together effectively!



TNO-ESI AT A GLANCE

SYNOPSIS

- Foundation ESI started in 2002
- ESI acquired by TNO per January 2013
- ~60 staff members many with extensive industrial experience
- 8 Part-time professors

FOCUS

Managing complexity of high-tech systems

through
- model-based engineering
- formal methods and
- artificial intelligence

delivering
- methodologies validated in cutting-edge industrial practice

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MODEL-BASED ENGINEERING

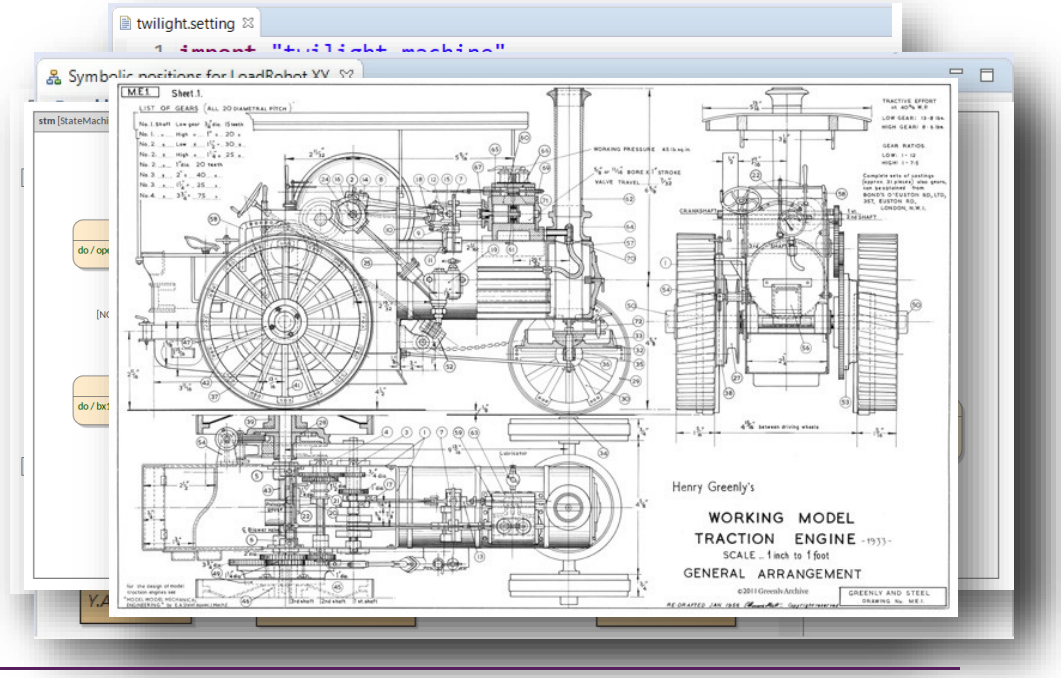
System complexity can be tackled through **model-based engineering** methodologies

Models expressed in some **formalism/language** are important artifacts during the life cycle of the system

- Provide **abstraction** from unnecessary details and serves as basis for **automation**

Models can be used as a **single source of truth** for:

- **Specification**
- **Communication** within and between disciplines
- **Analysis** of (non-)functional behavior
- **Synthesis** of design artifacts,
  e.g. documentation, code, and tests



Oortwijn, W., et al. "Vision and Outlook for System Evolution and Diversity" TNO Report 2024 R10716, 2025

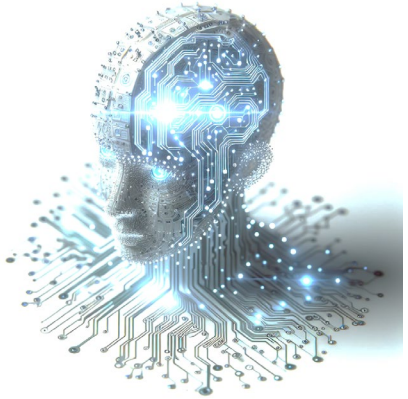
ARTIFICIAL INTELLIGENCE

Large Language Models (LLMs) have potential for increasing engineering productivity through **digital assistants**

- Quite mature technology for **knowledge consolidation, democratizing engineering** in large organizations
- Useful for semi-automatic **generation of documents and code**

Technology has potential to **facilitate transition** from document-based to model-based engineering through (semi-)automatically generation of other artifacts, considering organizational context, e.g.

