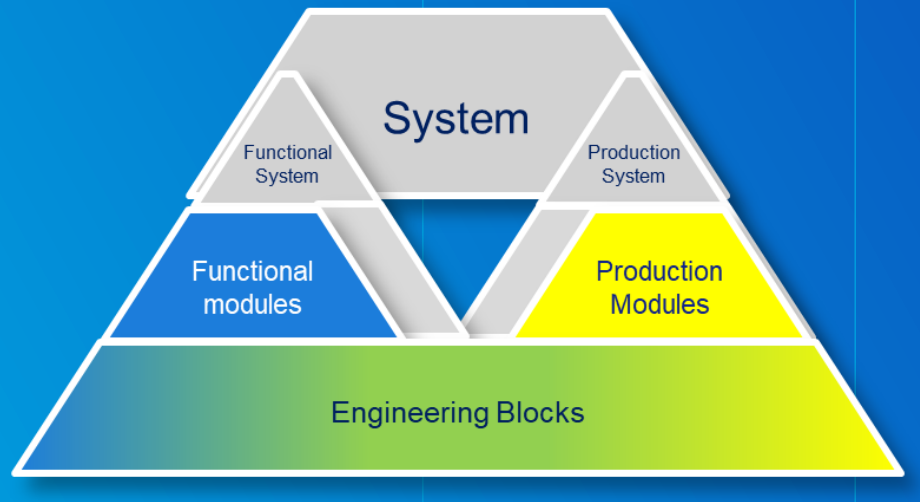


The role of the system model in the digital thread

Capella Days 2021

dr. ir. Jonnro Erasmus
System Architect – EUV Lithography

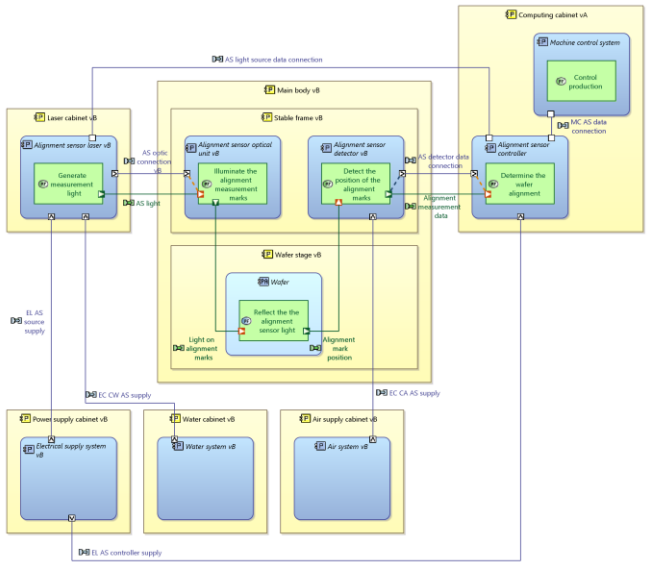
17 November 2021
Online

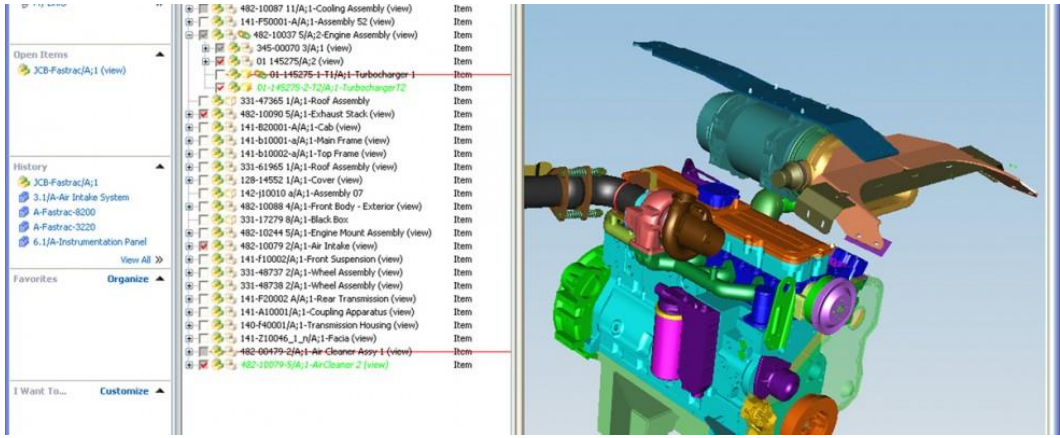
REVISION 1

Agenda

Introduction and overview

Introduction





We know MBSE is the way to go, but to what extent? Related to that, what do we expect from the model?

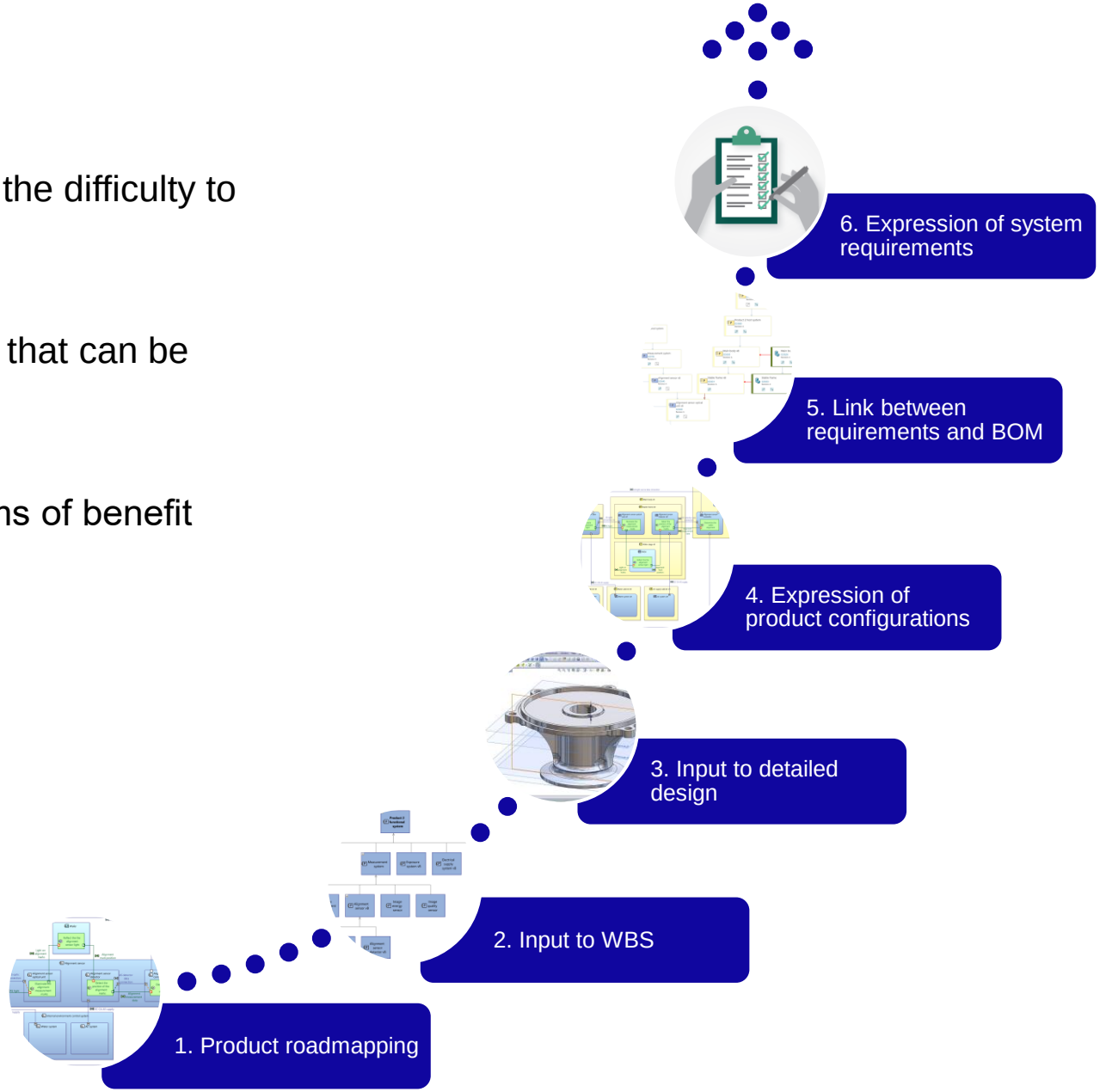
More specifically, what role does the system model play in the digital thread?

Objective statement

The expected value must be balanced with the difficulty to create and maintain the model.

This presentation aims to provide guidance that can be used to determine your level of ambition.

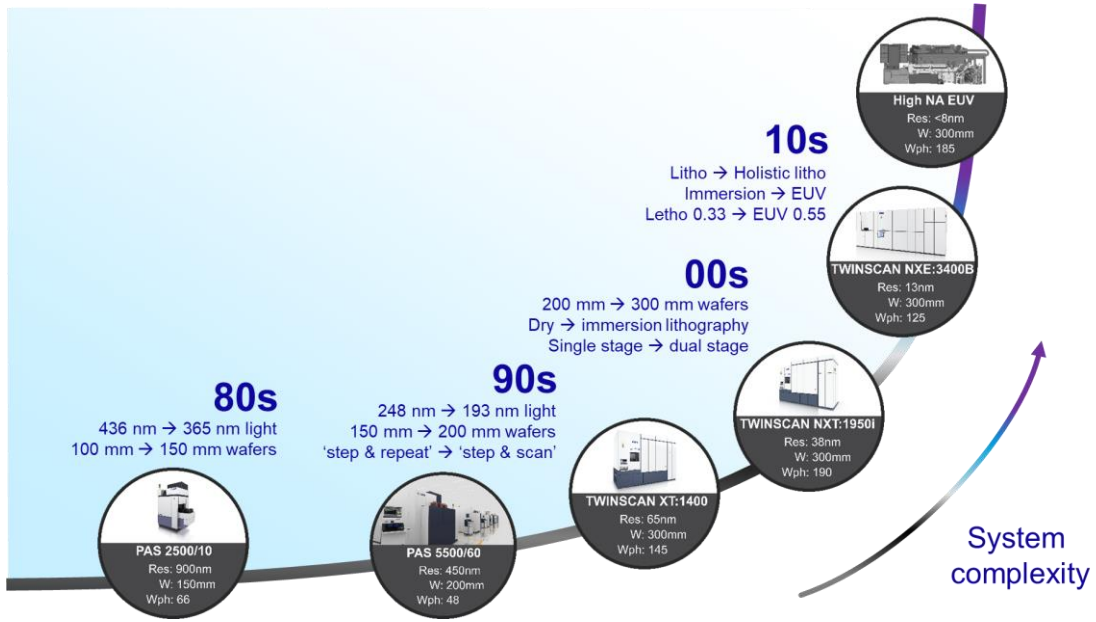
Each “level of ambition” is discussed in terms of benefit and cost.



Motivation

Why is this a question now?

Business pull



Information technology push

Capella™ + TEAMCENTER = SMW System Modeling Workbench

The architecture community collaboratively builds the system model using Team for Capella.

Then we publish the model to Teamcenter, making it available for downstream use.

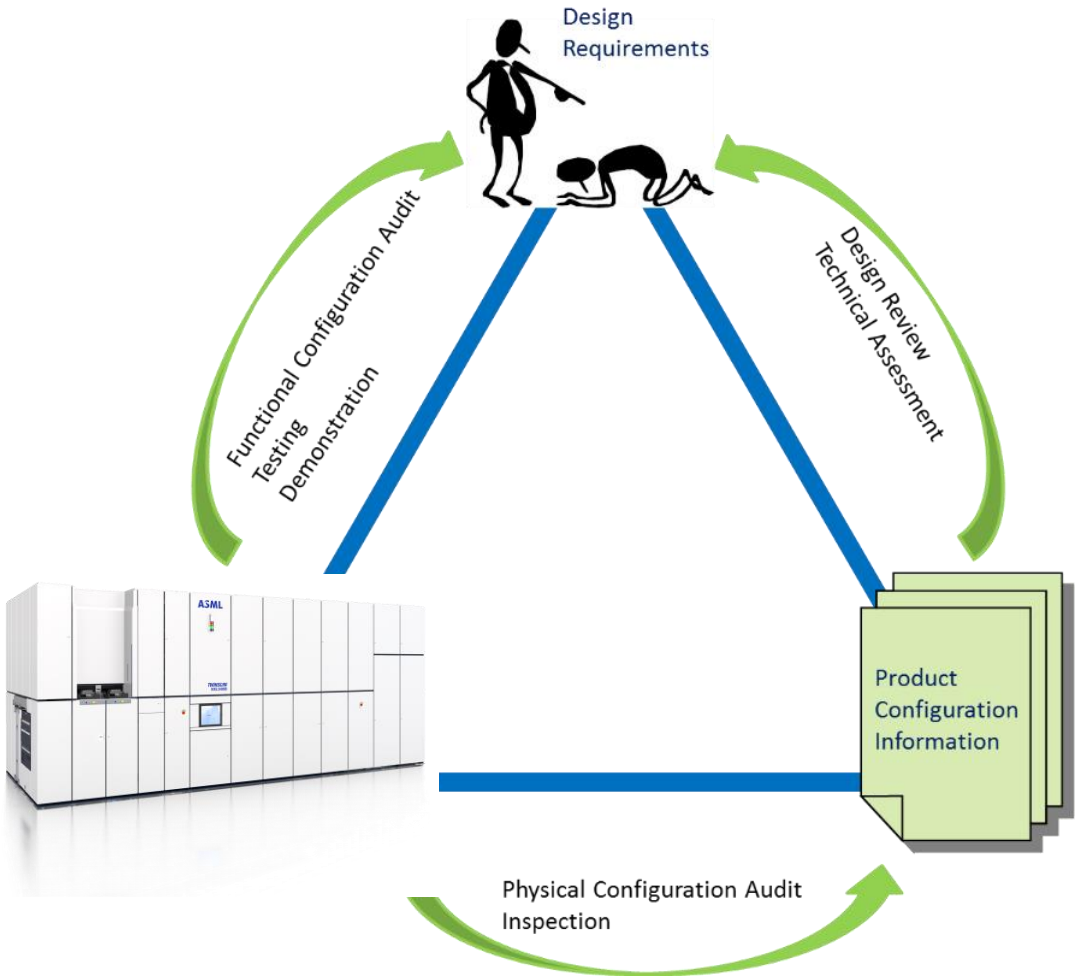
The digital thread

My view of configuration management

The objectives of configuration management are to:

1. establish consistency among design requirements, physical configuration, and documentation (including analysis, drawings, and procedures), and

2. maintain this consistency throughout the life of the product or activity, particularly as changes are being made.



DOE-STD-1073-2003 Configuration Management

The digital thread

My (simple) understanding of the digital thread

An SyRS Outline

Table of contents
List of figures
List of tables

1. Introduction

1.1 System purpose
1.2 System scope
1.3 Definitions, acronyms, and abbreviations
1.4 References
1.5 System overview

2. General system description

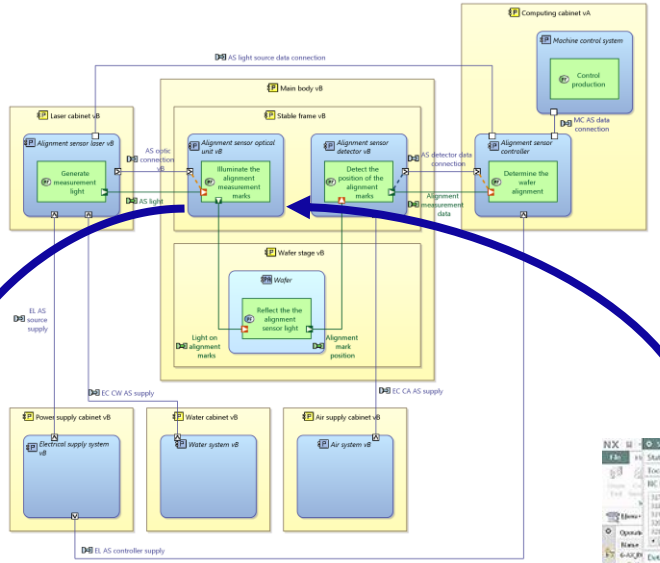
2.1 System context
2.2 System modes and states
2.3 Major system capabilities
2.4 Major system conditions
2.5 Major system constraints
2.6 User characteristics
2.7 Assumptions and dependencies
2.8 Operational scenarios

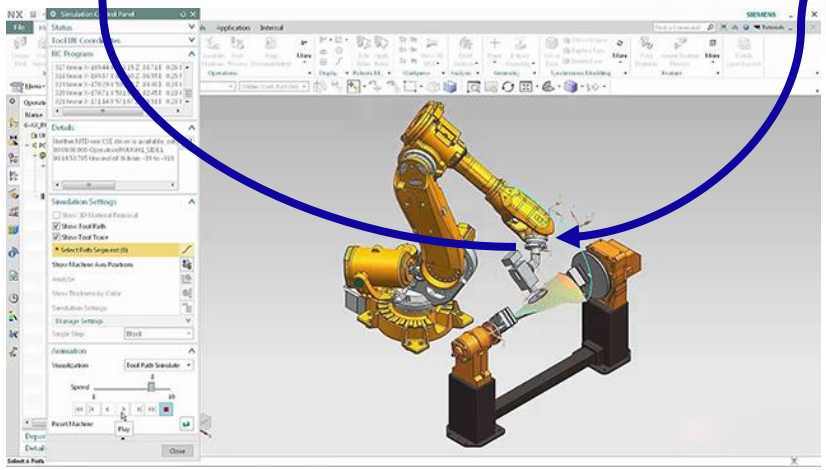
3. System capabilities, conditions, and constraints

NOTE—System behavior, exception handling, manufacturability, and deployment should be covered under each capability, condition, and constraint.

