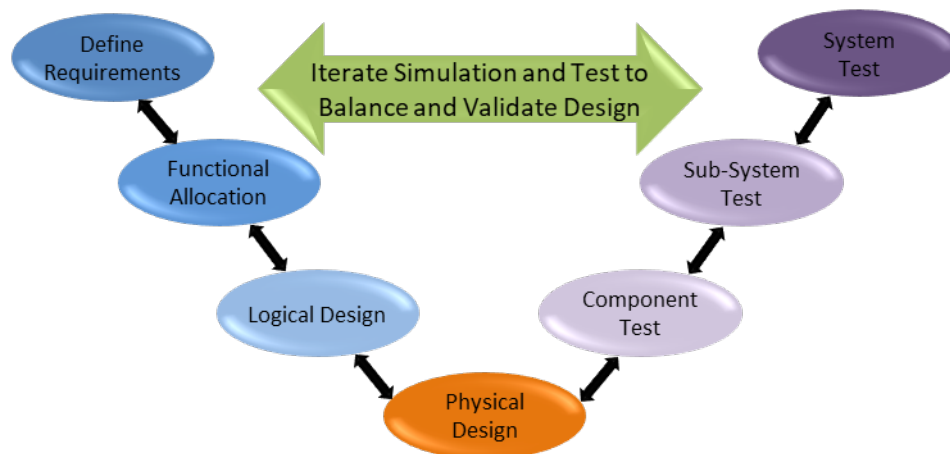


Linking System Requirements with Product Performance for Design Balance

Executive Summary

Modern product design has become more complicated due to increased customer demands and product complexity. Today's products have involved significantly increased usage of controls and software to provide the desired functionality. Engineers need to understand and trace the relationship between requirements and parts throughout the development process as they balance the design. Common tasks include addressing customer needs in specifications, evaluating system performance with what-if simulation and test, and managing product configuration in a collaborative environment. Balancing the design requires evaluating the performance of potential product variants to maximize product performance within the cost and weight targets. XLDyn® allows the product engineer to develop and track requirements associated with different verification methods, so the current project status is always available. In addition, XLDyn® has fully integrated system level Design of Experiments (DoE) that provides valuable design guidance to select the best set of parameters or parts. Even test data can be included in the DoE.



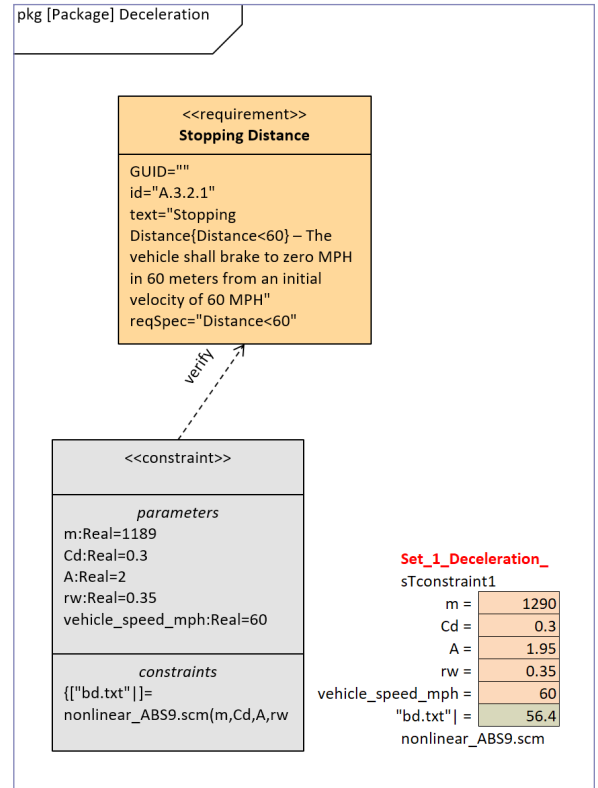
Introduction

XLDyn® has two fully integrated modules, XLSE for authoring SysML compliant MBSE models, and XL1D for 1D multi-physics simulation. XLDyn® uses Microsoft Excel as the GUI. XLSE includes the following SysML diagram types:

- Package (pkg)
- Block Definition (bdd)
- Internal Block (ibd)
- Parametric (par)
- Activity (act)
- Requirement (req)
- State Machine (stm)
- Use Case (uc)

Besides creation and management of SysML diagrams **XLSE** includes:

