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Automated trade study analysis based on dynamic requirements verification in the model-based system engineering

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Outline

- Motivation
- Trade study analysis process based on requirement verification
- CaseStudies
  - Systems Engineering Domain
  - System of Systems Engineering Domain
- Conclusions

Motivation

- One of the core processes in the architecture development lifecycle is to perform architecture evaluation
- The main goal of this process is to select architecture for design and implementation
- In order to automate this complex process, it is necessary to develop a digital, unambiguous, and precise model-based environment
  - MBSE is a backbone for automated trade study process
- The worldwide systems engineering community has acknowledged and is currently using various trade study analysis processes
- Most of the restrictions and constraints for a system solution space are specified with system requirement specifications.
- As the requirements define system constraints, they can be used as an adequate instrument for selecting evaluation criteria in trade study analysis.

Purpose

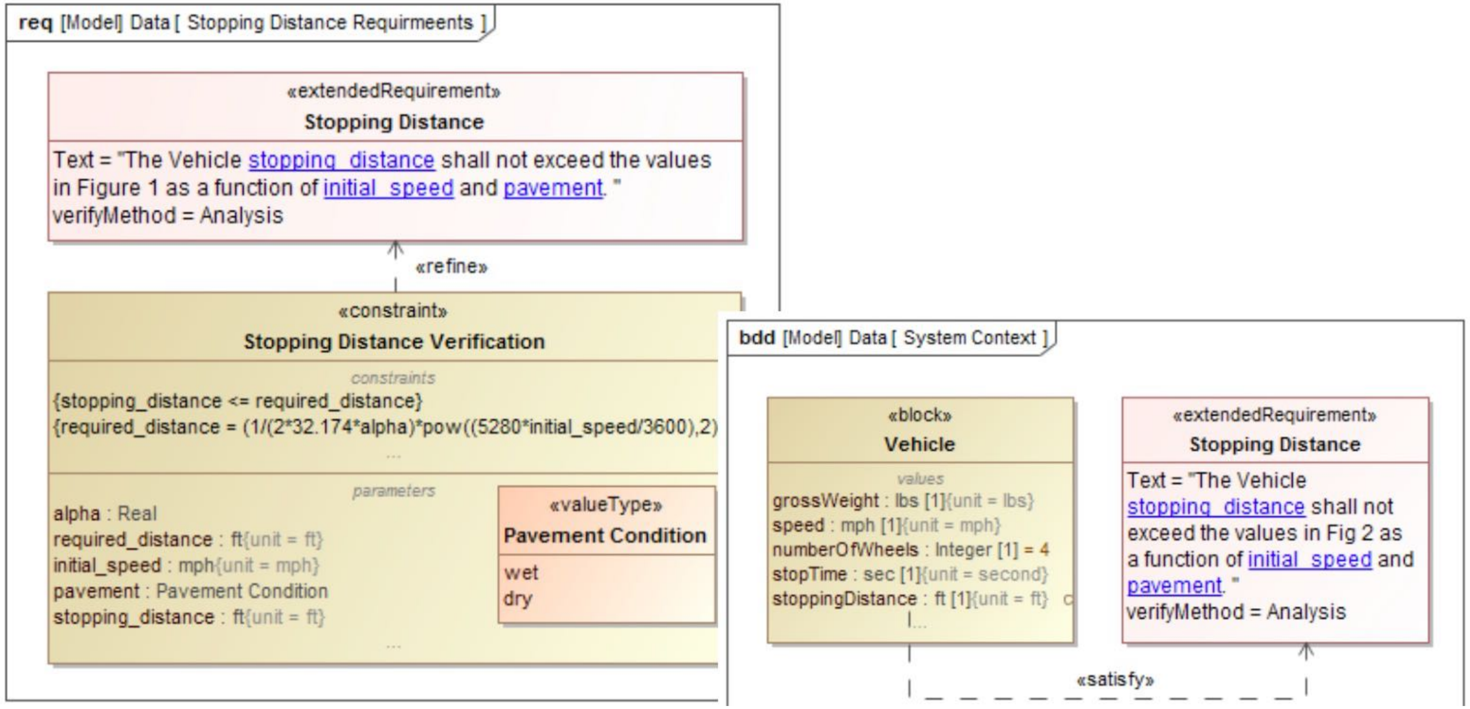
- The goal of this paper is to take the best practices from existing requirements verification approaches and propose an approach for an automated trade study analysis based on dynamic requirements verification in the model-based systems engineering environment, with a goal to support trade of analysis both in the system of systems and systems engineering domains.
- It is part of the larger research of the automated UAF-based trade study analysis process.

MBSE approach

- UAF is the collection of best practices used in systems, systems of systems, and enterprise engineering for more than 30 years. Moreover, UAF is applicable to any domain. Additionally, it is still the best choice to build DoDAF, NAF, and MODAF architectures.
  - Common Vocabulary and graphical SysML-based notation
  - Analysis and Simulation
- UAF has been designed to support trade studies at different levels:
  - trade-off operational scenarios against capability requirements,
  - or trade-off solution architectures against operational needs
- As UAF is based on SysML the requirements verification approach is applicable to both UAF and SysML