3.1 Physical
  3.1.1 Construction
  3.1.2 Durability
  3.1.3 Adaptability
  3.1.4 Environmental conditions
3.2 System performance characteristics
3.3 System security
3.4 Information management
3.5 System operations
  3.5.1 System human factors
  3.5.2 System maintainability
  3.5.3 System reliability
3.6 Policy and regulation
3.7 System life cycle sustainment

4. System interfaces

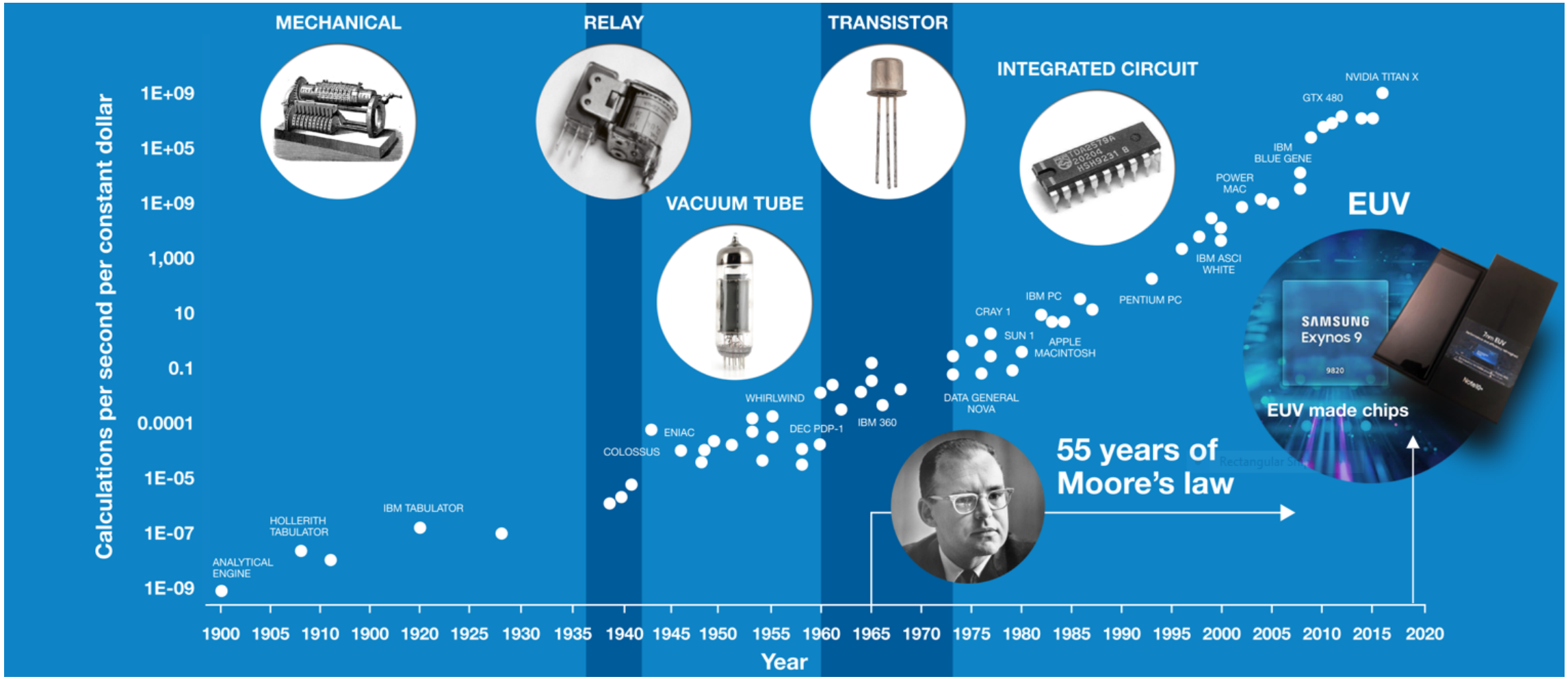




ASML introduction

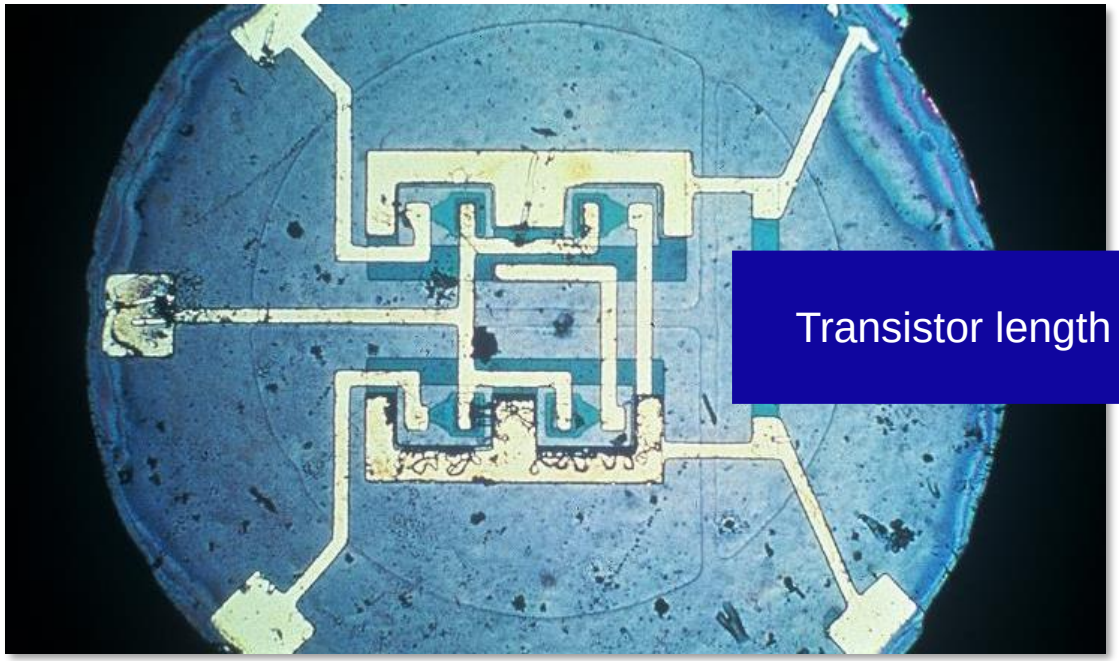
The world has been improving computer power for 120 years

18 orders of magnitude increase of calculation speed per dollar, and continuing

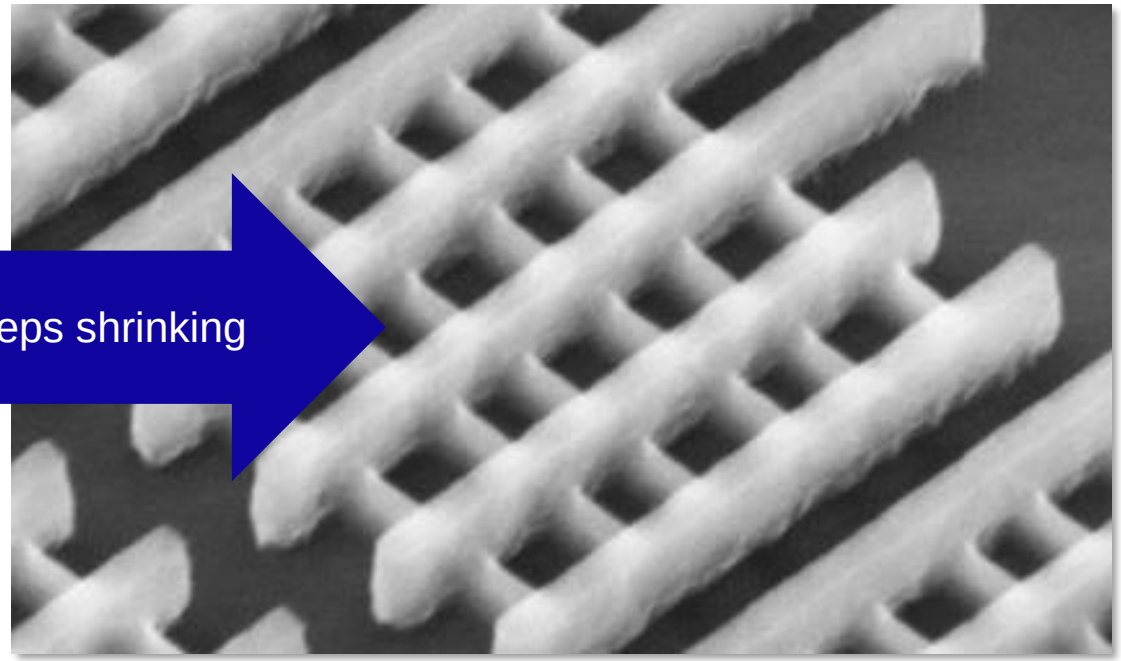


Source: Ray Kurzweil, Steve Jurvetson

Making smaller transistors...



Transistor length keeps shrinking



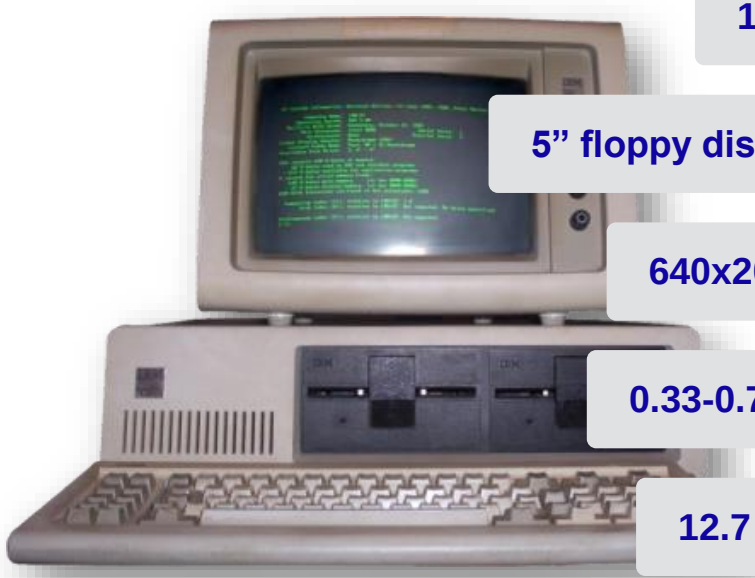
The first integrated circuit on silicon, on a wafer the size of a fingernail

(Fairchild Semiconductor, 1959)

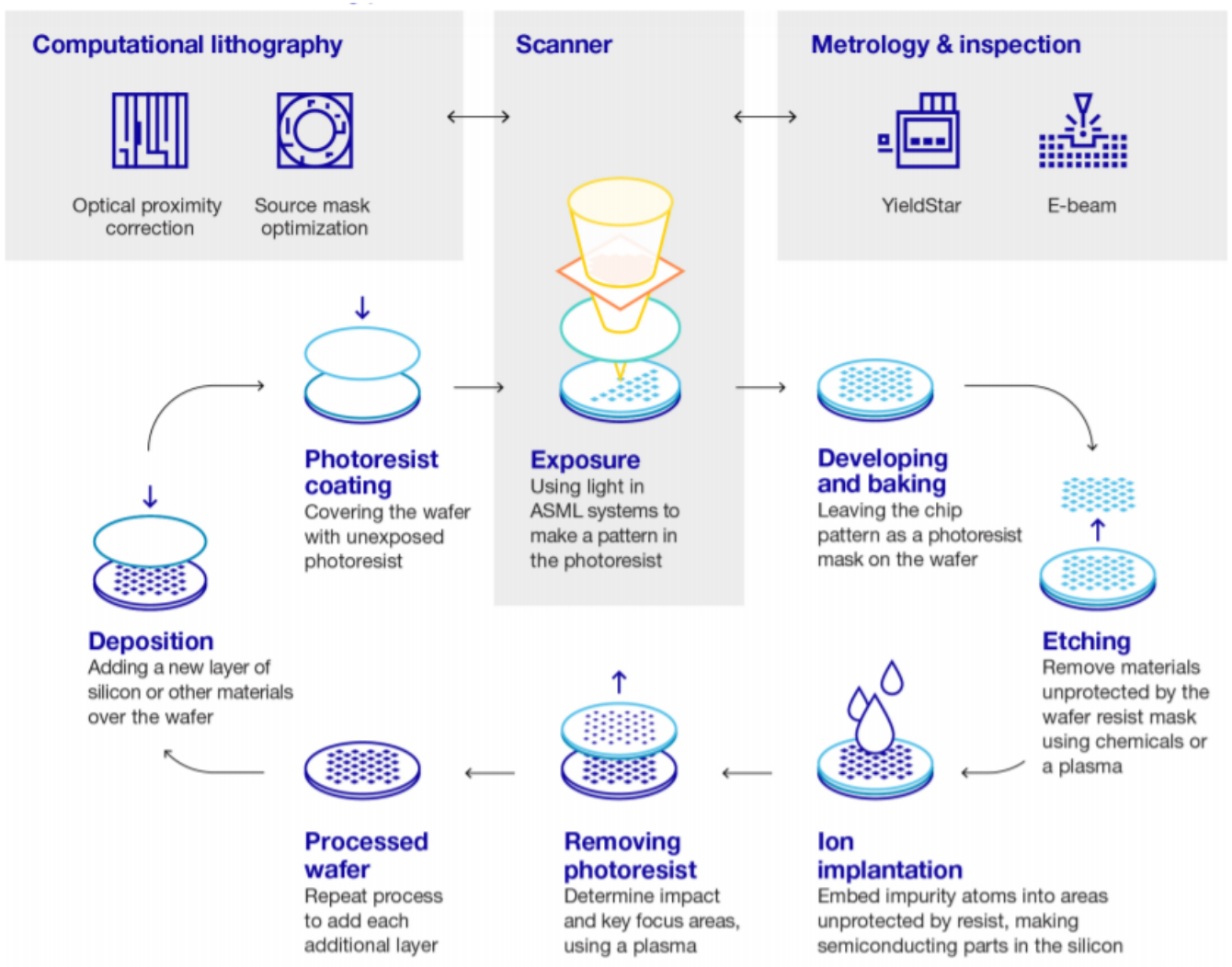
Today: Billions of transistors on the same area

… resulting in much more powerful electronic devices

IBM 5150		Apple iPhone 13 Pro
1984	year manufactured	2021
$1500-$3000 ($3500-$7000 today)	price	$999-$1299
16-bit Intel 8088 4.77 MHz	processor	Apple A15 bionic chip (5 nm EUV)
16-265 kB	working memory	6 GB
5” floppy disk 160 kB	internal storage	up to 1 TB
640x200 pixels	monitor	2532 x 1170 pixels
0.33-0.75 million	instructions per sec	16 trillion
12.7 kilogram	weight	203 grams



The semiconductor manufacturing loop



How a lithography system works

A chip is made of dozens of layers

ASML technology

This is why we are contemplating the central question.