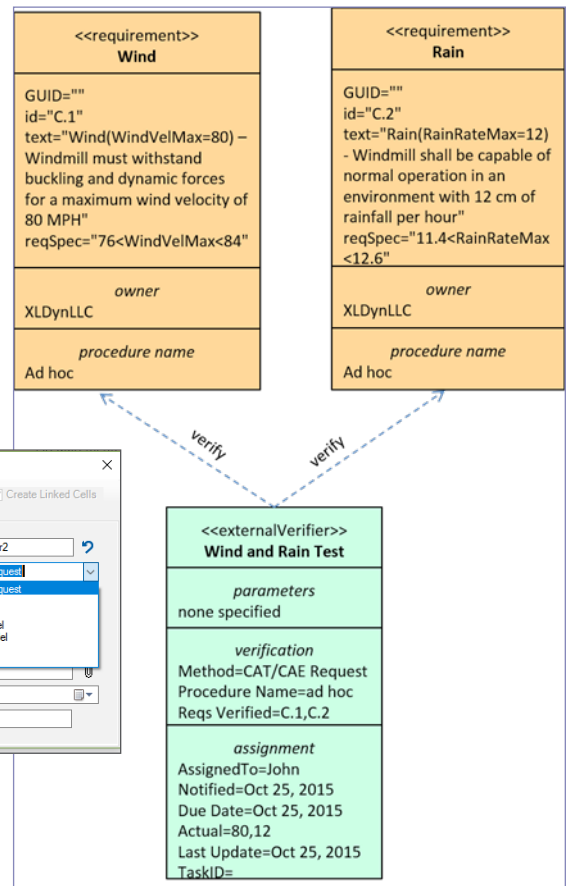
- a) **Requirement diagrams** can be created with a 'one click' operation from imported data or created directly within XLDyn®.
- b) **Verify requirements** with either simulation or test results. Simulations can be run **directly** from within XLDyn®.
- c) Document **Use Cases** and associate them with requirements. Use Cases can be **multi-level**.
- d) Create **State Machines** that can be **executed** directly from the diagrams.
- e) Create **executable Activity diagrams** with embedded Monte Carlo simulation.
- f) **Schematic diagrams** can be created from a list of parts that is either created in XLDyn® or imported from other systems. Reliability calculations can be **performed** directly from the schematic diagram.
- g) **Domain Maps** can be created with **one click** from the requirements and bdd (parts) diagrams. Use domain maps for peer reviews and assign relationships between parts and requirements.
- h) Create **DFMEA** diagrams and tables **directly** from the domain map by adding severity, occurrence, and detection.
- i) Perform a **System Level DoE** that can include any simulation or **test** used as a requirement verifier in the model. Learn the main effects and pick out the optimal design parameters to balance the system.



solidThinking Activate Model as Verifier

XLDyn supports multiple verification methods including actionable parametric, state machine, and activity diagrams.

- a) **Cell Equations** – Simple equations or Macros.
- b) **Worksheets** – Link the input/output cells of a worksheet to the results set.
- c) **CAT/CAE Request** – Automated e-mail request for a test or simulation. Automatic updates to SRT when work is completed.
- d) **Observation** – Automated e-mail request to make a simple observation, e.g. verify label is installed.
- e) **XL1D Model** – Use a XL1D model including reliability.
- f) **Activate Model** – Use a solidThinking Activate model.
- g) **act Diagram** – Calculate process time using an activity diagram.
- h) **stm Diagram** – Determine system state for different parameters and conditions.



The 'Create Verifier' dialog box has the following fields:

- Node Name: externalVerifier2
- Verification Method: CAT/CAE Request
- Node Location: Observation
- Procedure Name: Cell Equation
- Owner: Activate Model
- Attachment: Modelling Model
- Due Date: May 29, 2017
- Actual Value: TBD

Two requirements verified by one external test

solidThinking Activate enables product creators, system simulation and control engineers to model, simulate and optimize multi-disciplinary systems to ensure that all design requirements are successfully met while also identifying system level problems early in the design process.

Problem Definition and Solution

During the product development process, engineers are often presented with seemingly conflicting requirements that are being driven by a common set of design parameters. Our problem is balancing a set of design parameters for an automobile such that they are feasible and meet the established requirements. In this case, the high-level balancing needed during the vehicle concept phase to make sure fuel economy, braking, and acceleration targets are met. The braking requirement includes a stopping distance of 60 meters, the combined city/highway fuel economy must be greater than 34 mpg, and the zero to 60 mph acceleration time must be less than 8.7 seconds. The braking requirement is being verified by an solidThinking Activate 1D anti-lock braking model, while the fuel economy is being estimated with an Excel macro using a simple model that includes the EPA cycles. Lastly, the zero to 60 mph requirement is being calculated from an XL1D 1D multi-physics model.