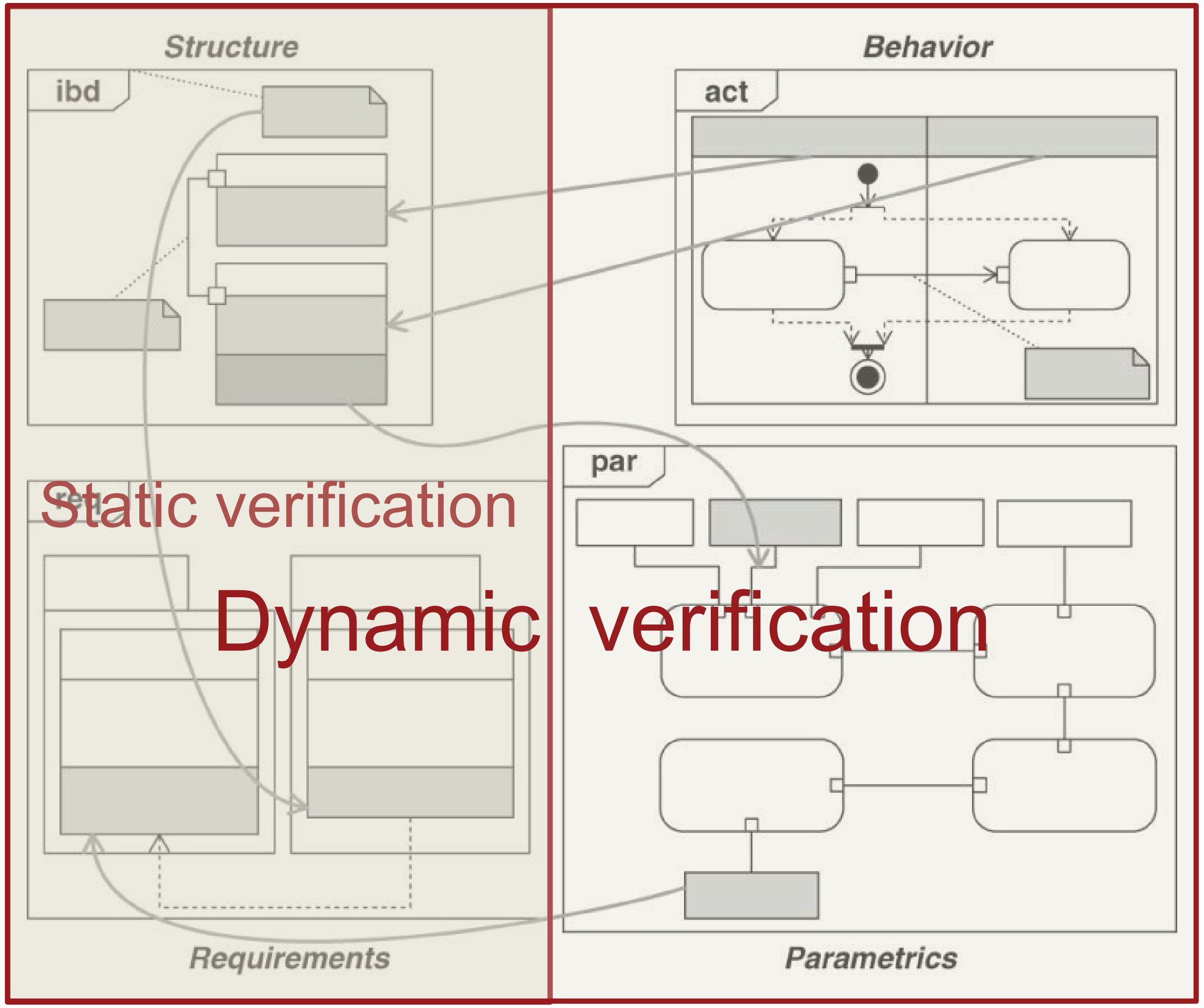
Work in the Area

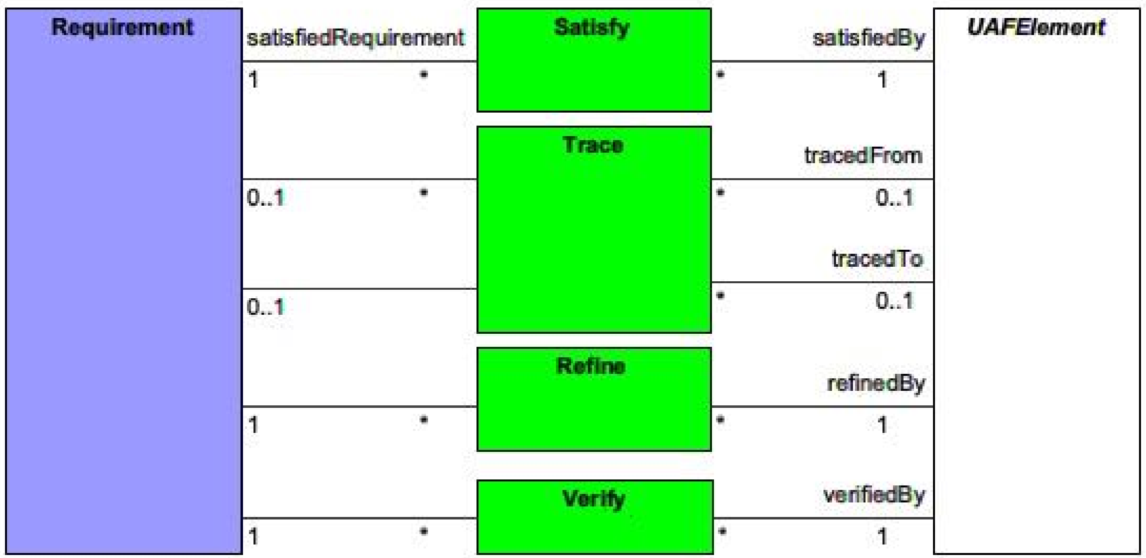
- Industry demand for standardized approach for automated requirements verification without manipulating the real system
- Work done in this area:
  - has very little prove of its successful application on real-industry cases
  - is very specific to a small area of applications
    Is dependent on specific tools
  - Model-based methods requires a specific non standardized extensions



- The work done is based on:
  An Approach: SysML-based Automated Requirements Verification published by IEEE ISSE 2015