R&D is our life blood: this is how we push technology further

Our R&D investments amount to >€2 billion per year

1980s:

PAS 2000/5000

1990s:

PAS 5500

2000s:

TWINSCAN

2010s:

EUV

2020s:

High-NA EUV

Lithography innovation keeps chip manufacturing affordable

80s

436 nm → 365 nm light
100 mm → 150 mm wafers

90s

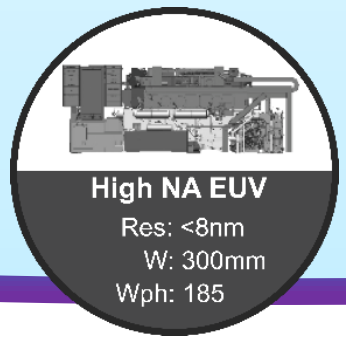
248 nm → 193 nm light
150 mm → 200 mm wafers
'step & repeat' → 'step & scan'

00s

200 mm → 300 mm wafers
Dry → immersion lithography
Single stage → dual stage

10s

Litho → Holistic litho
Immersion → EUV
Letho 0.33 → EUV 0.55



Relative cost per pixel

Technology-wise, we had to move mountains

Sometimes it seemed impossible– until we did it

80s

436 nm → 365 nm light
100 mm → 150 mm wafers

90s

248 nm → 193 nm light
150 mm → 200 mm wafers
'step & repeat' → 'step & scan'

00s

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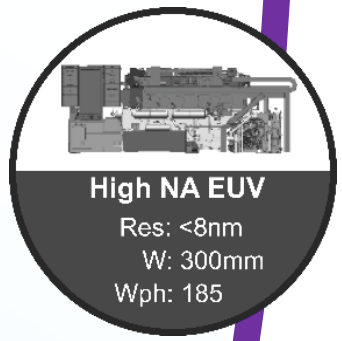
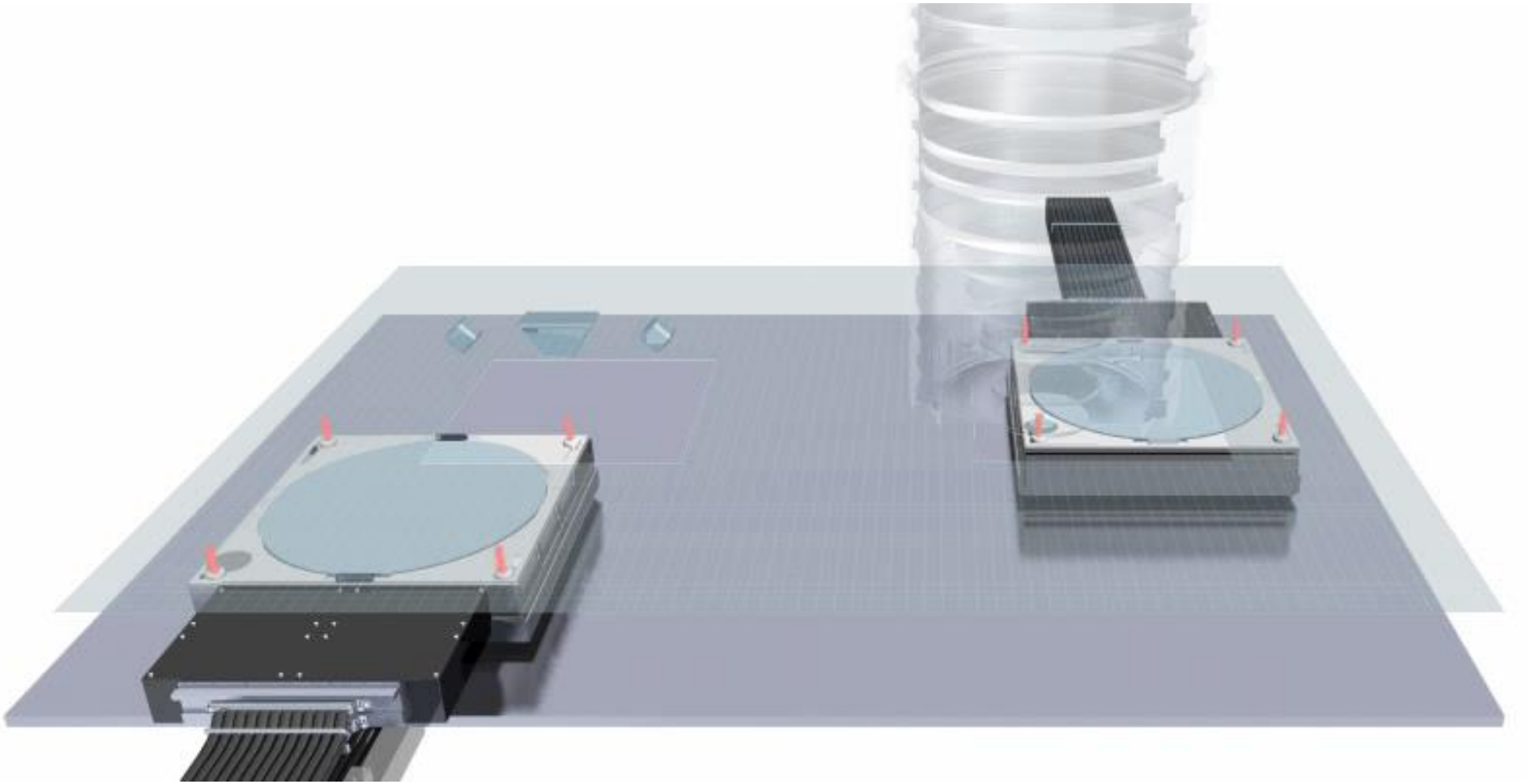
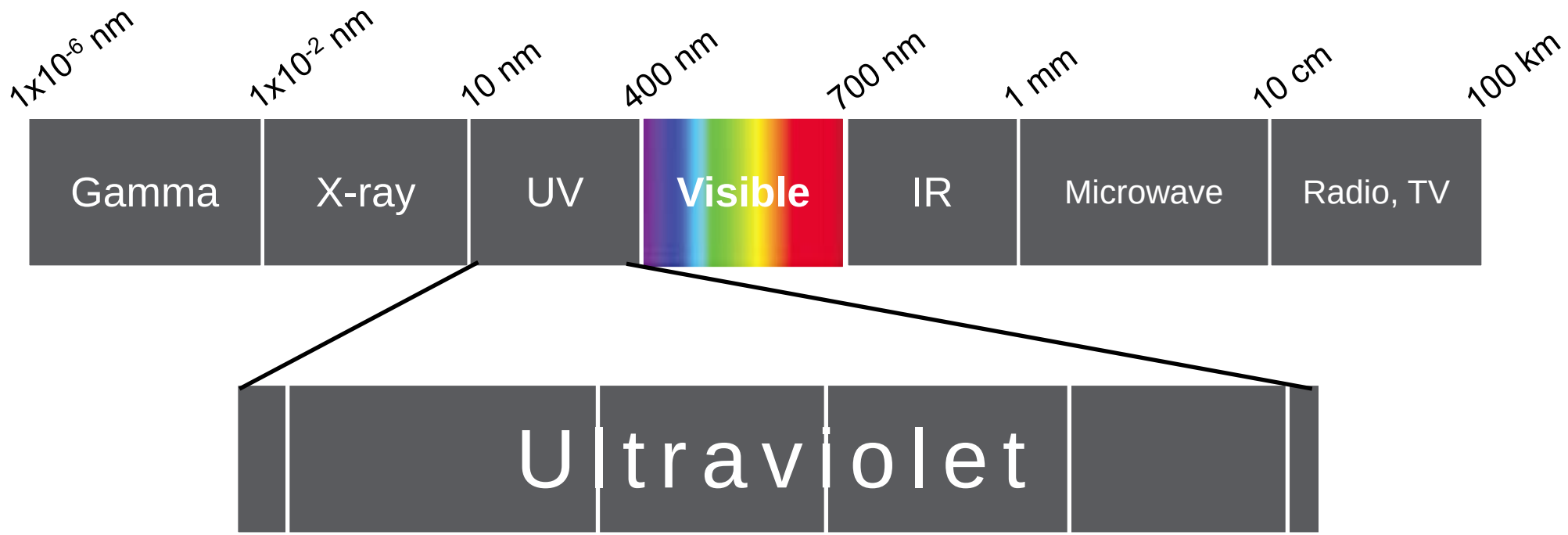


System complexity

Key innovation: TWINSCAN

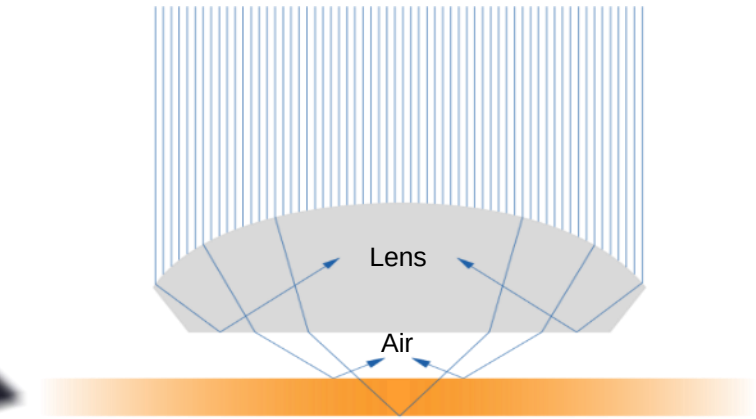


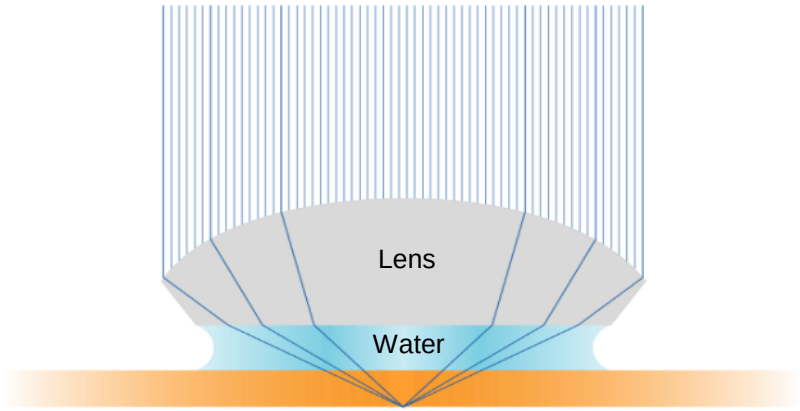
Key innovation: Wavelength changes



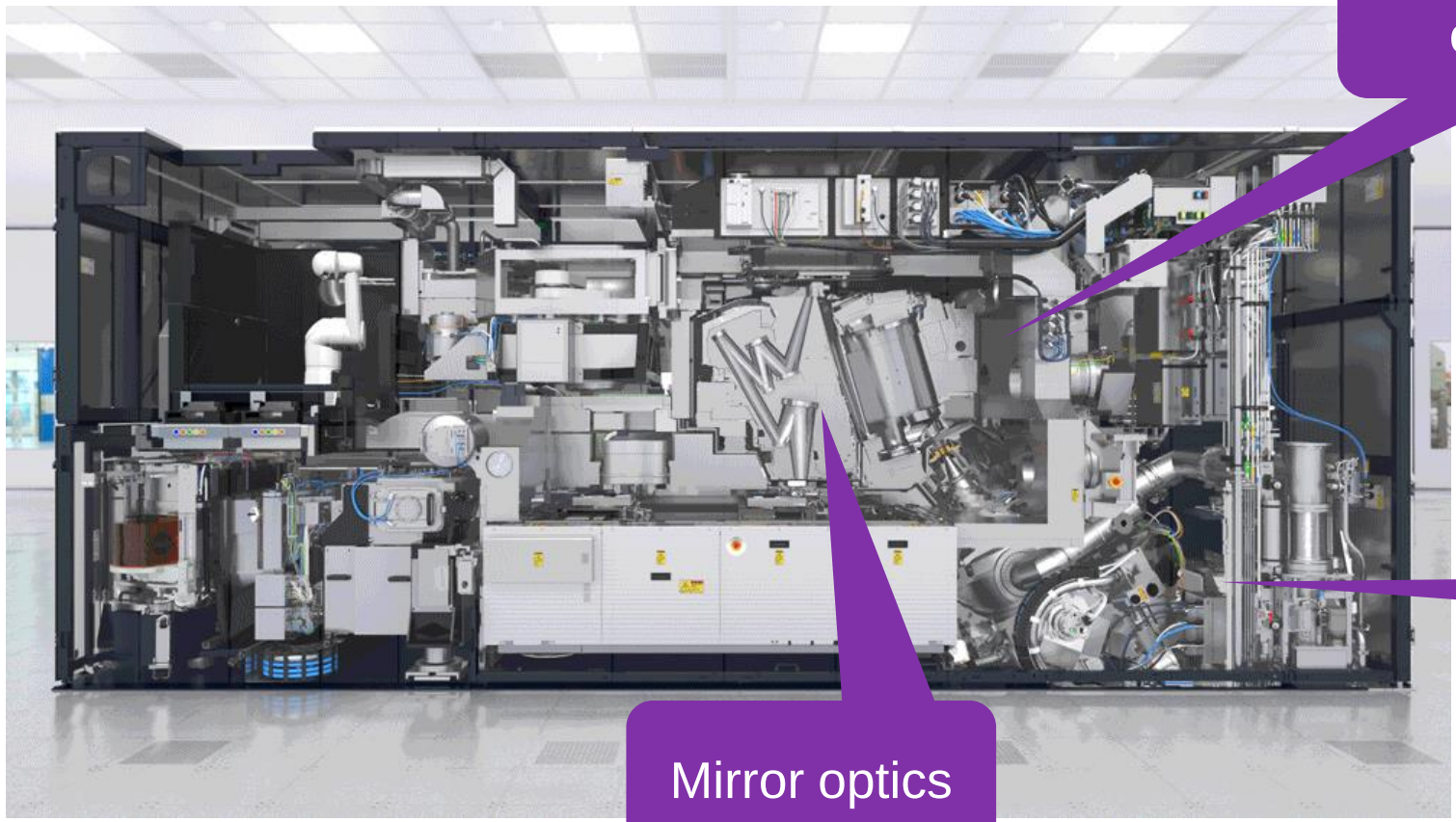
Wavelength	**13.5 nm**	**193 nm**	**248 nm**	**365 nm**	**436 nm**
Year	2011	2003	1992	1986	1984
Platform	EUV	Immersion	PAS 5500	PAS 5000	PAS 2000

Key innovation: Immersion lens

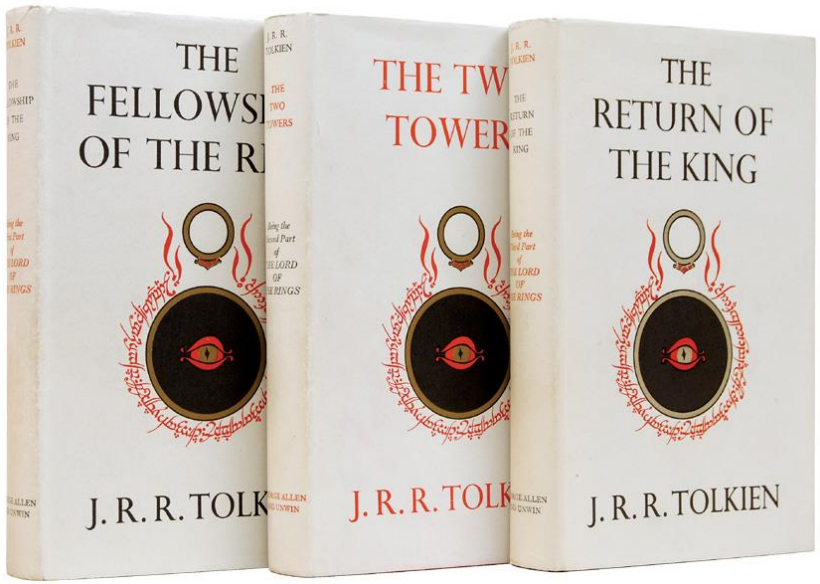




Key changes from DUV to EUV lithography



EUV’s crisper resolution means higher information density



EUV’s 13 nanometer resolution means that we could print the entire Lord of the Rings trilogy on the side of an A4 sheet of paper…

2,625 times!

In the world of EUV, everything is bigger

Transportation takes 40 containers, 20 trucks and 3 fully loaded 747s

NXE has over 100,000 individual parts, 3,000 cables, 40,000 bolts and 2 km of hosing…