While there are many more requirements and verifiers in our model, including test verifications, we will focus on these three for our System Level DoE. We have a simple regression model for estimating the mass of small IC engine vehicles that was created from test data. This model shows that vehicle mass can be predicted rather accurately from two parameters, vehicle trackwidth and powertrain mass. Since mass is required for all three of our simulations it will be estimated using this regression model. If either the powertrain mass or trackwidth are changed, the mass will update in all three simulations. Additional common parameters included in the study are vehicle frontal area and coefficient of drag.

The steps in the process are simple and as follows:

- a) Import the requirements and create all of the SysML requirements diagrams and hierarchy using the 'one click' method.
- b) Link the verifiers to the requirements, in this case as verifiers we will use:
 1. solidThinking Activate - Stopping Distance
 2. XL1D - 0-60 Time
 3. Excel Macro - Combined City/Highway Fuel Economy
- c) After performing the simulations with the initial parameter set, we get the results shown in this System Requirements Table (SRT).

A.2	Energy	Energy - Vehicle shall meet fuel economy, range, and emission require		
A.2.1	Fuel Economy	Fuel Economy - Vehicle shall meet fuel economy standards		
A.2.1.1	Fuel Economy Highway	Fuel Economy Highway Cycle {HWF Ad hoc	HWFET>41	40.9
A.2.1.2	Urban Driving Cycle	Urban Driving Cycle {UDDS>28} - Urban Driving	UDDS>28	29.10
A.2.1.3	Combined City/Highwa	Combined City/Highway Fuel Econ Ad hoc	CombCtyHiv	33.5
A.2.2	Range	Range{Range>400} - Vehicle shall travel 400 mi	Range>400	401
A.2.3	Emission	Emission - Emission requirements are TBD		
A.3	Vehicle Dynamics	Vehicle Dynamics - The vehicle shall meet acceleration, deceleration, h		
A.3.1	Acceleration	Acceleration - The vehicle shall meet all acceleration requirements		
A.3.1.1	0-60 Time	0-60 Time {Z60<8.7} - The time for the vehicle t	Z60<8.7	9.14
A.3.2	Deceleration	Deceleration - The vehicle shall meet all deceleration requirements		
A.3.2.1	Stopping Distance	Stopping Distance{Distance<60} - The vehicle s	Distance<60	56.4

Initial System Requirement Table

d) The fuel economy and acceleration requirements are not being met.

e) Let's set up a DoE from System DoE Configuration panel to better understand the problem. Note, all verifiers in the model are automatically available to participate in a DoE, even test data. Select the MoEs and associated parameters of interest. Next, select the level. In this case, L2, and the number of simulations. See Figure 1 to the right.

f) The system level design matrix will be constructed, and the simulations will begin once the simulation times are entered.

g) Once the simulations are finished, the table will be completed as shown in Figure 2

From the DoE summary table, we observe that vehicle trackwidth has the largest effect on our design as it drives the overall mass. If we decrease the trackwidth, the frontal area will also be reduced. So, we will reduce the trackwidth by 3 cm and the frontal area by 0.1 m². By making those two changes and performing the simulations again we get the results show in Figure 3, indicating that our design is balanced and we have met our objective for fuel economy, acceleration, and stopping distance.