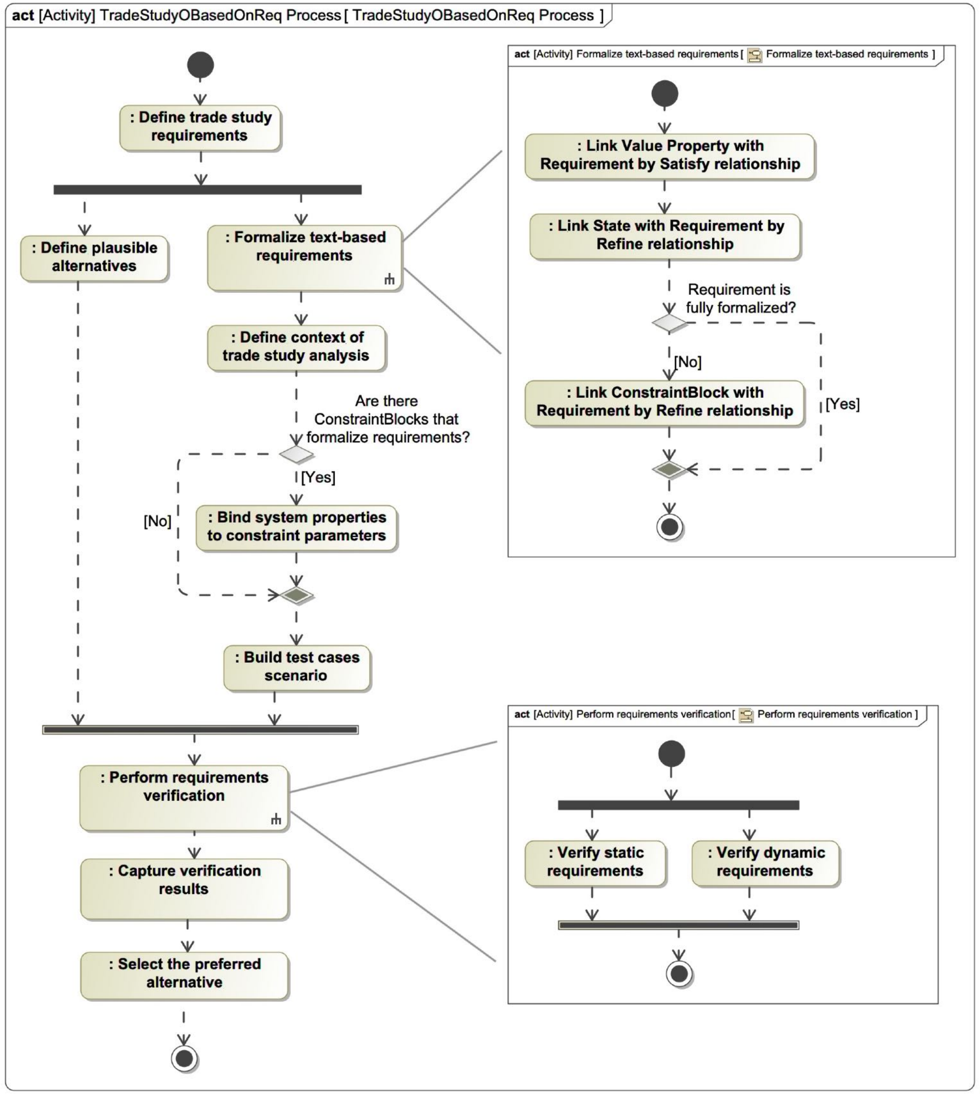
Application to SE and SoSE





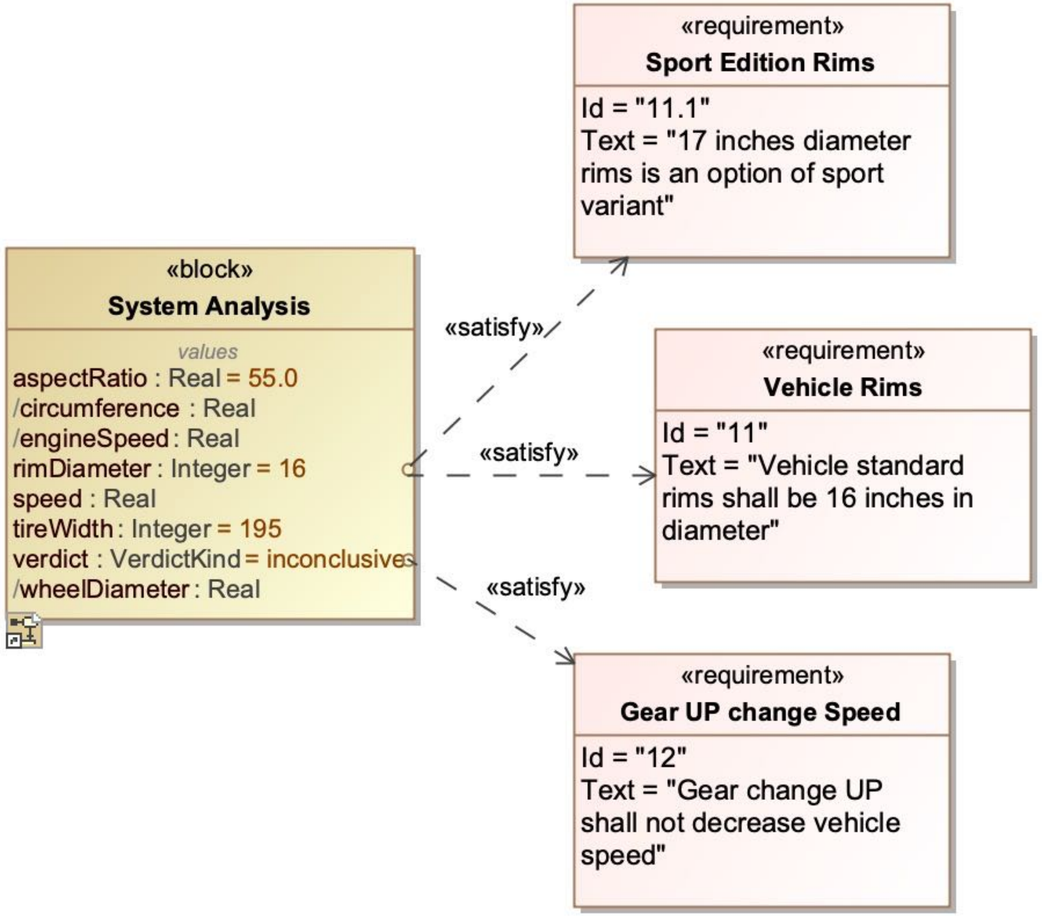
Trade study analysis process based on requirement verification

Trade study analysis process



Define trade study requirements

- Requirements describe the necessary functions and features of the system.
- Requirements can be used as a set of trade study selection criteria.
- In this step, a set of requirements should be established that will be used in a trade study analysis.