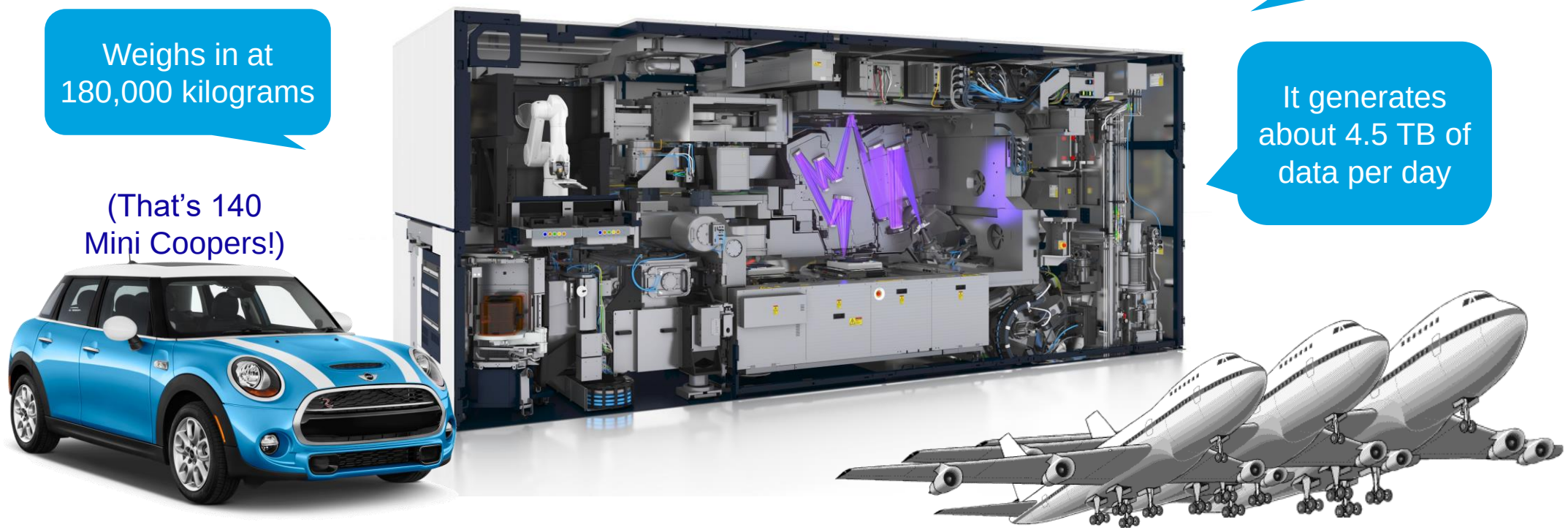
20 years of sustained R&D

Transportation takes 40 containers, 20 trucks and 3 fully loaded 747s

It has about 1,500 sensors to capture imaging data

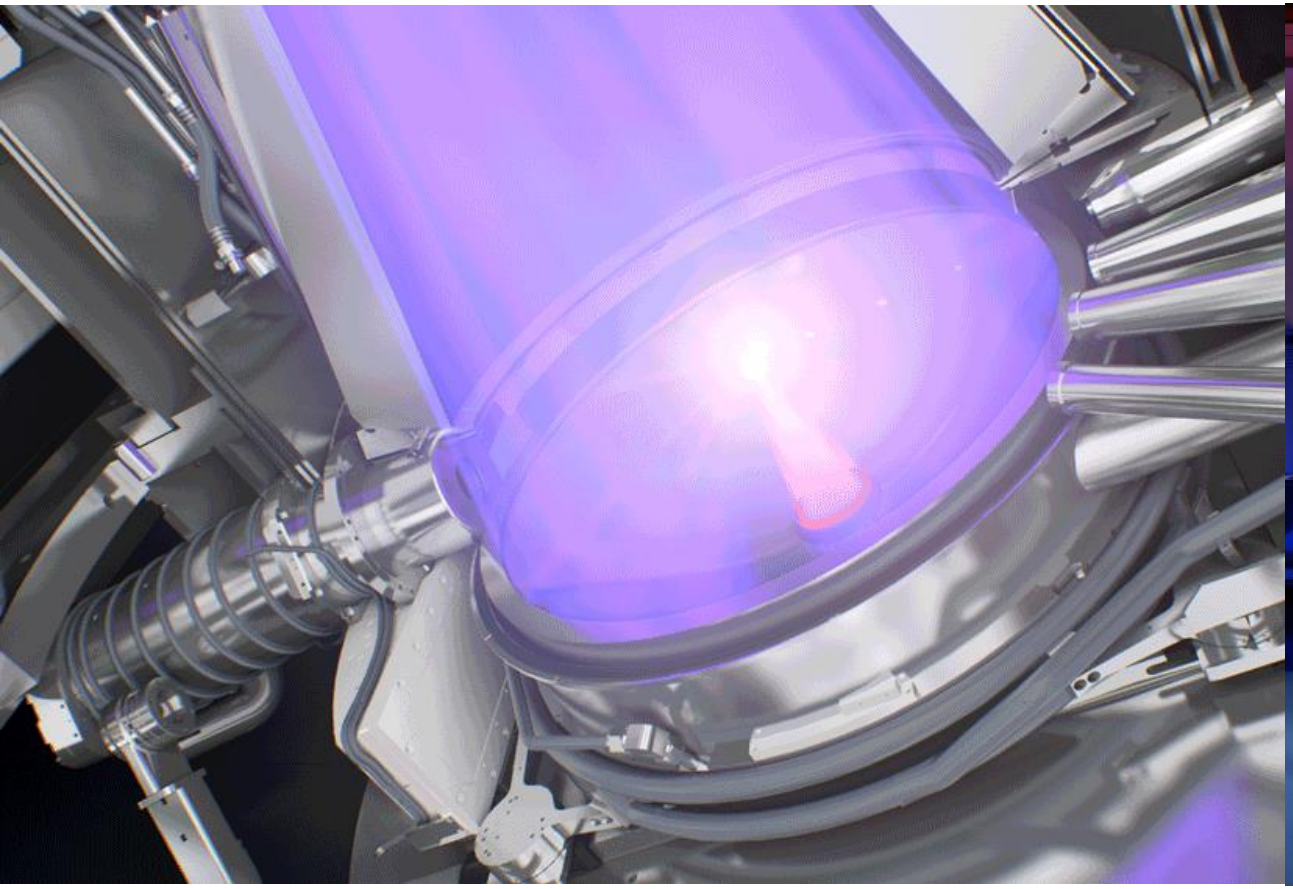
Weighs in at 180,000 kilograms

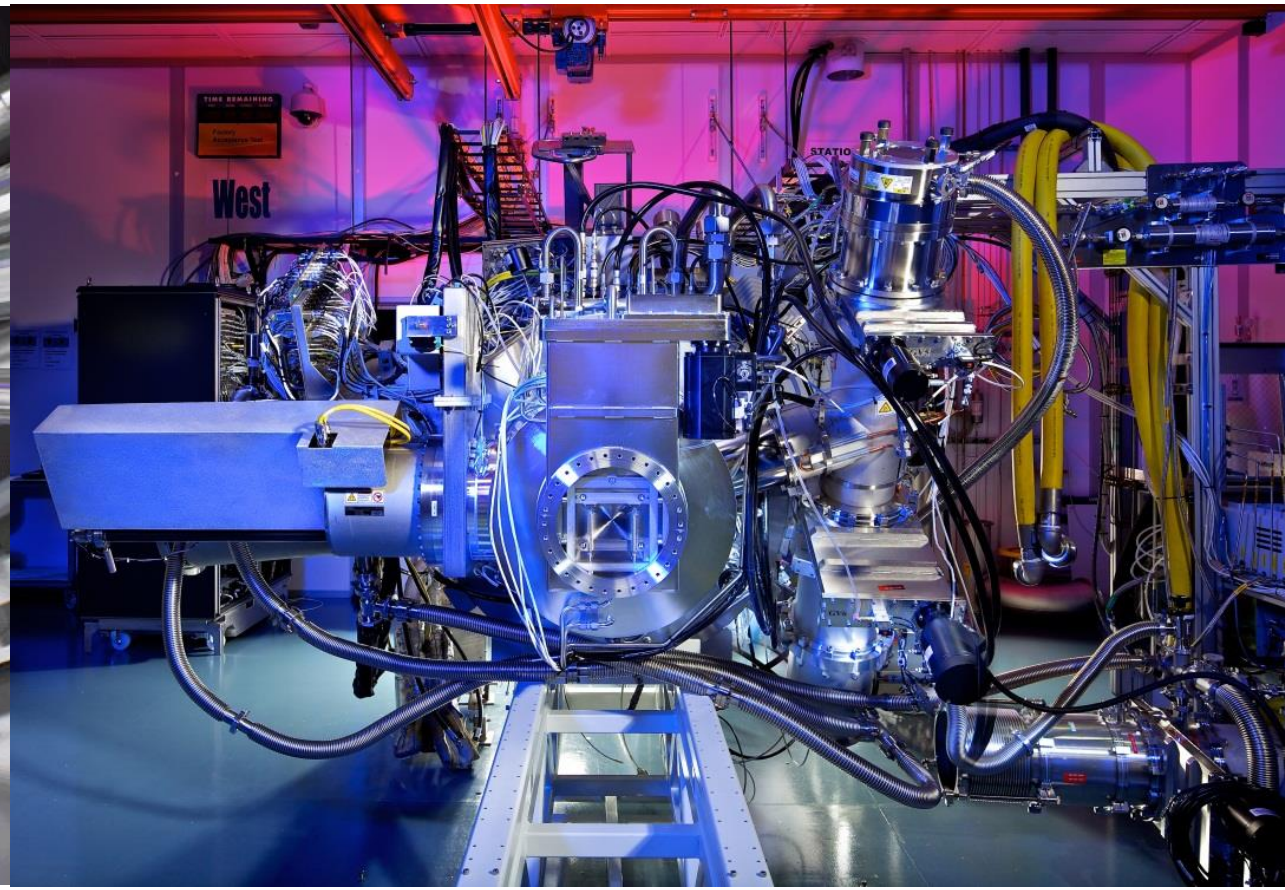
(That's 140 Mini Coopers!)



It generates about 4.5 TB of data per day

Firing a laser on a tin droplet 50,000 times a second



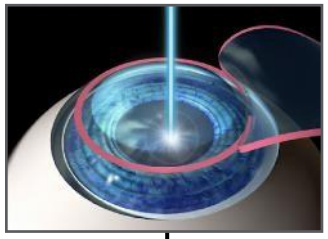


So, how strong is this CO_2 laser ?

Laser pen

1 mW

Laser surgery



50 - 250 mW

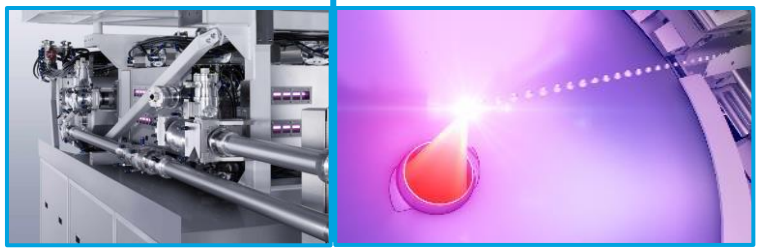
Laser blue ray

400 mW

Laser industrial cutting

1.5 – 6 kW

25 kW



Laser defense system

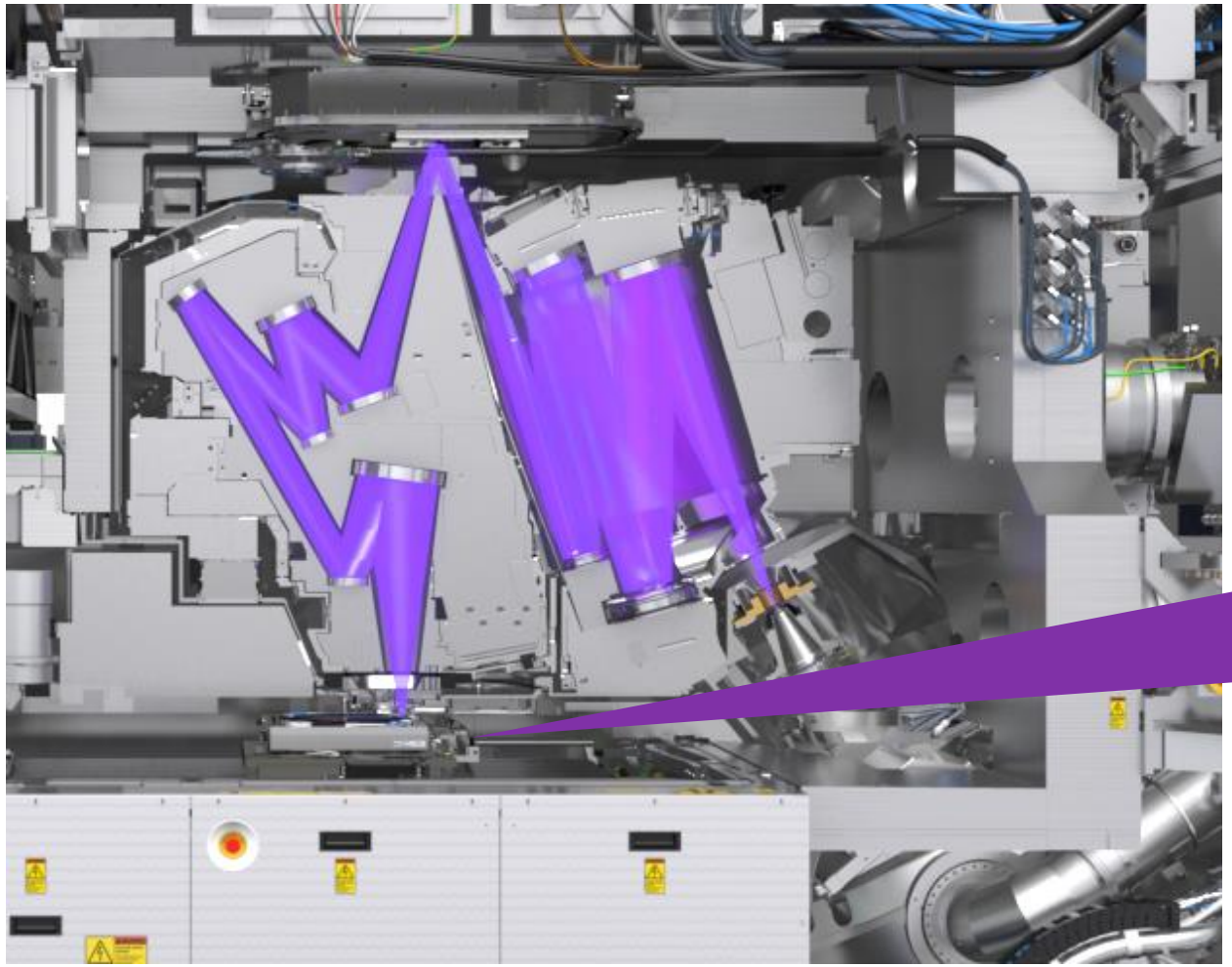
30 kW

Mirrors: Polished to sub-nanometer accuracy

EUV mirrors are polished to an accuracy of ~50 picometers – less than the diameter of a silicon atom.

Blown up to the size of Germany, the biggest difference in height would be less than a millimeter.

Maintaining a clean vacuum



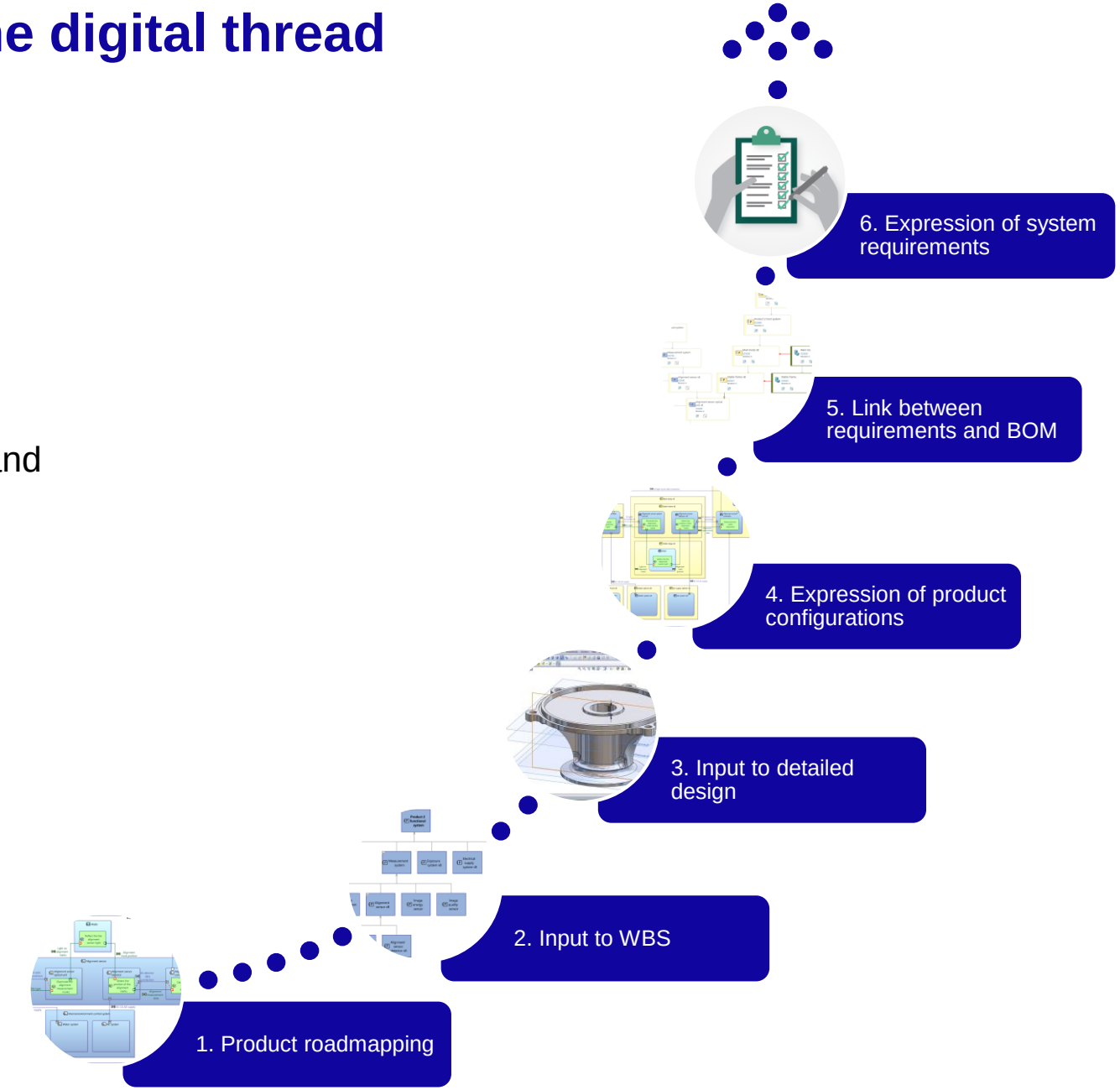
We need to maintain a clean vacuum, but every time we expose a wafer, the photoresist releases trillions of particles

The role of the system model in the digital thread

The role of the system model in the digital thread

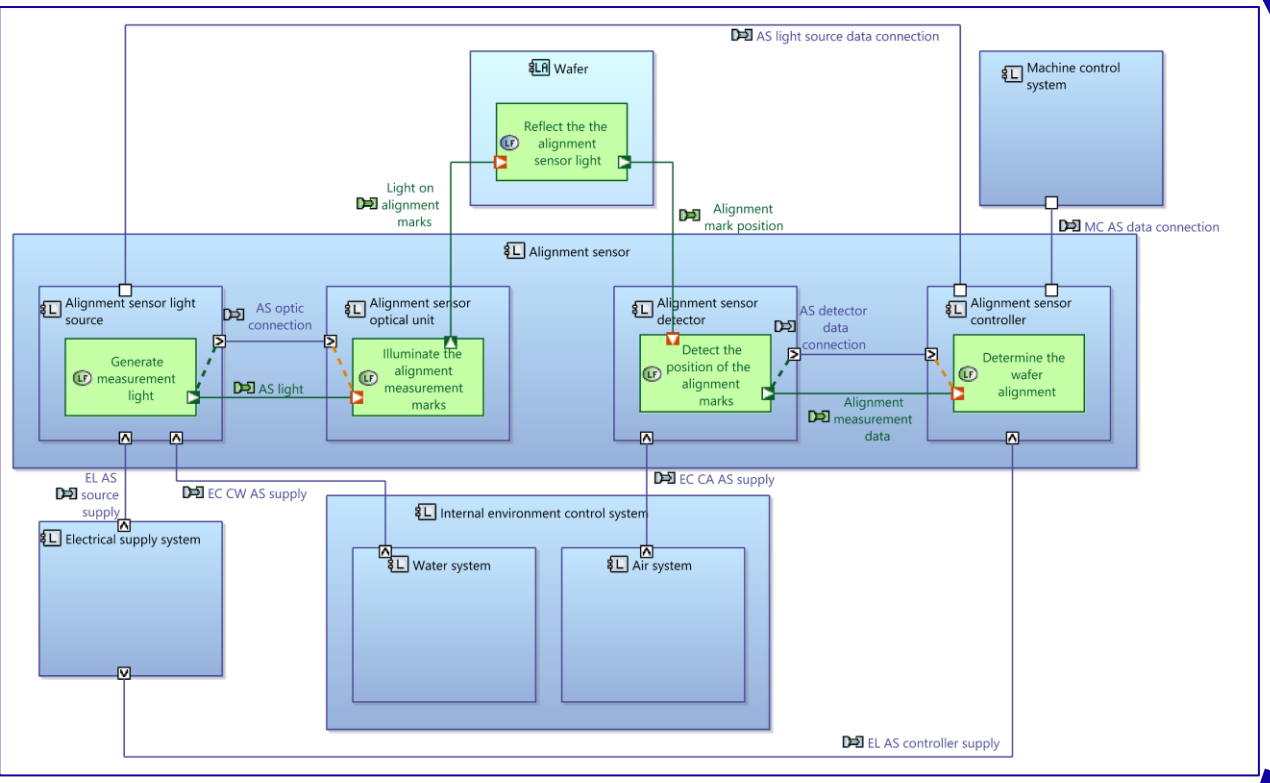
Roughly listed from easy to difficult.