- Structural or behavioral **MBSE models** to reduce modelling effort (scales to complex systems?)
- **Models for formal methods**, democratizing their use (sufficient available examples?)



RENAISSANCE: REDUCING EFFORT FOR MAINTAINING AND MODERNIZING LEGACY SOFTWARE

COSTLY DEBT OR VALUABLE HERITAGE?

The high-tech equipment industry develops **long-living software-intensive systems**

- The software inside these systems inevitably suffers from accumulated **technical debt**
- Large code bases using obsolete libraries, frameworks, or design patterns
- Hampers development of innovative new features for customers

Technical debt is **extremely costly**

- Software technical debt is estimated to cost 1.52 trillion dollars in the US [1]
- Maintenance is estimated at 75% to 90% of software development life cycle cost [2, 3]
- Legacy software is, at the same time, an inevitable burden and a **valuable heritage**

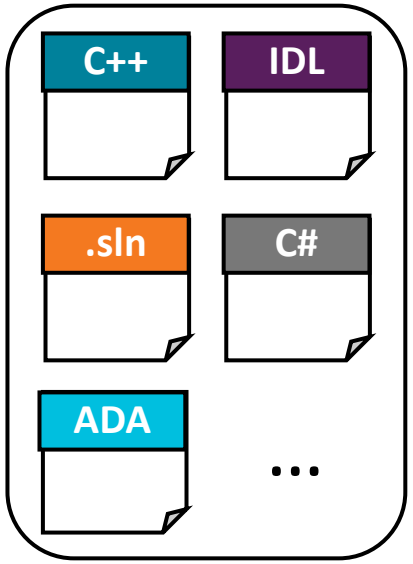
There is a broad need for **efficient and scalable solutions** to maintain and modernize legacy software

- Opportunities for **automation** using a model-based approach based on **static analysis** [4]

[1] Krasner, Herb. "The cost of poor software quality in the US: A 2022 report." Proc. Consortium Inf. Softw. Quality (CISQ). (2022)
[2] https://galorath.com/blog/software-maintenance-costs/
[3] https://web.archive.org/web/20120313070806/http:/users.jyu.fi/~koskinen/smcosts.htm
[4] Dams, Dennis, et al. "Model-based software restructuring: Lessons from cleaning up COM interfaces in industrial legacy code." Proc. SANER, 2018

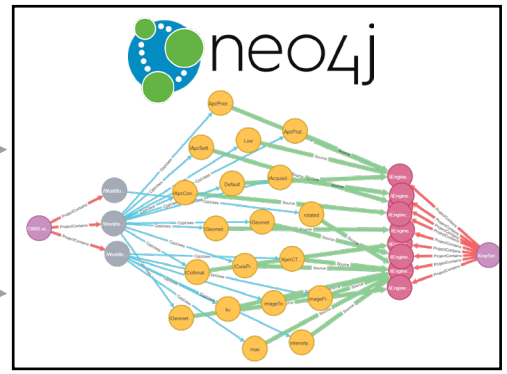
RENAISSANCE: CODE ANALYSIS AND RESTRUCTURING

GEN AI SUPPORT
- Text2Cypher
- Graph2Text
- Graph2Table
- ...



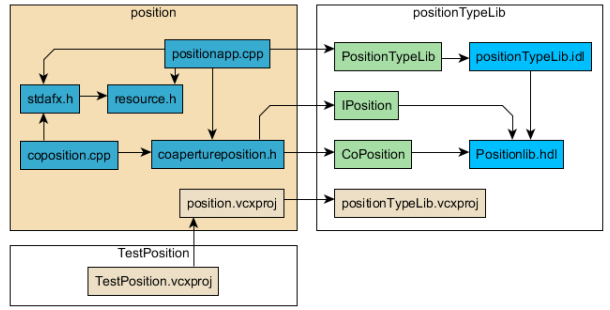
1 Parse

2 Extract



3 Analyse

ARCH VIEWS



4 Transform

FLUENT

```
transformation {
    action.find(BEFORE)
    .replace(AFTER)
    ...
}
```