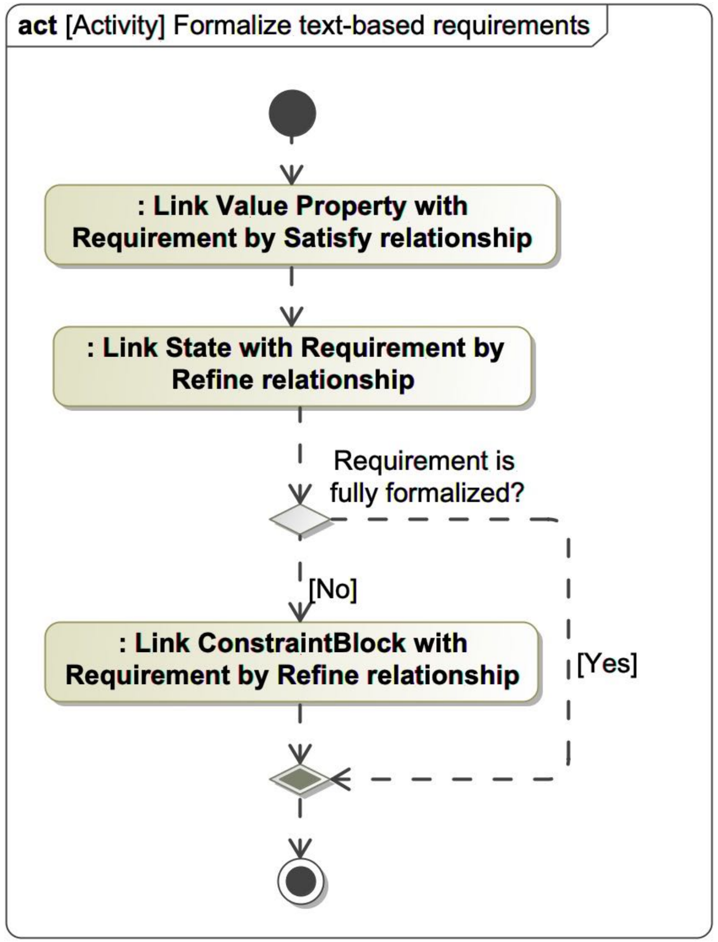
Define plausible alternatives

- Plausible alternatives can potentially achieve the goals and objectives of the systems.
- Alternatives can be defined by selecting potential solutions that are already known or desirable.

#	Name	ATU.ratioDifferential_1 : Real	ATU.ratioDifferential_2 : Real	ATU.ratioDifferential_3 : Real	ATU.ratioDifferential_4 : Real	ATU.ratioDifferential_5 : Real
1	system variant 1	3.789	2.951	1.435	1	0.865
2	system variant 2	3.751	2.86	1.9	1.31	1
3	system variant 3	3.287	2.499	1.397	1	0.853

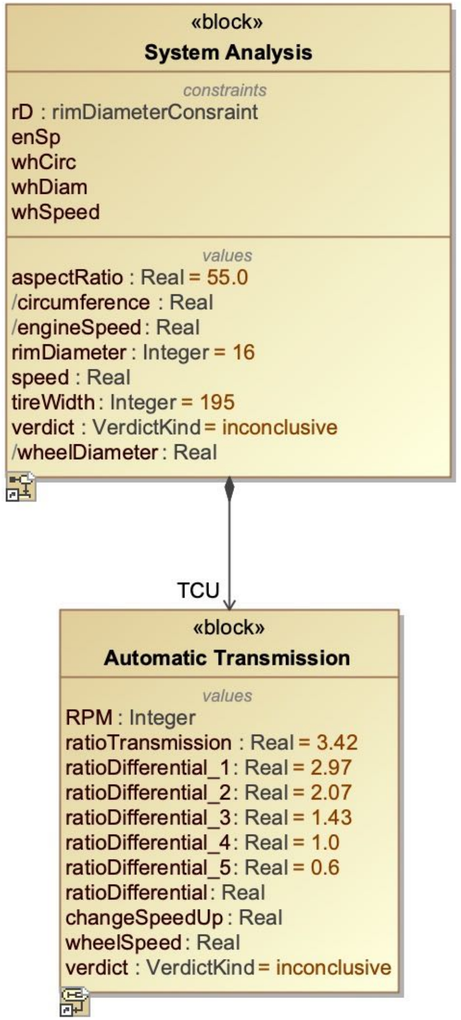
Formalize text-based requirements

- SysML introduces the ability to model text-based requirements.
- Refine relationship is used between requirements and constraint blocks.
- A requirement refined by a state means that the requirement constraint is valid only if a system is in a specific state.



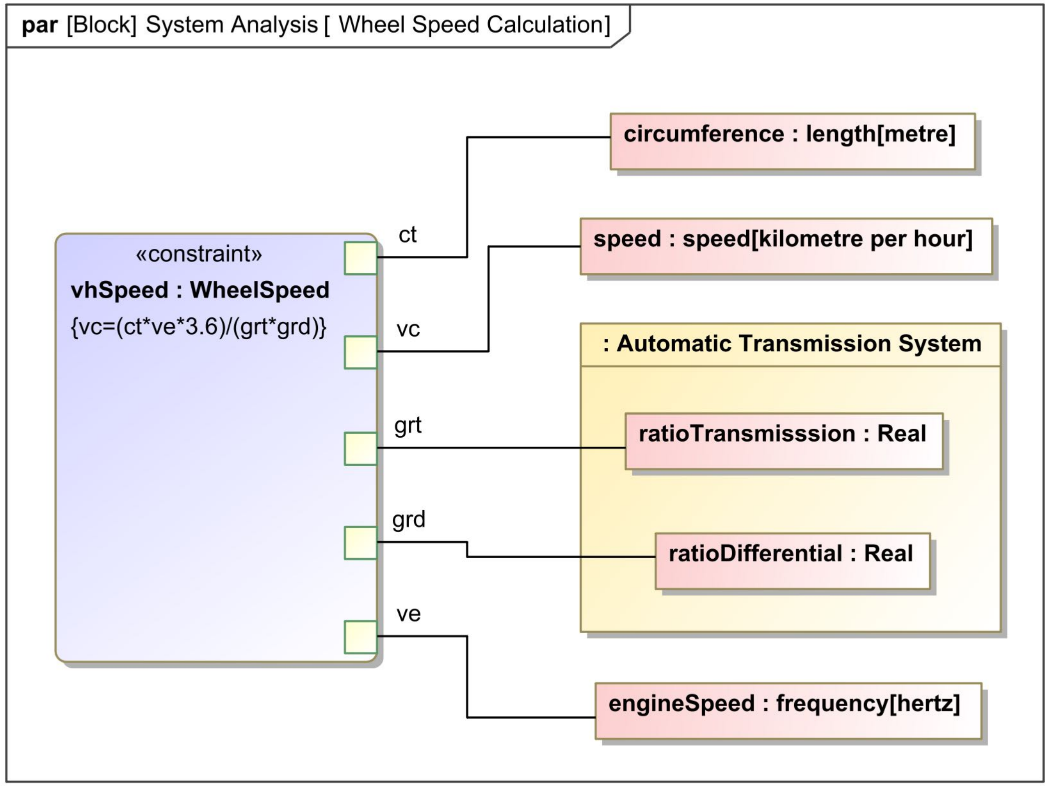
Define context of trade study analysis

- Analysis context prevents any direct impact or changes to the original system architecture.
- In this step, the context of the trade study analysis is defined and the constraints that will be used to analyze the system should be set.



