Model-Based Systems Engineering (MBSE) Case Study: Replacing Traditional SE Documents in an ASML Lithography System

1 Introduction

ASML lithography scanners, such as the TWINSCAN NXT and EXE series, integrate nanometer-level precision mechatronics, optics, thermal control, vacuum systems, and real-time control. Traditionally, ASML engineering relies on hundreds of heavily detailed documents—EPS, TPS, EDS, EPDS, FMEA, TAR—each describing different aspects of system performance, testing, safety, or maintenance.

In a Model-Based Systems Engineering (MBSE) approach, these static documents are replaced with formal digital model elements (SysML Requirements, Constraint Blocks, TestCases, Interfaces, Activity Diagrams, etc.). The **system model becomes the single source of truth**, and documents become **auto-generated outputs** instead of manually updated specifications.

This case study illustrates how MBSE replaces these documents for a representative subsystem of an ASML machine: the **Reticle Stage (RS)**, a dual-stage nanometer-precision mechanism responsible for positioning the reticle during exposure.

2 EPS Replacement: Elementary Performance Specification

Traditional EPS

The EPS for the RS defines system performance targets, including:

- Reticle stage positioning error ≤ 0.5 nm RMS
- Maximum stage velocity ≥ 3 m/s
- Settling time ≤ 150 μs
- Vibration isolation across frequency bands

MBSE Replacement

EPS content becomes:

- SysML **Requirement Blocks** with quantitative constraints
- **Value Properties** (e.g., `stage_velocity`)
- **Parametric Diagrams** linking mechanics and control equations
- **SatisfiedBy** relationships to design elements

A change in flexure stiffness updates all dependent requirements and simulation results automatically.

3 TPS Replacement: Test Plan Specification

Traditional TPS

The TPS describes metrology instruments, test conditions, environmental requirements, and measurement frequency for validating the EPS constraints.

MBSE Replacement

Replaced by:

- SysML **TestCase** elements
- **Verification Method** definitions (instrument, frequency)
- **Executable test sequences** using Activity or State diagrams
- Automated **pass/fail** evaluation using the behavioral model

Testing becomes integrated into the system lifecycle instead of a stand-alone document.

4 EDS Replacement: Engineering Design Specification

Traditional EDS

Contains:

- Functional decomposition
- Mechanical/optical architecture
- Control architecture
- Interfaces (power, cooling, data)
- Compliance and safety constraints

MBSE Replacement

EDS becomes the **entire system architecture model**:

- Block Definition Diagrams (BDDs)
- Internal Block Diagrams (IBDs) defining all interfaces
- Activity diagrams for exposure and alignment workflows
- State machines modeling RS operational modes
- Traceability to requirements, simulations, and tests

The traditional 100+ page EDS becomes a multi-view SysML architecture.

5 FMEA Replacement: Failure Modes and Effects Analysis

Traditional FMEA

Lists failure modes, severity, occurrence, detectability, and mitigation.

MBSE Replacement

Replaced with:

- SysML **FailureMode** stereotypes
- **Fault trees** linked to physical and behavioral models
- Reliability **parametric models** computing impacts
- Auto-generated FMEA tables extracted from relationships

A failure in a voice-coil actuator automatically propagates to requirements, behaviors, and risk scores.

6 TAR Replacement: Test Analysis Report

Traditional TAR

Summarizes test executions, results, deficiencies, readiness.

MBSE Replacement

Produced automatically:

- Simulation results stored as model properties
- TestCase verdicts (pass/fail)
- Verification matrices updated in real time
- Generated PDF/HTML reports summarizing coverage and readiness

TAR becomes a push-button model extraction.

7 Integrated Example: Change Request Propagation

Scenario

A change in RS flexure stiffness affects dynamic performance.

Traditional Process

1. Update EPS, notify teams
2. Update TPS for new measurement conditions
3. Modify EDS interface definitions
4. Re-run and update FMEA spreadsheets
5. Update TAR templates

Propagation time: **weeks**

MBSE Process

1. Update stiffness parameter in SysML model
2. Parametrics and simulations refresh automatically
3. TestCases re-evaluate and update verification matrices
4. Requirement satisfaction updates
5. Reports auto-regenerated

Propagation time: **minutes to hours**

8 Conclusion

MBSE does not eliminate documentation; it transforms documents into **digital model elements**. EPS, TPS, EDS, EPDS, FMEA, and TAR documents still exist as concepts, but they are maintained *through the model*, not as isolated files. This creates alignment, reduces engineering labor, and ensures consistency in a system as complex as an ASML lithography machine.