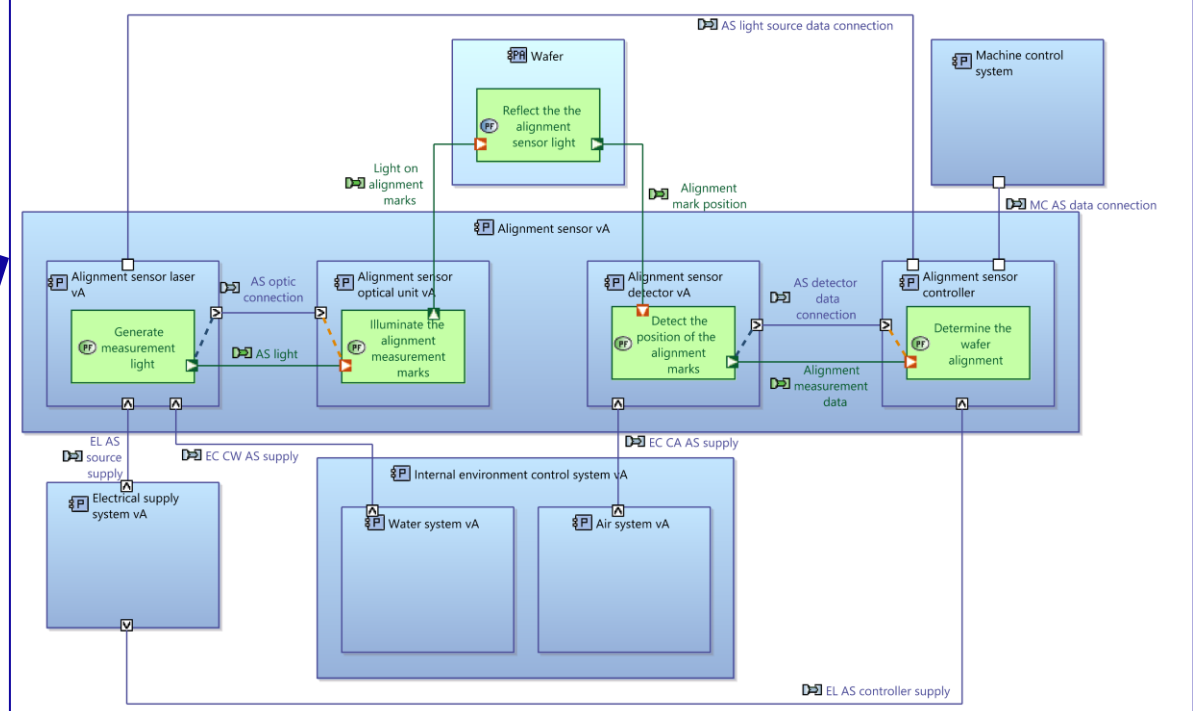
1. Product roadmapping.
2. The system model as input to the work breakdown structure.
3. The system model as input to the detailed design and engineering analyses.
4. The system model as an expression of product configurations (compatibility and commonality).
5. The system model as the link and/or translation between system requirements and BOM items.
6. The system model as a source of system requirements.

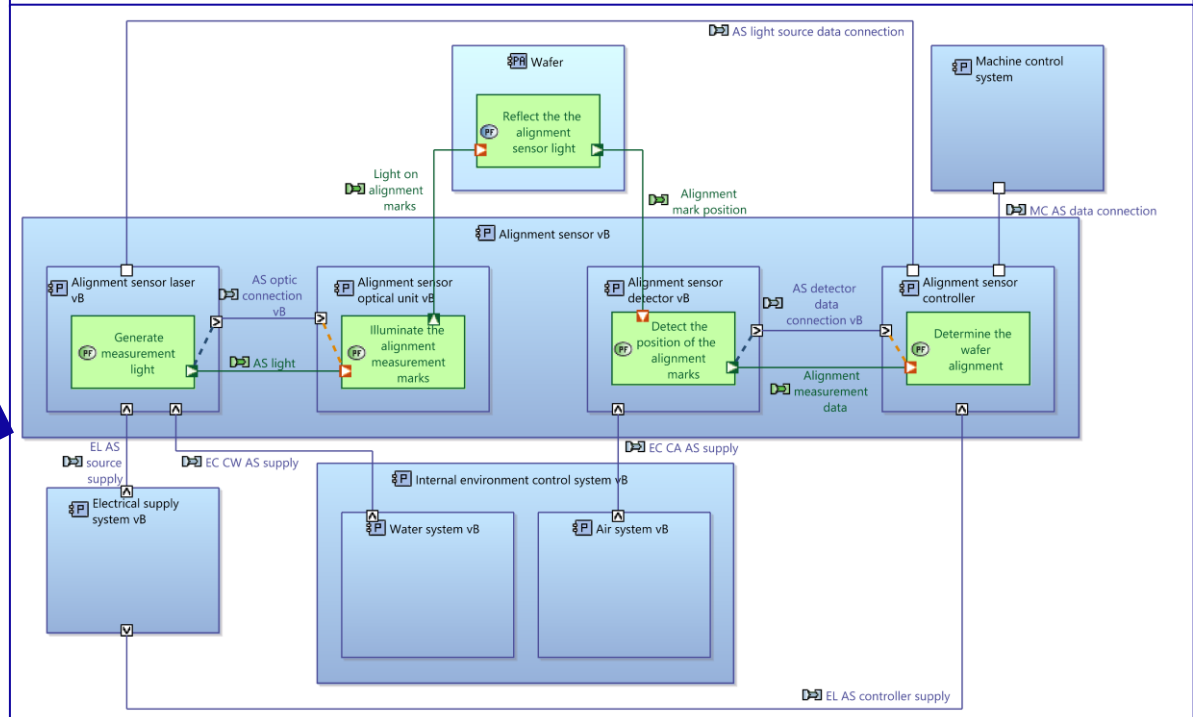


1. Product roadmapping

An architectural record of the product evolution



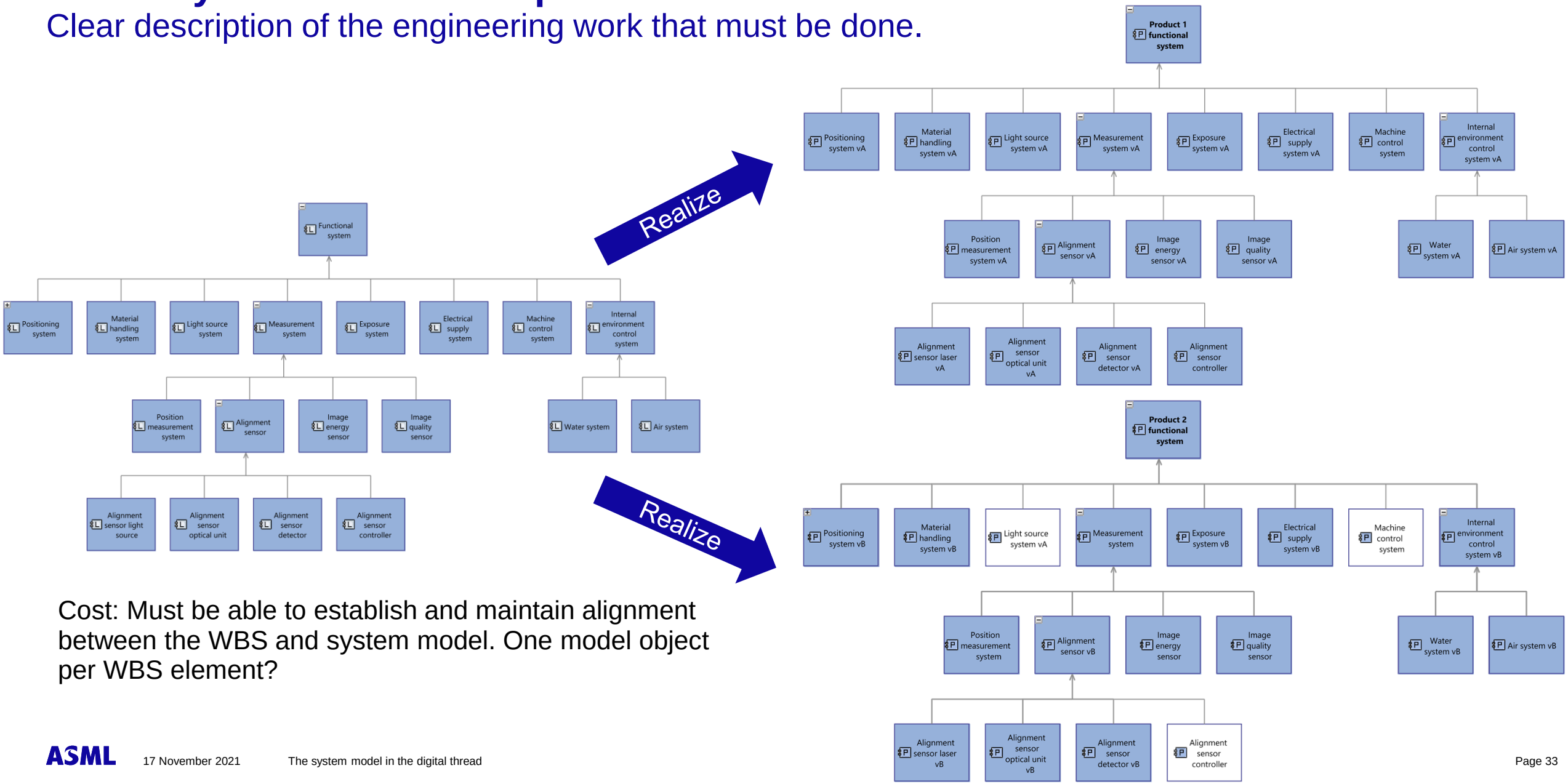




Practically no constraints on the modelling, apart from syntax.

2. The system model as input to the work breakdown structure

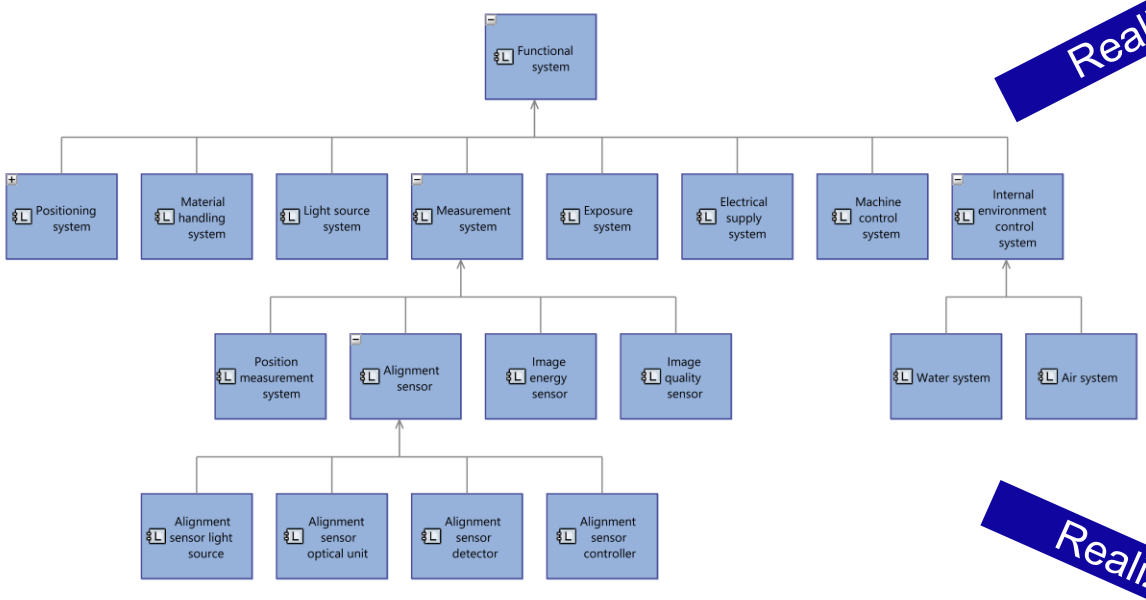
Clear description of the engineering work that must be done.



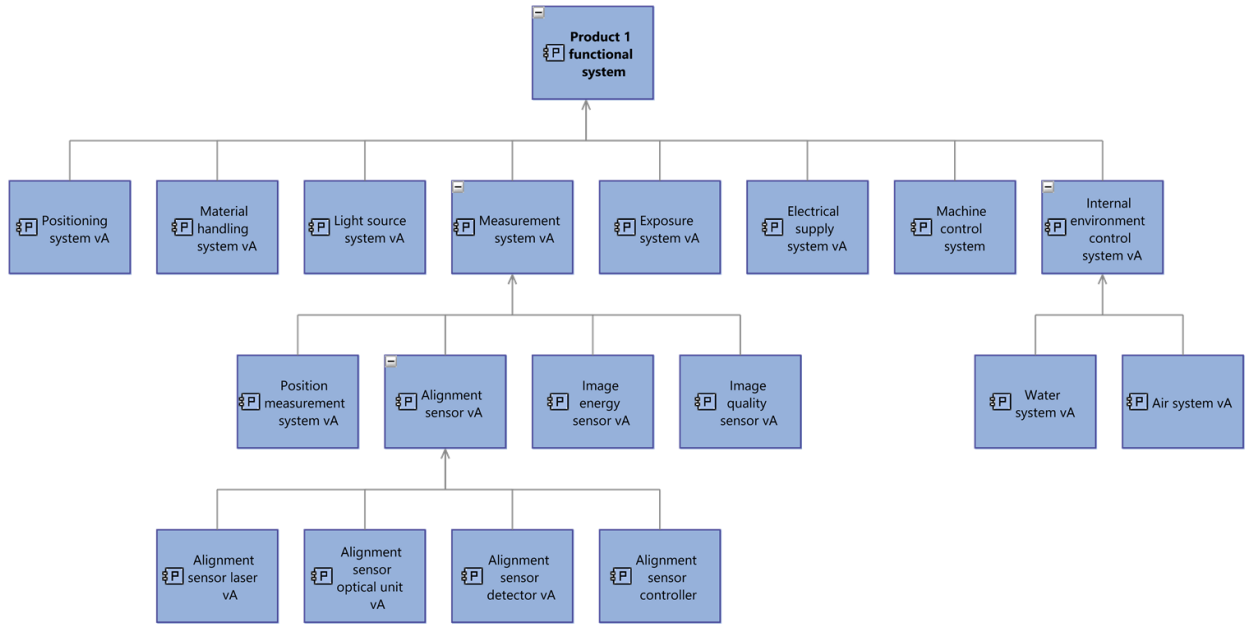
Cost: Must be able to establish and maintain alignment between the WBS and system model. One model object per WBS element?