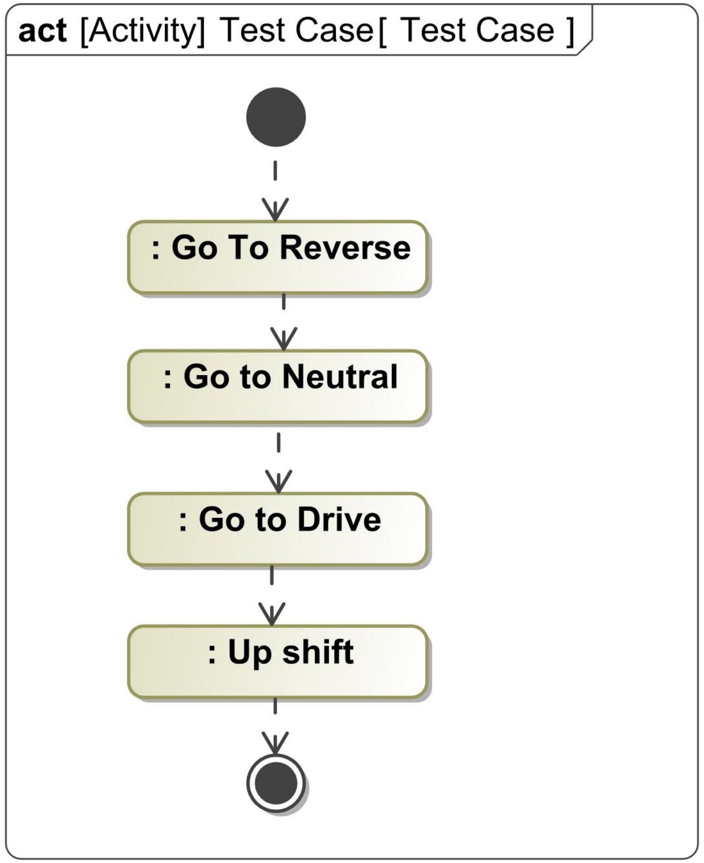
Bind system properties to constraint parameters

- Constraint blocks should be defined to formalized complex logic.
- In this step, the variables of a constraint block should be bound with the value properties that are examined in the requirement verification.



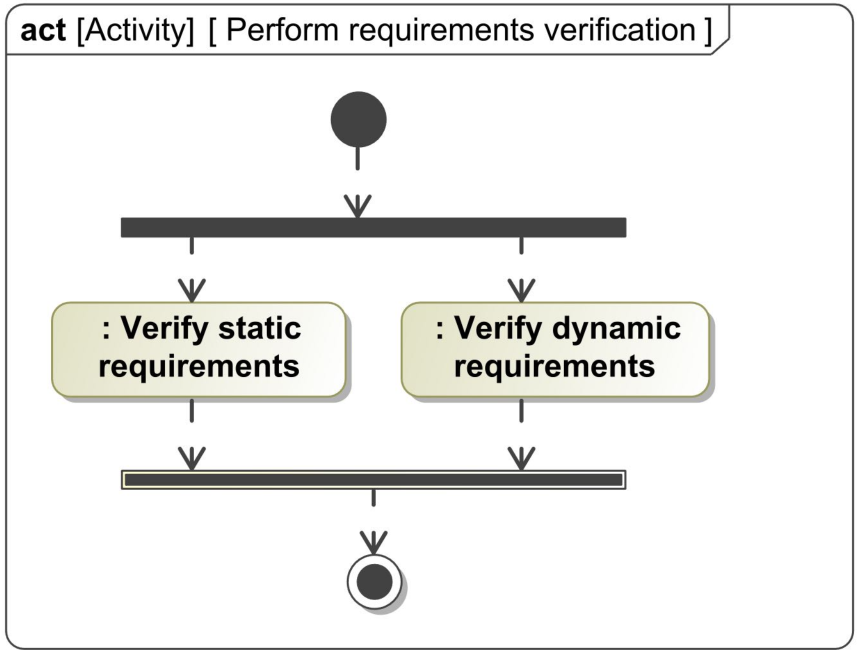
Build test case scenario

- Some variables change depends on the operation of the system.
- To verify such variables against the determined requirements, test case scenarios is created using activity or sequence diagrams.



Perform requirements verification

- The possible solutions of a trade study are judged by their overall satisfaction of the determined requirements.
- Requirements are verified on the basis of established requirements traceability relationships and formalized requirements.



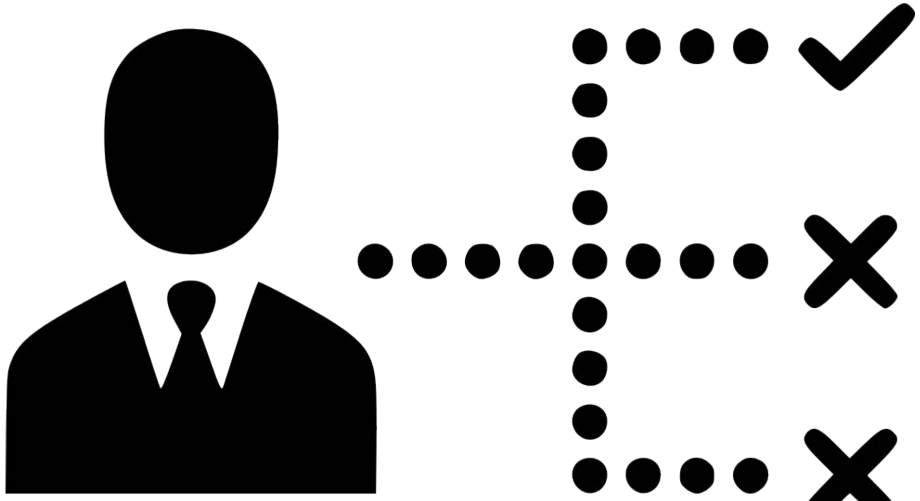
Capture verification results

- Once the requirement verification is completed, the results should be recorded to perform an analysis of the results.
- Each outcome of the alternative should be kept separate in order to examine requirements that were not satisfied.