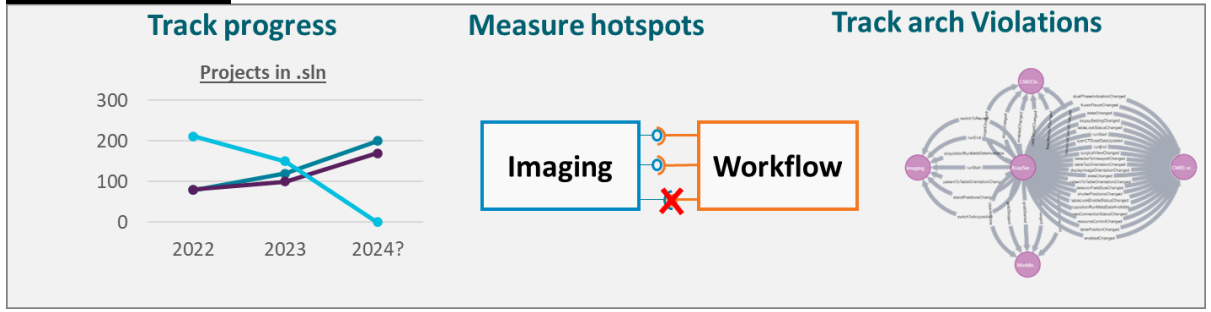
BEFORE

```
void FooTest::TestMethod(){
    CPPASSERT(avariable);
}
```

AFTER

```
TEST_F(FooTest,TestMethod){
    EXPECT_TRUE(avariable);
}
```

DASHBOARD



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INDUSTRIAL IMPACT

Renaissance was developed and validated with several industry partners to assure **fitness for industrial practice**

A **training program** has been developed and followed by **50 engineers** from industry

Two **implementation partners** are applying Renaissance in their commercial offerings

Thermo Fisher Scientific – Electron Microscopy

- Reported that they "**managed to significantly reduce the time it takes us to build a new version of the software**"

Philips Healthcare – Image Guided Therapy Systems

- Reported that Renaissance empowers them to "**apply large scale analysis & refactoring that would otherwise be impossible**".

ITEC/Nexperia

- Reported that they already **saved 300k$ and estimated to save another 900k$ using the approach while the investment was below 100k$**.

CONCLUSIONS

CONCLUSIONS

High-tech industry challenged to **increase engineering productivity** due to **growing system complexity**

New **methodologies** and **tools** required to increase engineering productivity and address scarcity of engineers

- Combining **model-based engineering**, **formal methods**, and **artificial intelligence**
- Technologies provide **abstraction**, **automation**, and **democratization** of engineering

An example methodology and tools from our ecosystem was demonstrated and its **impact** discussed

- **Rensaissance**: Reducing efforts for maintaining and modernizing legacy software

CALL TO ACTION

We want to continue talking to you about our open innovation eco-system, methodologies and tools, and competence development!

We are also happy to **collaborate** on research in areas including:

- Systems Architecting
- System Performance
- Intelligent Diagnostics
- Software Rejuvenation
- Verification of Systems and Software
- AI for systems engineering

Please join us at the **ESI Symposium** on October 7 in Eindhoven

BIOGRAPHY

Benny Akesson completed his doctoral studies at the Eindhoven University of Technology in the Netherlands in 2010. He is presently a Senior Research Fellow at TNO-ESI, leading applied research projects in collaboration between the public sector and industry. As the TNO-ESI Science Lead he also sets the scientific direction and orchestrates early knowledge development, including academic collaborations. Since 2019, he has been a Professor at the University of Amsterdam, where he holds the Chair of Design Methodologies for Cyber-physical Systems. His research interests include model-based engineering, real-time systems, and system performance engineering. Prof. Akesson has published over 80 peer-reviewed articles in conferences and journals and has been recognized with three Best/Outstanding Paper Awards and a CODES+ISSS Test-of-Time Award. A Senior Member of the IEEE, Prof. Akesson has contributed to approximately 40 program committees, also in chairing roles.

ABSTRACT

Engineering the Future: Addressing System Complexity in High-Tech Equipment

The Netherlands has a vibrant high-tech equipment industry in application domains including semiconductors, medical systems, and defense. Many companies in this industry are world-leading in their respective market segments and contribute significantly to the economy. However, this industry is challenged by a number of market and technology trends that result in increasing system complexity, driving up development and maintenance costs. To enable future systems to be developed cost-efficiently, new engineering methodologies are required to address the increasing complexity.

This presentation explores the trends contributing to the rising system complexity and present promising research directions to tackle this challenge. Addressing this will require a concerted effort from academia, applied research organizations, and industry, working together in an innovation chain.