2. The system model as input to the work breakdown structure

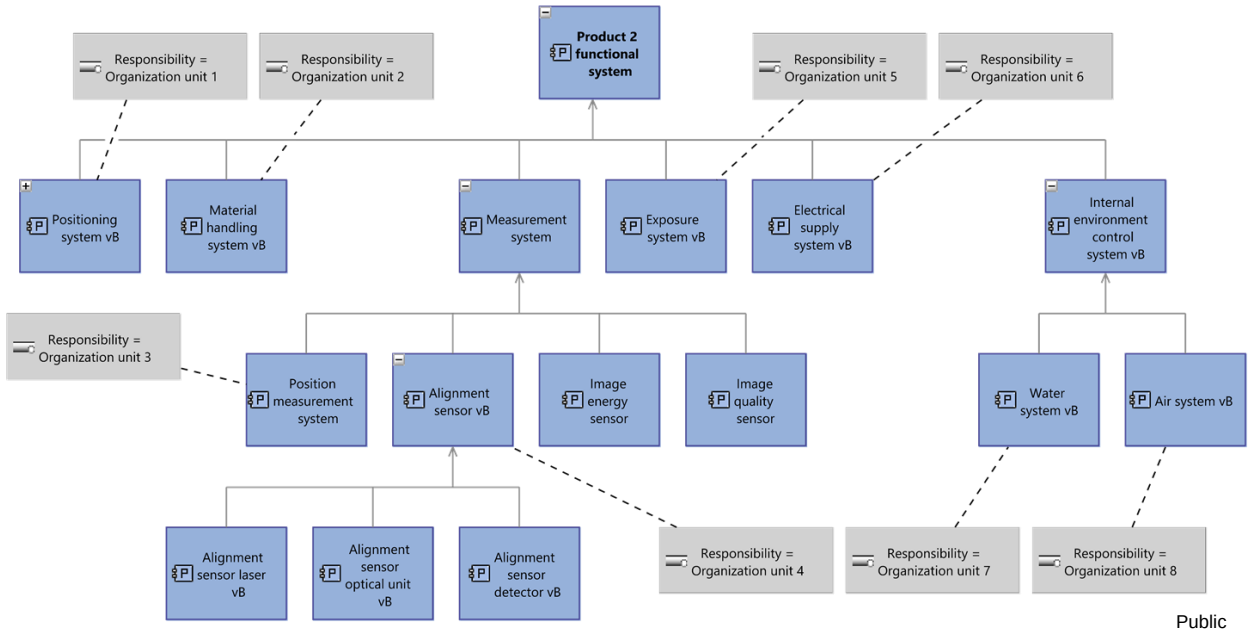
Assignment of responsibility and accountability.



Realize



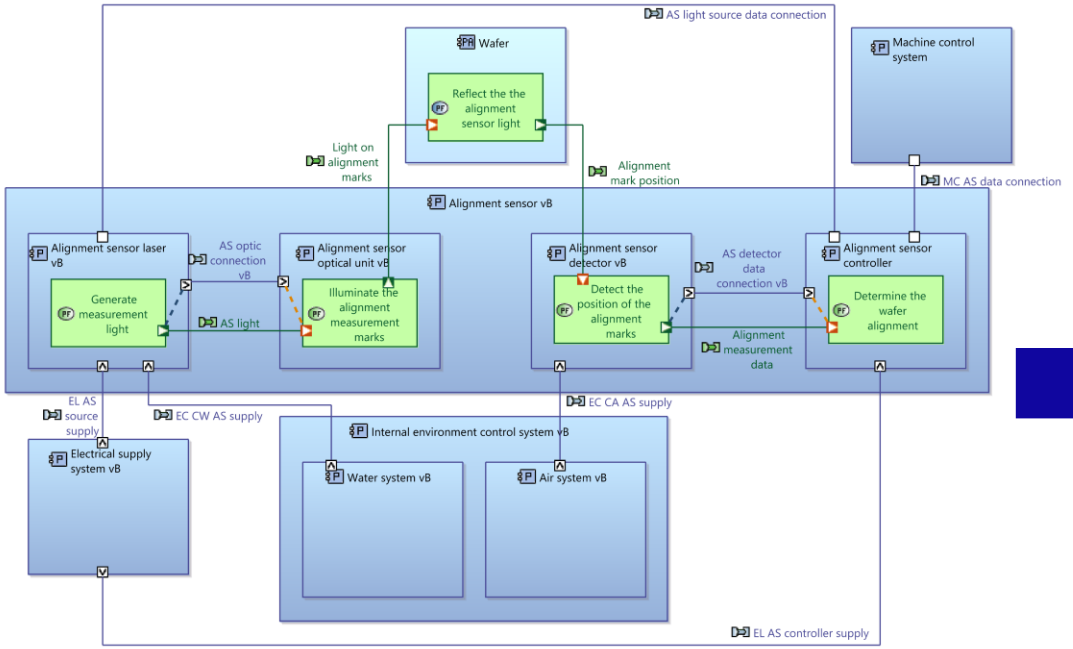
Realize



Cost: Organizational information must be captured and maintained in (relation to) the system model objects.

3. The system model as input to detailed design and engineering analyses

Centralized definition of functions and system elements that can be used in analyses.



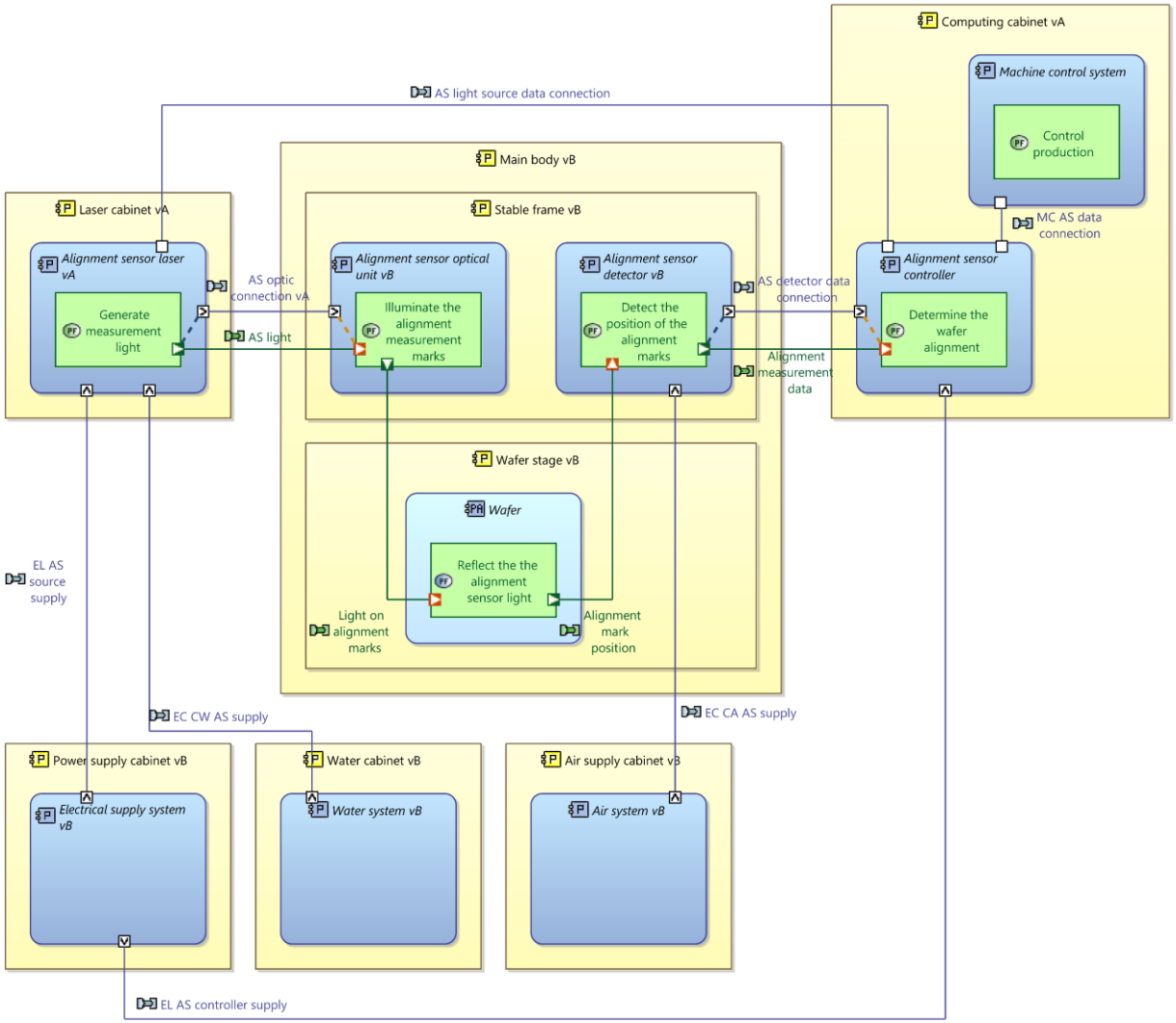
ID	Function Description	FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL EFFECT(S) OF FAILURE	SEV	CLASS	POTENTIAL CAUSE(S)/ MECHANISM(S) OF FAILURE	OCCUR	CURRENT DESIGN CONTROLS	DETECT	RPN	RECOMMENDED ACTION(S)	ACTION RESULTS SEV	OCC	DET	RPN	F	RPN/F
BB-2	**Analog Audio signals**	RX Path	Aux. Audio "Pop"	"Pops" heard when pressing On/Off switch	5		Wrong Integration	10	N/A	10	500	1. Add recommendations in Developer guide	5	3	10	150	1	350
												2. Integration with host product	5	2	10	100	5	80
BB-3	**Logic circuits & Memories**	Main functionality of the phone	Unit issues reset out and turns off at OS startup (after completing initialization) - logo presented	Phone is not functioning at all	8		Internal Discontinuity in PCB	7	N/A	10	560	1. Improve the vendor's process	8	2	10	160	9	44
												2. Add test at the vendor facility before shipping to Motorola for every batch (sampling)	8	3	10	240	4	80
												3. Add Acceptance Inspection (100% at Motorola door)	8	1	10	80	8	60
BB-5	**IGNITION**	No Ignition functionality	Radio doesn't turn on/off due to Ignition, but turns on/off from audio_out_onoff	Protection diode and resistor burn-out,	5		inadequate zener diode, burs out easily, drawing additional current through the resistor as well	10	N/A	10	500	1. Protection diode 2. Resistor derating	5	1	10	50	3	150
												3. Add testing in the Final Test	5	10	4	200	2	150
												Improve Design (1.2) & Increase Detectability (3)	5	1	4	20	3	160
RF-2	**RF TX Path**	timing error / Frequency error	TX parametric errors: timing error / Frequency error	Dropped calls.	7		1. Factory assembly defects. 2. Defective parts.	5	Tested any proto in extremes	9	315	Test 100% in factory.	7	5	1	35	3	93
			Damage to power amplifiers	Loss of radio fuctionality	8		High VSWR on the antenna ports Due to Damage to output cable / antenna	5	N/A	10	400	PA's specified to ruggedness of x:1 which is sufficient because of the loss from the PA output pin to the antenna ports.	8	1	10	80	2	160

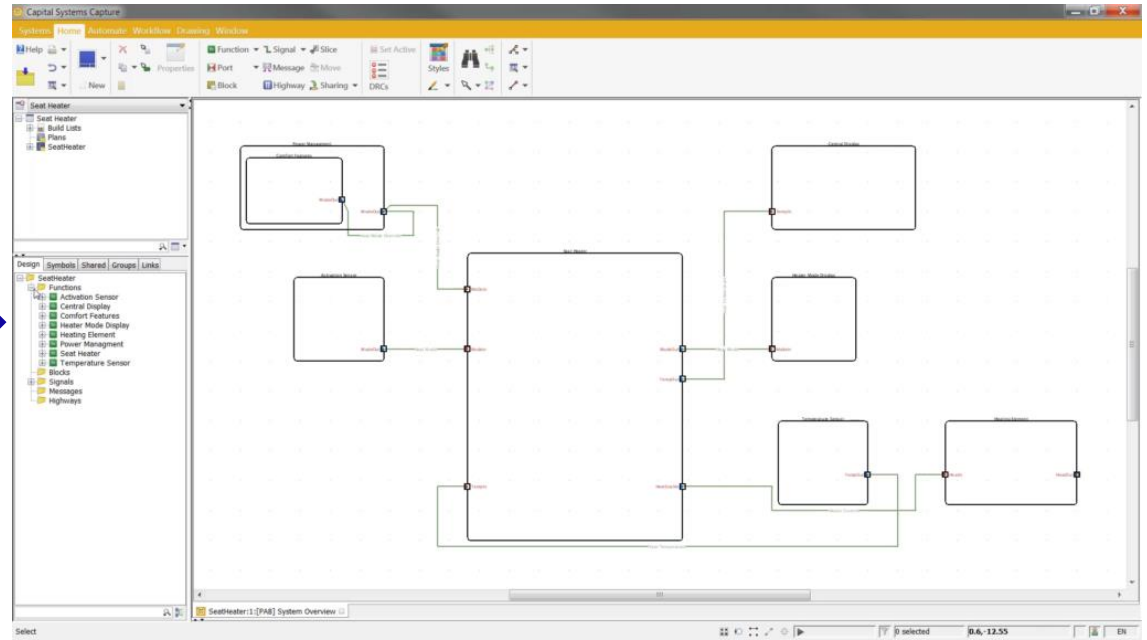
Cost: The system model must be an acceptably accurate representation of the product.

Blivband, Z., Grabov, P., Nakar, O., 2004. Expanded FMEA (EFMEA). Annual Symposium Reliability and Maintainability, 2004 - RAMS 31–36.

3. The system model as input to detailed design and engineering analyses

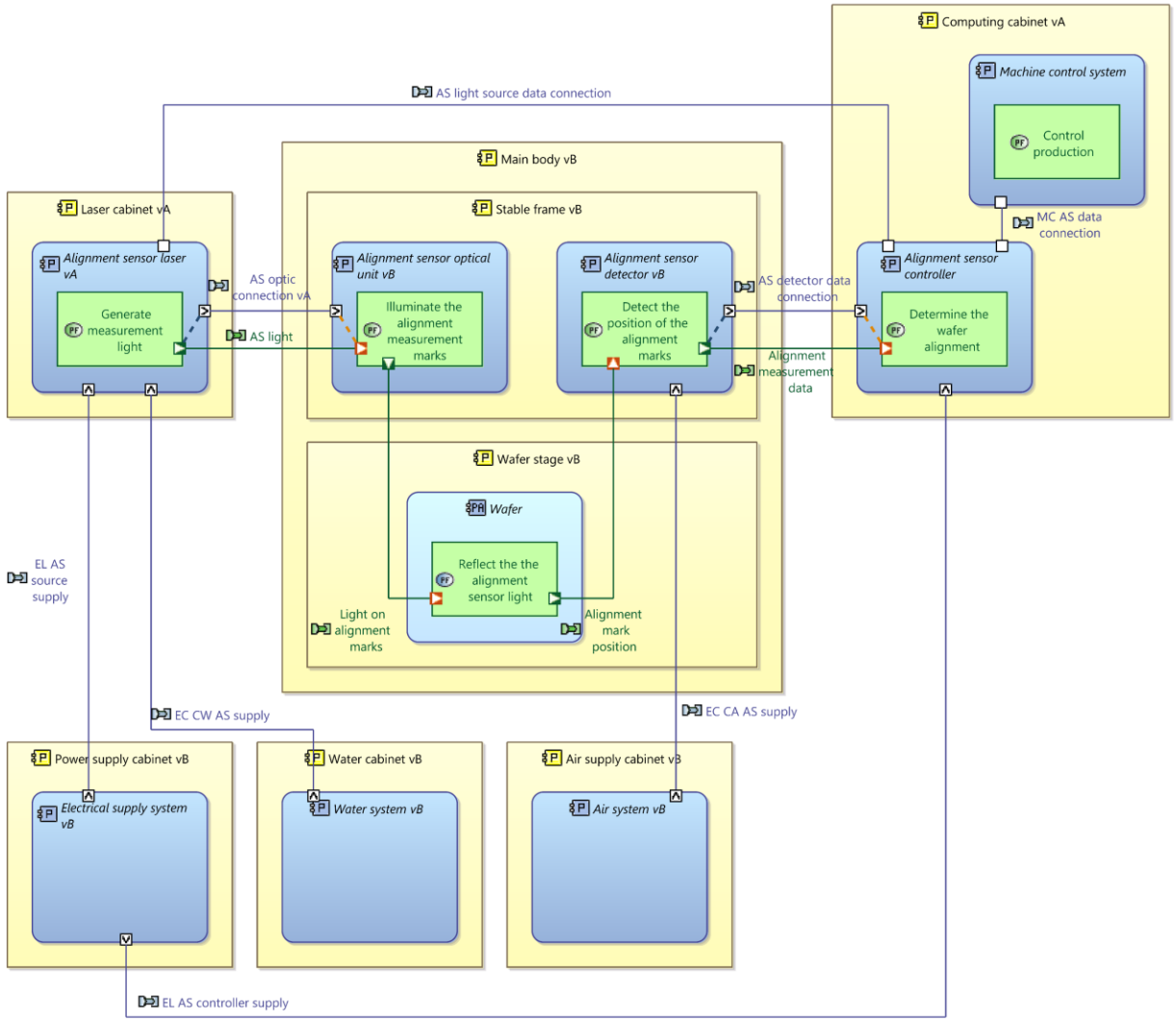
Delegation to engineering disciplines and specializations.