#	Name	ATU.ratioDifferential_1 : Real	ATU.ratioDifferential_2 : Real	ATU.ratioDifferential_3 : Real	ATU.ratioDifferential_4 : Real	ATU.ratioDifferential_5 : Real	verChSpeed : Wheel Speed Verification	rimDiameter : length[inches]	rDVer : rimDiameterVerification
1	system variant 1	3.789	2.951	1.435	1	0.865	fail	16 "	pass
2	system variant 2	3.751	2.86	1.9	1.31	1	fail	17 "	pass
3	system variant 3	3.287	2.499	1.397	1	0.853	fail	16 "	pass
4	system variant 4	3.566	2.056	1.384	1	0.85	pass	16 "	pass
5	system variant 5	3.587	2.022	1.384	1	0.861	pass	16 "	pass

Select the preferred alternative

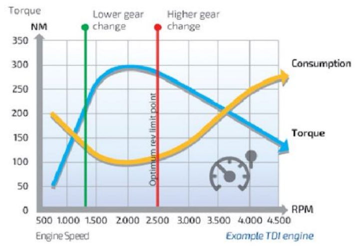
- Analysis is carried out based on the results of the requirement verification.
- The goal of this step is to indicate the most suitable alternative that corresponds to all or most of the specified requirements.



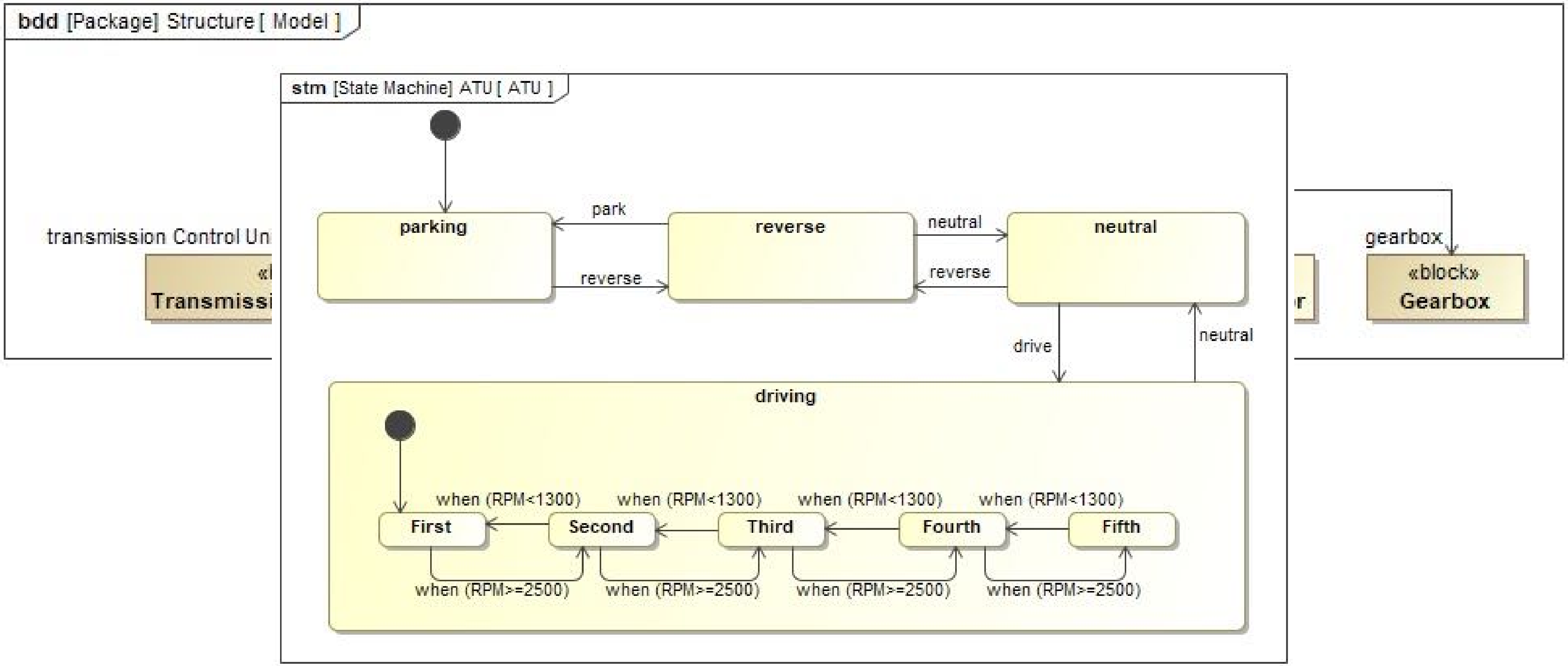
Case Study:
Systems Engineering Domain

SysML-based Case Study: Vehicle Automatic Transmission

- System Requirements for Vehicle Automatic Transmission

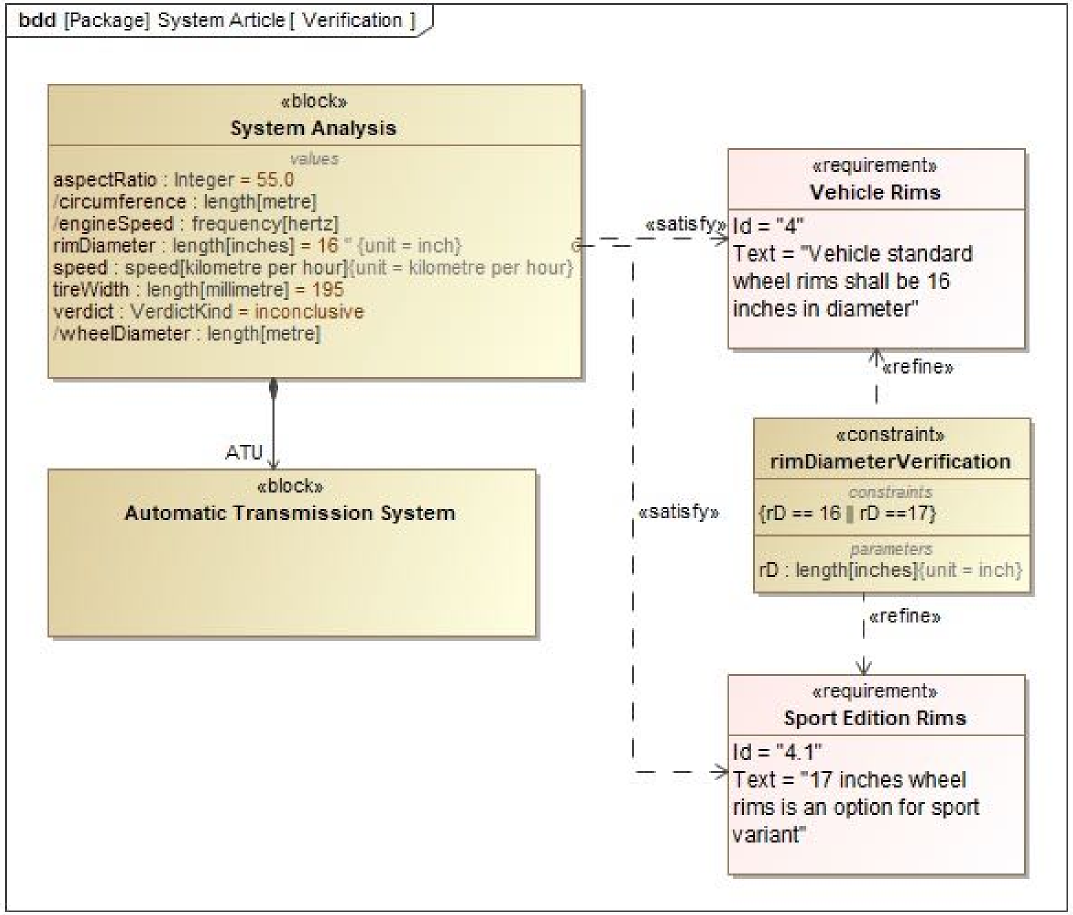
#	Name	Text
1	1 Engine Fuel Consumption	Gear shift up and down shall be performed in the lowest possible fuel consumption range and highest possible engine torque range: 
2	1.1 Engine Speed Upshift	Optimal gear upshift should be performed when engine RPM reaches 2500 value