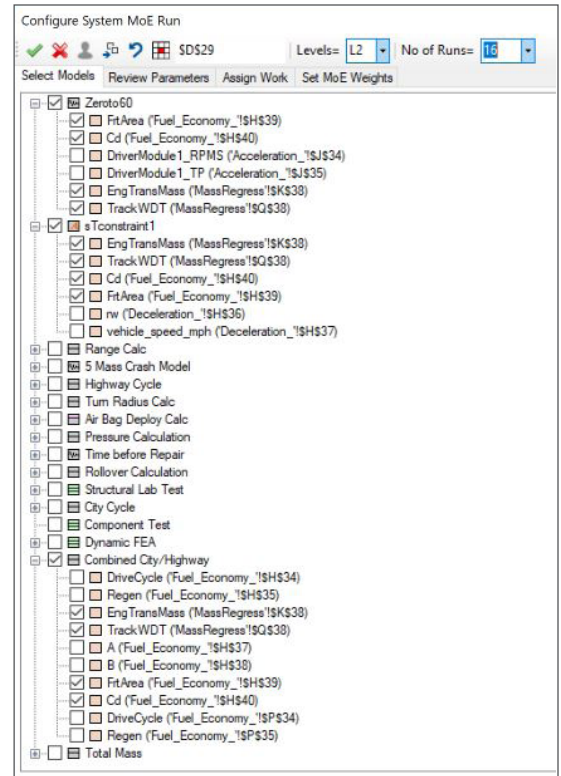


Figure 1: System DoE Configuration Panel

Run	FrntArea	Cd	EngTransMe	TrackWDT	Z60 =	"bd.txt" =	CombCtyHiw	Current, Z60	Current, "	Current, C	Total_Deviatio
1	1.755	0.27	157.5	140.6	7.04	55.4	37.4	9.19	56.4	33	0.21195
2	1.755	0.27	157.5	155.4	10.17	58.0	33.8	9.19	56.4	33	0.1676
3	1.755	0.27	192.5	140.6	7.72	53.7	36.3	9.19	56.4	33	0.15996
4	1.755	0.27	192.5	155.4	10.37	58.1	32.8	9.19	56.4	33	0.19603
5	1.755	0.33	157.5	140.6	7.04	55.2	35.8	9.19	56.4	33	0.2016
6	1.755	0.33	157.5	155.4	10.17	57.9	32.4	9.19	56.4	33	0.18192
7	1.755	0.33	192.5	140.6	7.72	53.6	34.8	9.19	56.4	33	0.15621
8	1.755	0.33	192.5	155.4	10.37	57.9	31.55	9.19	56.4	33	0.21304
9	2.145	0.27	157.5	140.6	7.04	55.2	35.8	9.19	56.4	33	0.2016
10	2.145	0.27	157.5	155.4	10.17	57.9	32.4	9.19	56.4	33	0.18192
11	2.145	0.27	192.5	140.6	7.72	53.6	34.8	9.19	56.4	33	0.15621
12	2.145	0.27	192.5	155.4	10.37	57.9	31.55	9.19	56.4	33	0.21304
13	2.145	0.33	157.5	140.6	7.04	55.0	33.9	9.19	56.4	33	0.20421
14	2.145	0.33	157.5	155.4	10.17	57.7	30.87	9.19	56.4	33	0.20665
15	2.145	0.33	192.5	140.6	7.72	53.6	33.0	9.19	56.4	33	0.16669
16	2.145	0.33	192.5	155.4	10.37	57.7	30.11	9.19	56.4	33	0.23813
Main Effects:	0.08014	0.08014	-0.05814	0.1399							

Figure 2: System DoE Matrix

A.2	Energy	Energy - Vehicle shall meet fuel economy, range, and emission require
A.2.1	Fuel Economy	Fuel Economy - Vehicle shall meet fuel economy standards
A.2.1.1	Fuel Economy Highway	Fuel Economy Highway Cycle [HWf Ad hoc] HWFET>41 42.2
A.2.1.2	Urban Driving Cycle	Urban Driving Cycle [UDDS>28] - Urban Driving UDDS>28 30.10
A.2.1.3	Combined City/Highway	Combined City/Highway Fuel Econ Ad hoc CombCtyHiw 34.5
A.2.2	Range	Range[Range>400] - Vehicle shall travel 400 mi Range>400 415
A.2.3	Emission	Emission - Emission requirements are TBD
A.3	Vehicle Dynamics	Vehicle Dynamics - The vehicle shall meet acceleration, deceleration, h
A.3.1	Acceleration	Acceleration - The vehicle shall meet all acceleration requirements
A.3.1.1	0-60 Time	0-60 Time [Z60<8.7] - The time for the vehicle t Z60<8.7 8.52
A.3.2	Deceleration	Deceleration - The vehicle shall meet all deceleration requirements
A.3.2.1	Stopping Distance	Stopping Distance[Distance<60] - The vehicle s Distance<60 56.8

Figure 3: Final Systems Requirement Table Balanced Design

Conclusion

During the product development process, it is important that product requirements be established. Simulations, test, and design reviews are necessary to understand if the requirements are being met so that design parameters can be adjusted early in the process. In this study, we found that the initial design parameters did not meet the requirement objectives. After performing the DoE to better understand the design, the parameters were easily adjusted to satisfy all of the initial requirements. XLDyn® provides the tools for defining and tracking requirements, integrating the associated verifications, and performing the design balance process with DoE tools. Altair's solidThinking Activate is a comprehensive 1-D multi-physics simulation tool for verification and is fully integrated with XLDyn®.

	FrtArea	Cd	EngTransWDT	TrackWDT	Z60	Brake Dist	CombCty Hiwy
Target					8.7	60	34
Baseline	1.95	0.3	175	148	9.14	56.4	33.5
Final	1.85	0.3	175	145	8.52	56.8	34.5

Summary Table - Baseline vs. Final