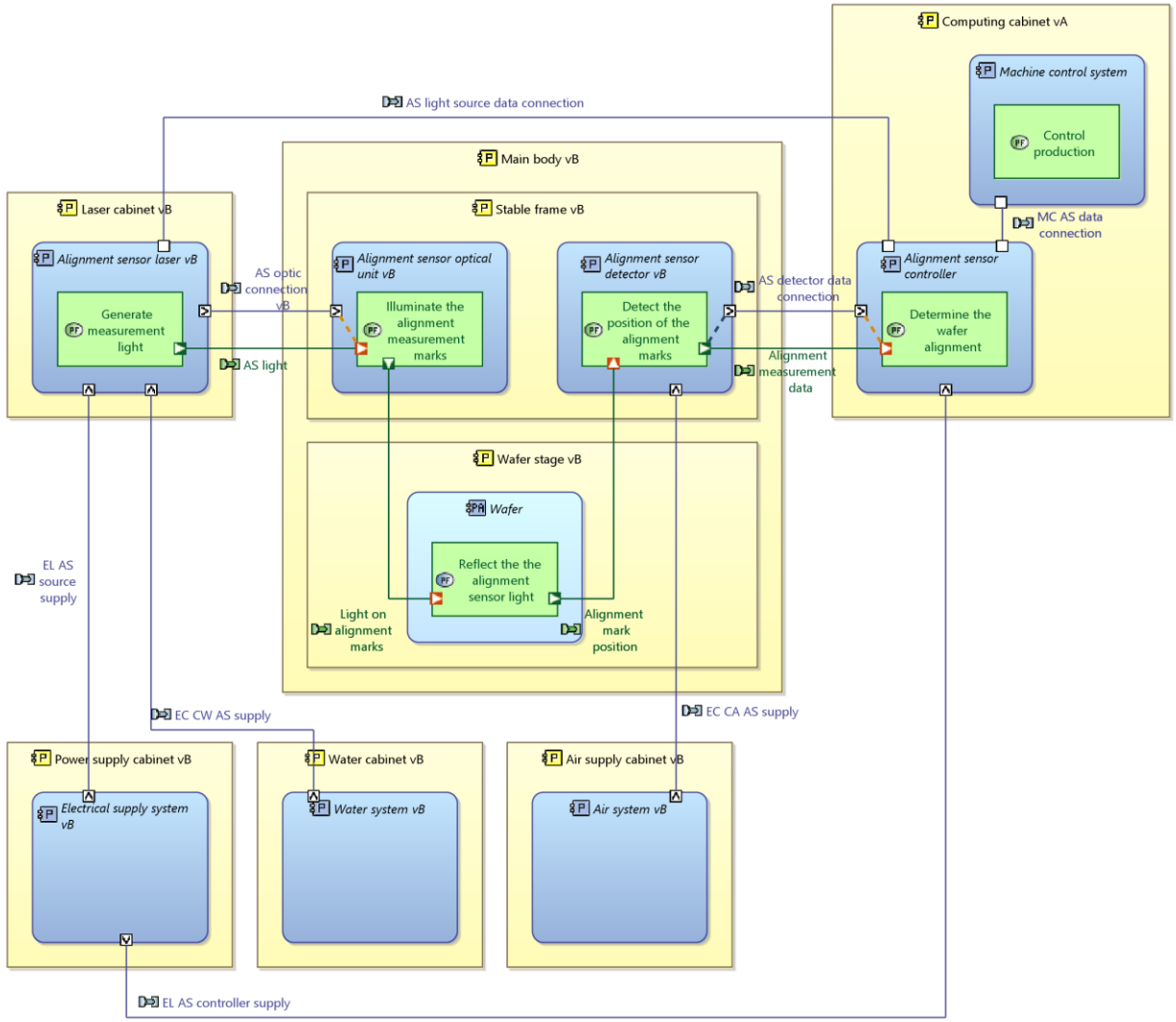




4. The system model as an expression of product configurations

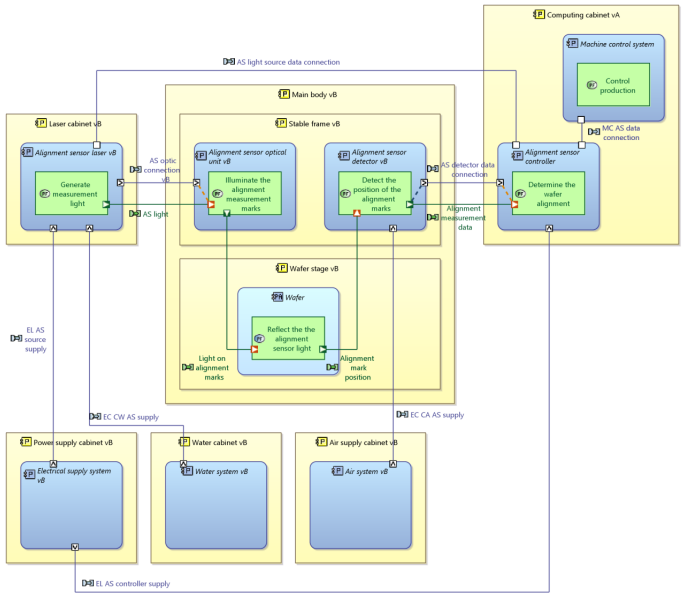
An expression of compatibility and commonality.

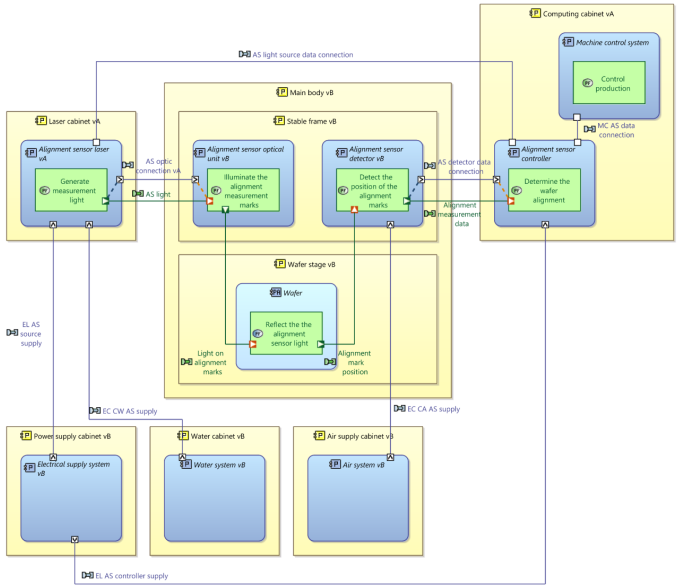


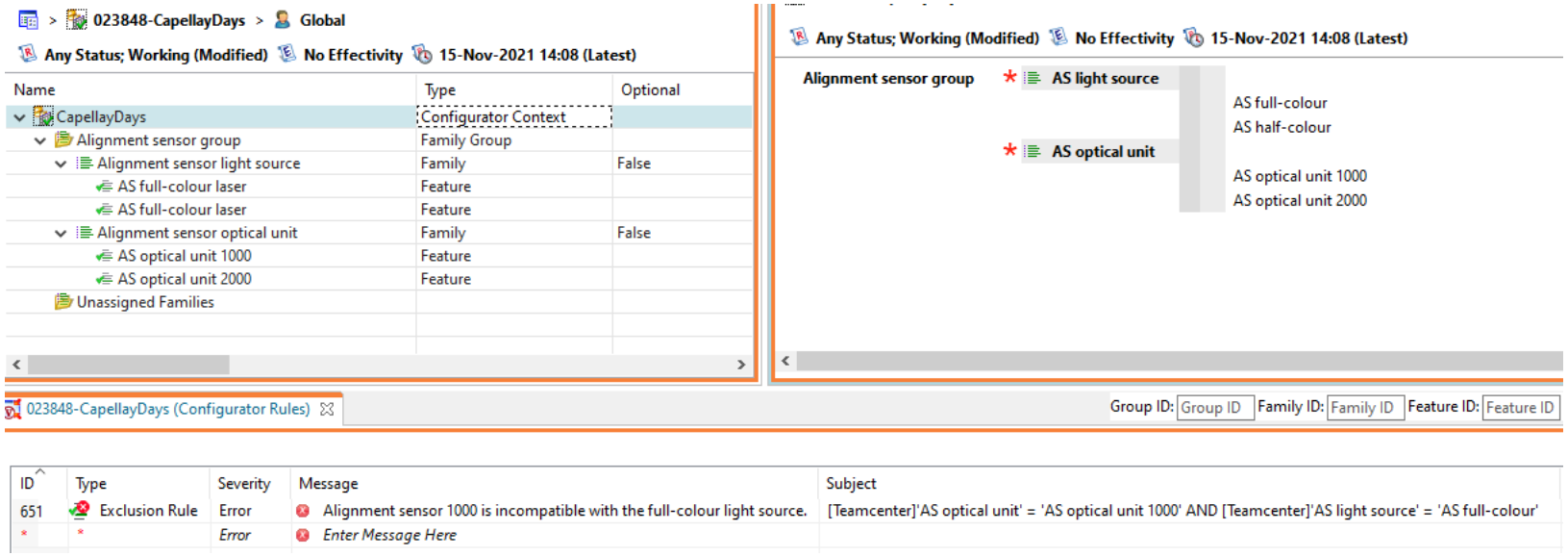


4. The system model as an expression of product configurations

Derive Production Configuration definitions and rules from the model.





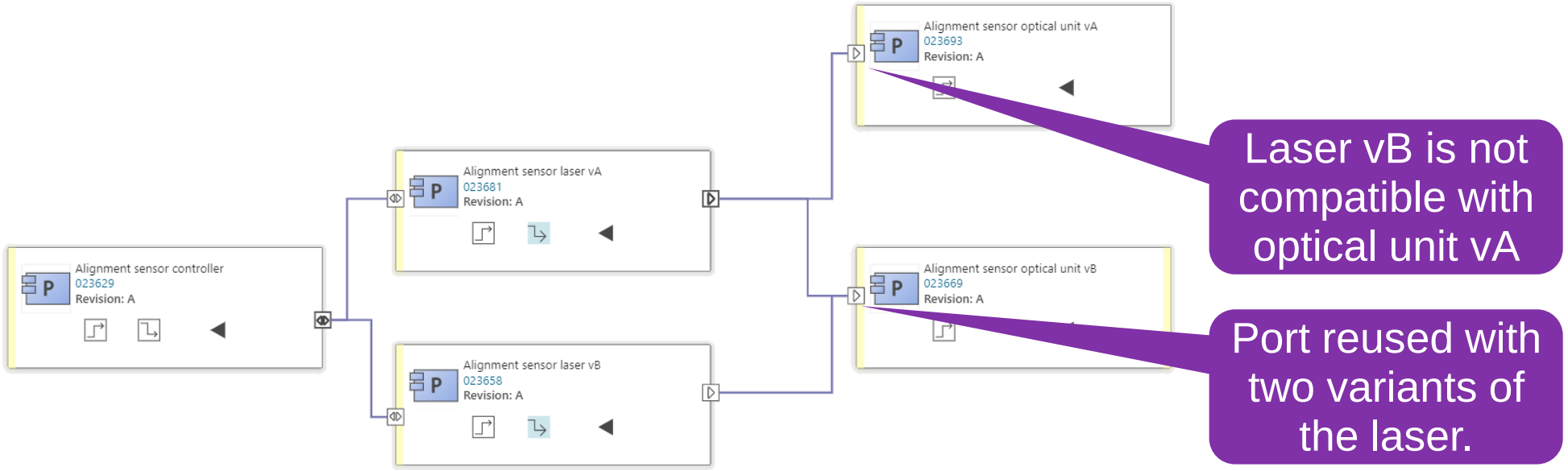


The model does not contain an interface between the laser vB and optical unit vA. Therefore, this combination is not allowed.

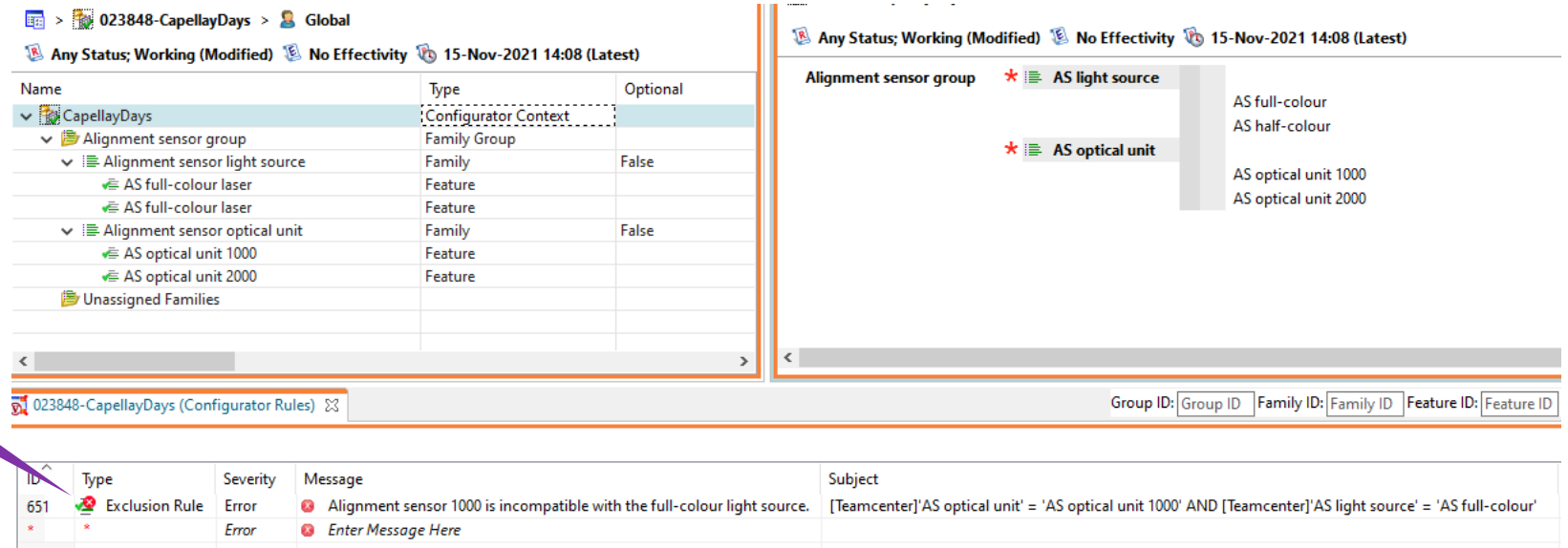
This relationship is not (yet) represented in the data, but the model contains (some of) the knowledge necessary to derive the product configuration definition and rules.

4. The system model as an expression of product configurations

Derive Production Configuration definitions and rules from the model.

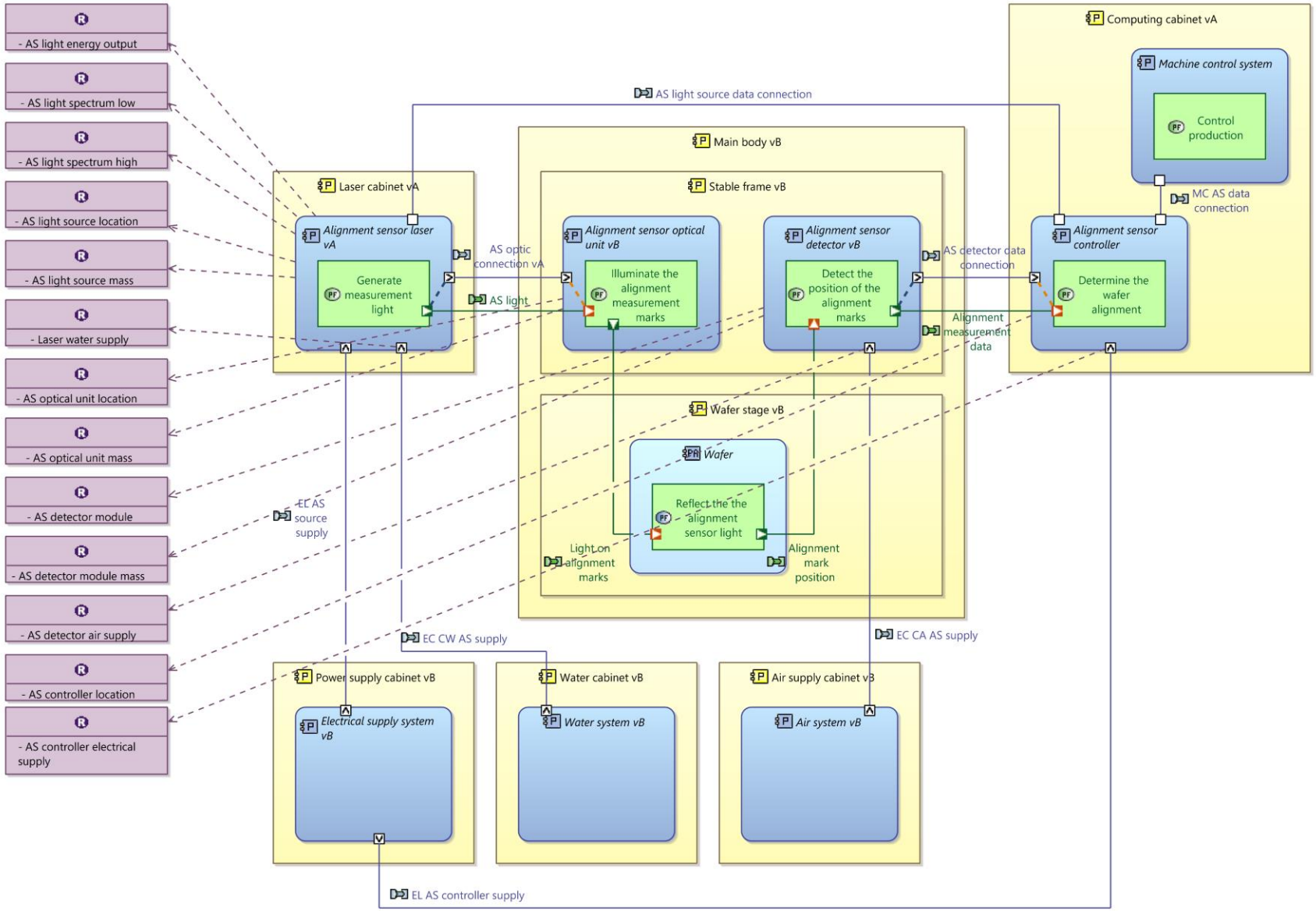


Derive a configurator rule.