3	1.2 Engine Speed Downshift	Optimal gear downshift should be performed when engine RPM reaches 1300 value
4	1.3 Optimal Engine Speed	The best fuel consumption and torque is achieved in the RPM range from 1900 to 2100. This RPM range shall be used as criteria for optimizing vehicle performance.
5	1.3.1 Gear Ratio Differential	Differential gear ratio values shall result into usage of optimal RPM performance range during the gear change
6	1.3.1.1 RPM Drop	Differential gear values shall be configured to allow RPM drop up to 600 during upshift of the gear
7	1.4 Engine Brake	Gear upshift shall not result into engine brake
8	1.4.1 Wheel Speed Upshift	Wheel speed shall be equal or greater than the wheel speed before gear upshift
9	3 Gear Change Sequence	Gear change UP and DOWN shall be performed in a series manner
10	3.1 Gear Change UP	Gear upshift shall be increased by one incremental step
11	3.2 Gear Change DOWN	Gear downshift shall be decreased by one decremental step
12	4 Vehicle Rims	Vehicle standard wheel rims shall be 16 inches in diameter
13	4.1 Sport Edition Rims	17 inches wheel rims is an option for sport variant
14	5 Transmission Gears	Vehicle automatic transmission shall be 5 speed transmission

SysML-based Case Study: Vehicle Automatic Transmission Model Description

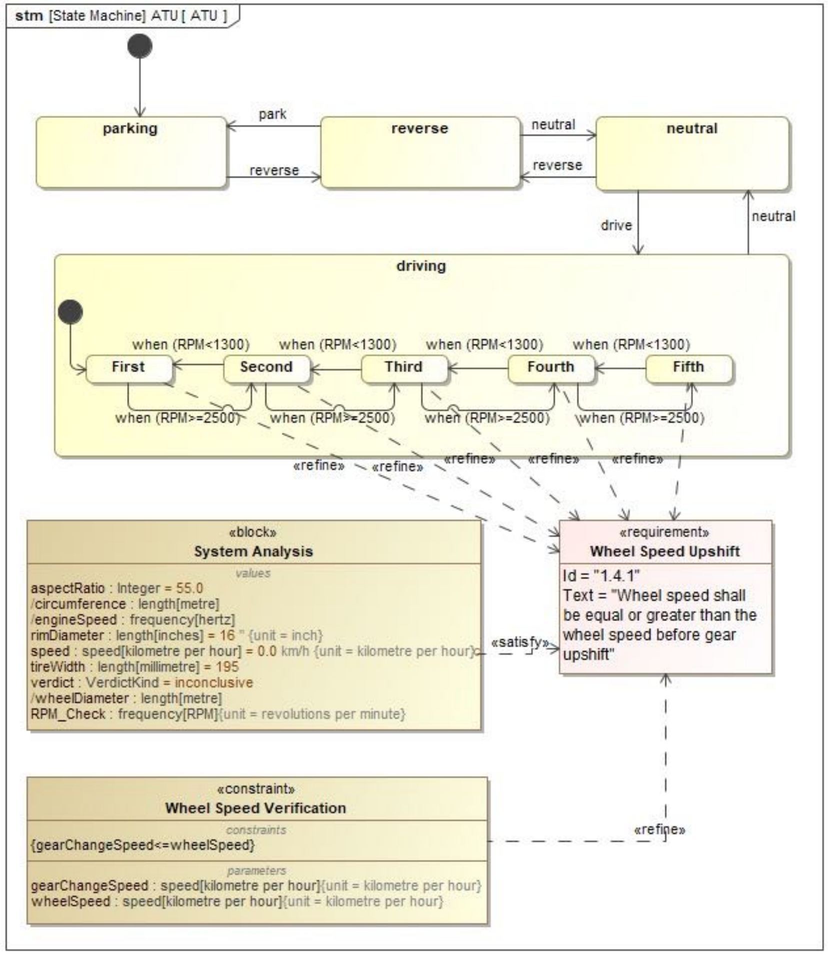


SysML-based Case Study: Analysis and Verification of Vehicle Automatic Transmission