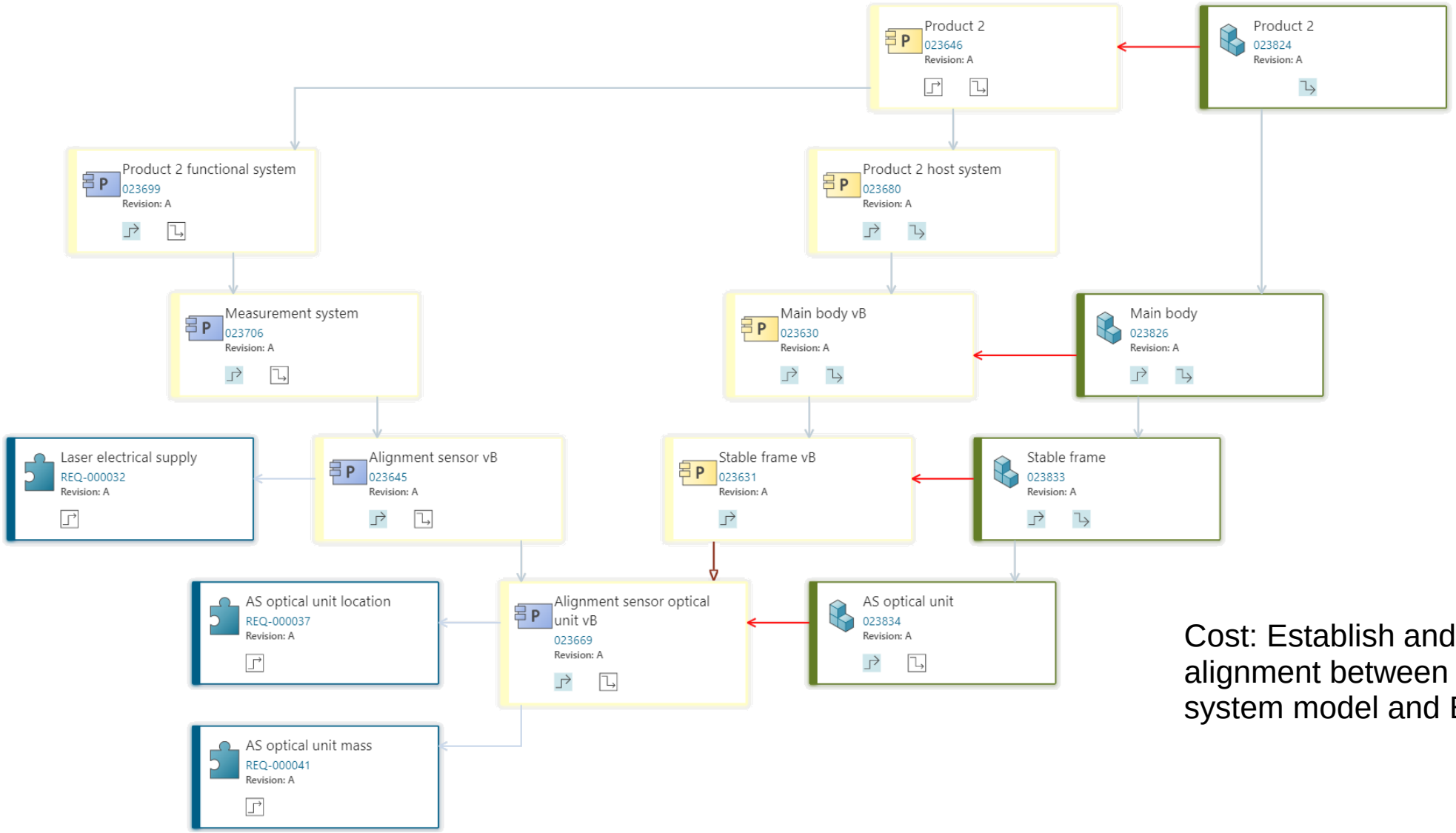
5. The system model as the link between requirements and the BOM

System architecture modelling complemented by textual requirements.



5. The system model as the link between requirements and the BOM

System model objects as constituent members of the digital thread.

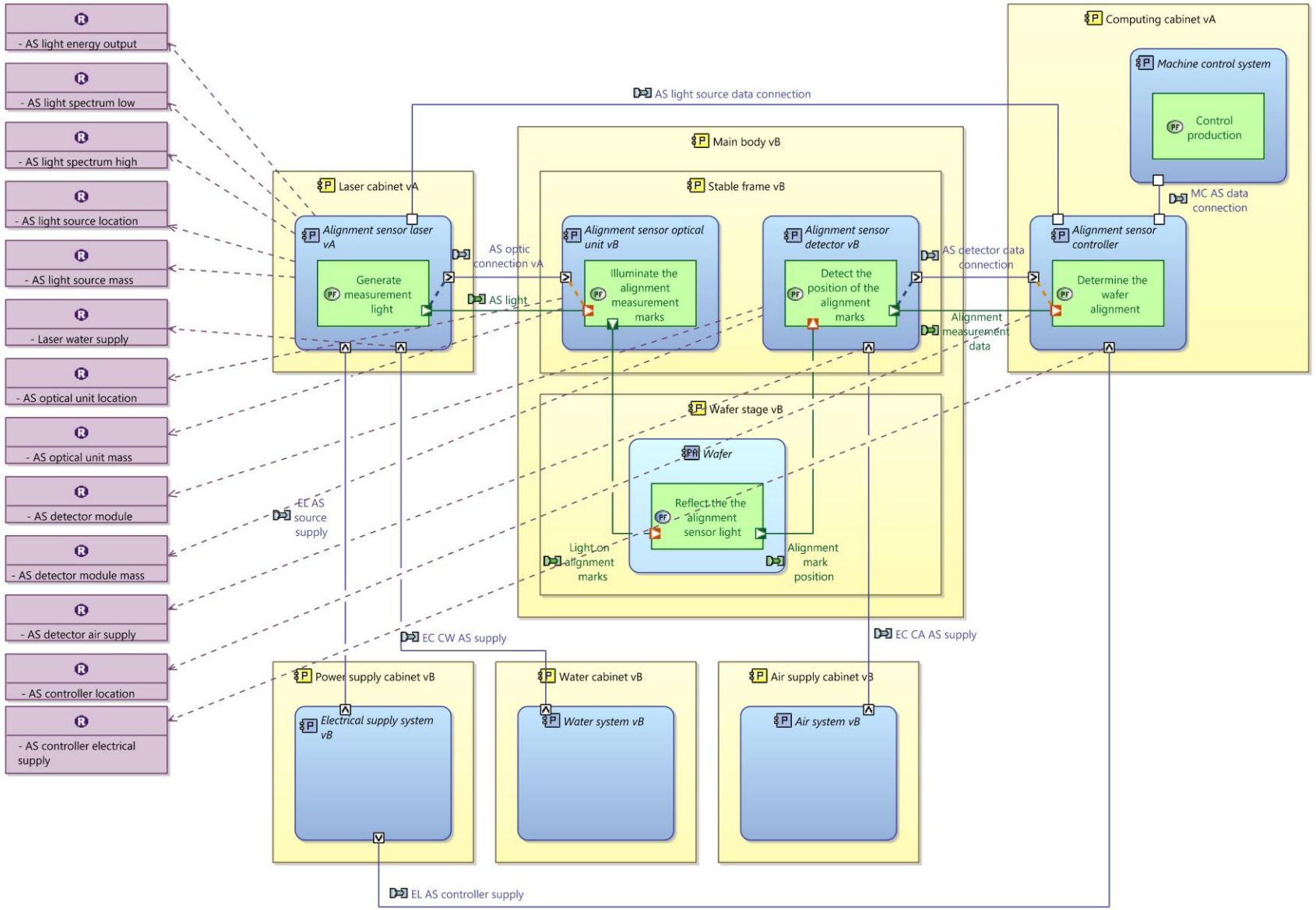


Cost: Establish and maintain alignment between the requirements, system model and BOM.

6. The system model as a source of system requirements

Natural language isn't necessarily the best format for all requirements.

These requirements are already expressed in the model.



6. The system model as a source of system requirements

Architecture diagram in the system requirements specification

Benefits:

- Consistent reference to the same system element.
- Simultaneous definition of system requirements and architecture.
- Establish tracelinks directly in the “document”.

Cost: Probably a significantly different way-of-working. For example, how do we verify against a graphical diagram/model?

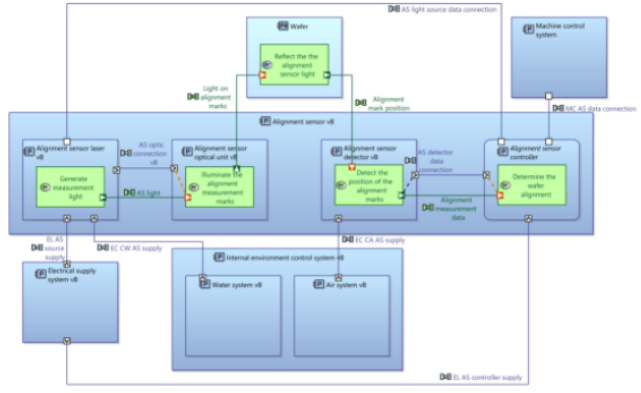
Element	ID	Variant F
Product 1 SRS	023825	
1 Introduction	023837	
1.1 System purpose	023838	
1.2 System context	023839	
1.3 System scope	023840	
1.4 Document overview	023841	
1.5 Terms and abbreviations	023842	
2 System requirements	023843	
2.1 Functional requirements	023844	
2.1.1 Alignment sensor light source variant B	023849	
2.1.1.1 AS light energy output	REQ-000033	
2.1.1.2 AS light spectrum low	REQ-000034	
2.1.1.3 AS light spectrum high	REQ-000035	
2.2 System constraints	023845	
2.2.1 System element location	023851	
2.2.1.1 AS controller location	REQ-000039	
2.2.1.2 AS light source location	REQ-000036	
2.2.1.3 AS optical unit location	REQ-000037	
2.2.1.4 AS detector module	REQ-000038	
2.2.2 Mass constraints	023852	
2.2.2.1 AS light source mass	REQ-000040	
2.2.2.2 AS optical unit mass	REQ-000041	
2.2.2.3 AS detector module mass	REQ-000042	
2.3 System interfaces	023846	
2.3.1 Laser electrical supply	REQ-000032	
2.3.2 Laser water supply	REQ-000044	
2.3.3 AS detector air supply	REQ-000045	
2.3.4 AS controller electrical supply	REQ-000043	

Save Edits | Cancel Edits | Word Roun... | Export to... | Reuse Document | Split Requirement | Generate Table o... | Show Parameters | Show Comments | Full Screen

023825-Product 1 SRS

1 023837- Introduction

This new alignment sensor is so much better than the previous one. We've improved everything you can think of. Perhaps even things you haven't thought of yet.



Functional architecture diagram of the alignment sensor variant B.

The following system elements, as identified in figure 1, are referred to in this document.

System element ID	System element name	Description
023658	Alignment sensor laser vB	The brand new laser that generates full-colour light.
023669	Alignment sensor optical u nit vB	The new alignment sensor optical unit 2000.
023673	Alignment sensor detector vB	Mostly similar to variant A, but capable of detecting the full spec trum of light.

1.1 023838- System purpose

Conclusion

Conclusion

Climbing up the ladder of ambition brings value, but you also incur cost.

This list is cumulative. As you move up the ladder, you gain additional benefit and incur additional cost, but still retain the previous benefits and costs.

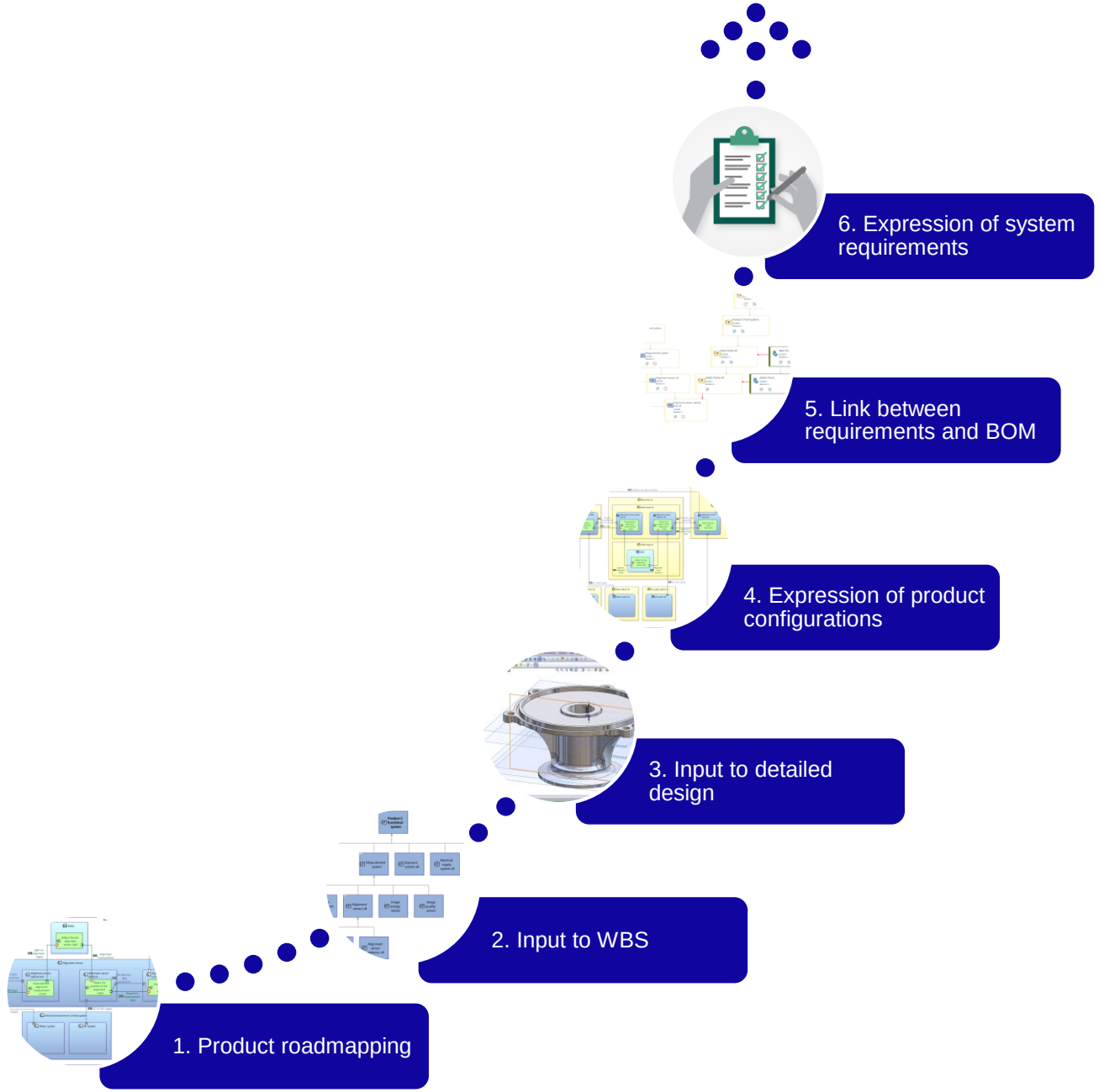
Level	Potential benefits	Likely costs
1. Product roadmapping	Consistent definition of product evolution. Possibility to the product roadmap in context.	Organizational and/or cultural change necessary.
2. Input to WBS	Clear description of new developments.	Organizational information must be maintained in (relation to) the model.
3. Input to detailed design	Single source of product architecture information. Multidisciplinary architecture description.	System model must be an acceptably accurate representation of the product.
4. Expression of product configurations	The model helps the architect to analyse the configurations. Explicit expression of product configurations.	Increased complexity of a 150% model.
5. Link between requirements and BOM	Integrated definition of system requirements and architecture.	Establish and maintain alignment between the requirements, system model and BOM.
6. Expression of system requirements	More consistent requirements definition. Simultaneous definition of system requirements and architecture.	Significant departure from traditional way-of-working (e.g. Document-centric requirements and V&V).

Conclusion

Moving up the ladder of ambition can lead to any combination of the following:

- Model increases in size (more objects).
- Model increases in complication.
- More users of the model.
- More contributors to the model.
- Stricter modelling rules and conventions.
- More pressure on accuracy and correctness.

...but it can also deliver great value to the enterprise.



dr. ir. Jonnro Erasmus
System engineer

jonnro.erasmus@asml.com

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