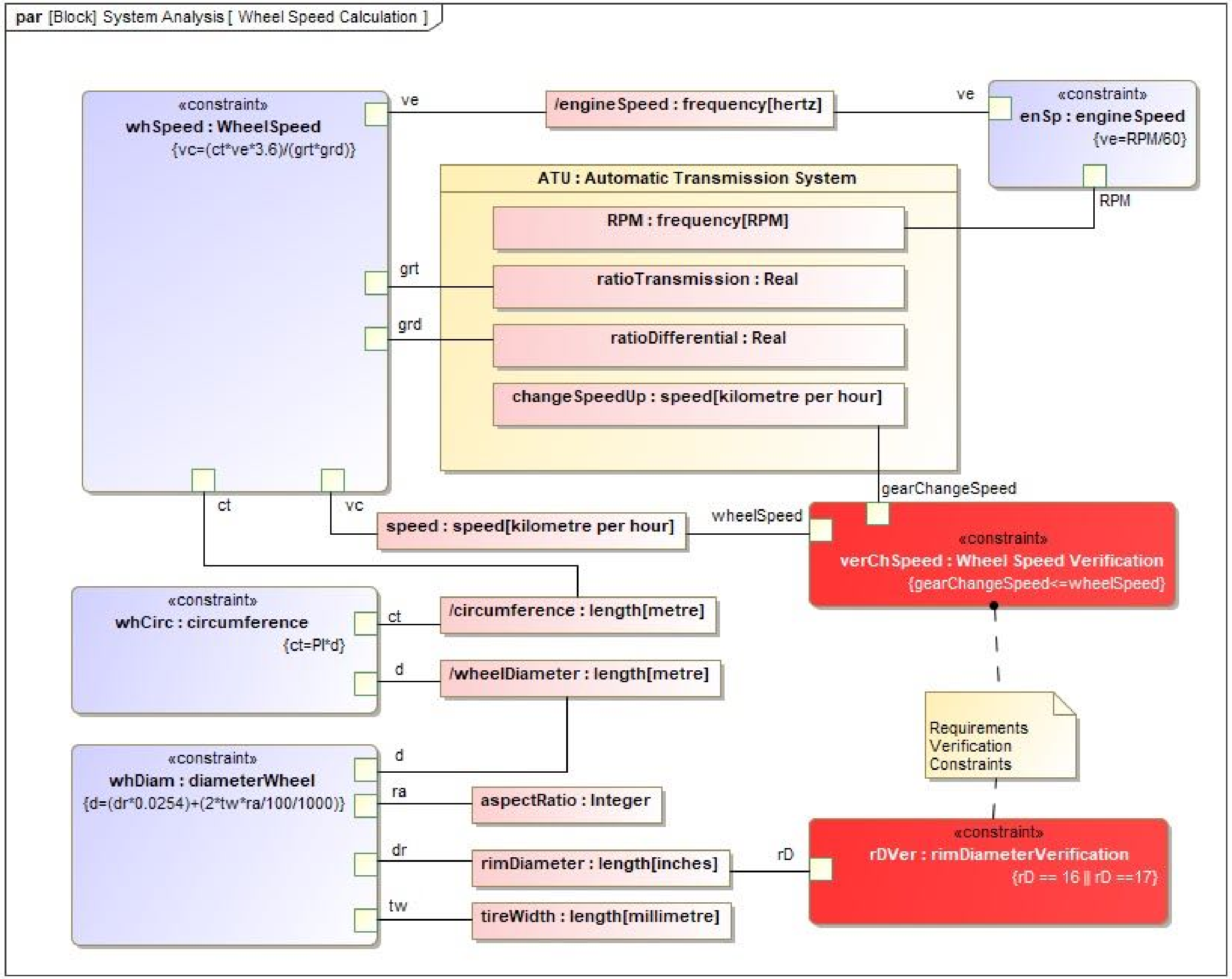
A. Static



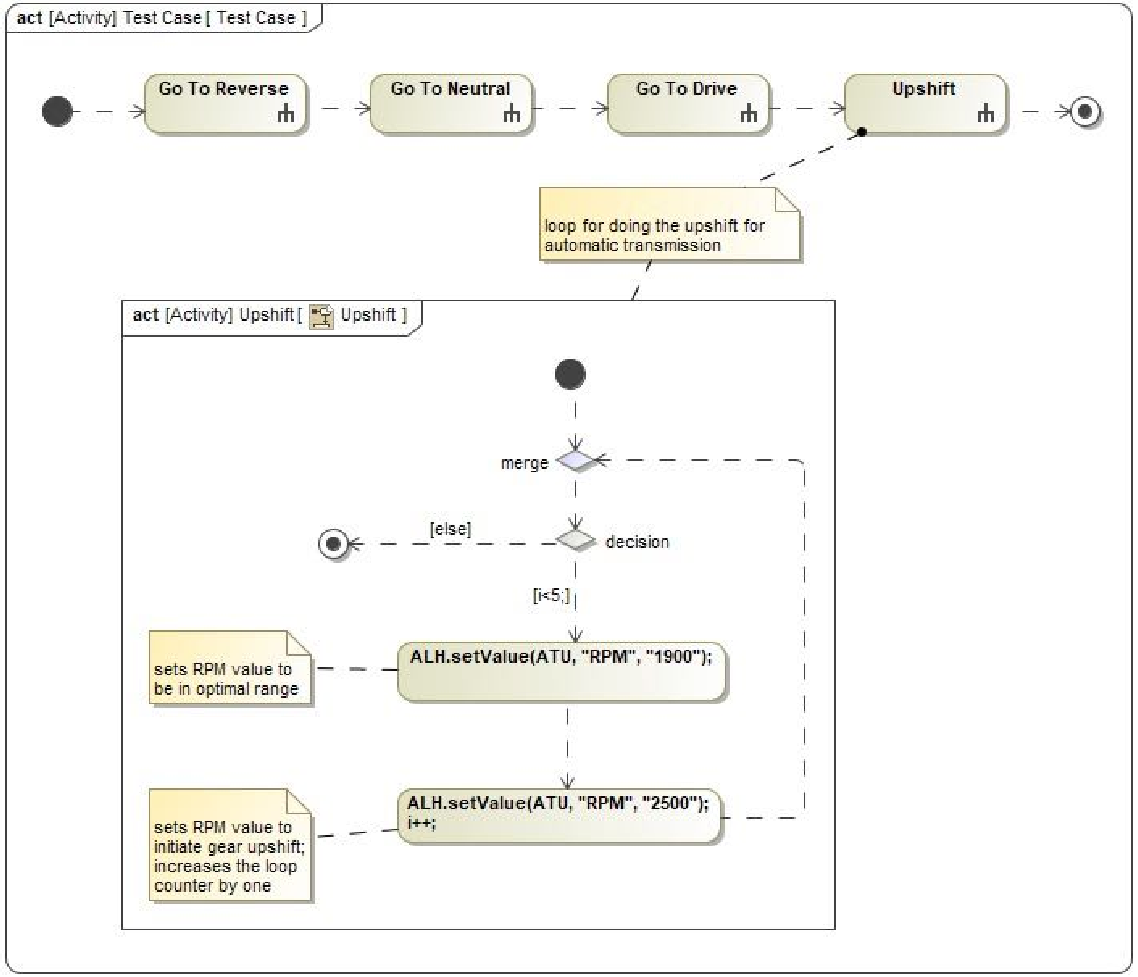
B. Dynamic



SysML-based Case Study: Parametrization of Vehicle Automatic Transmission Requirements



SysML-based Case Study: Test Case Definition



SysML-based Case Study: System parameters variation definition and verification of them

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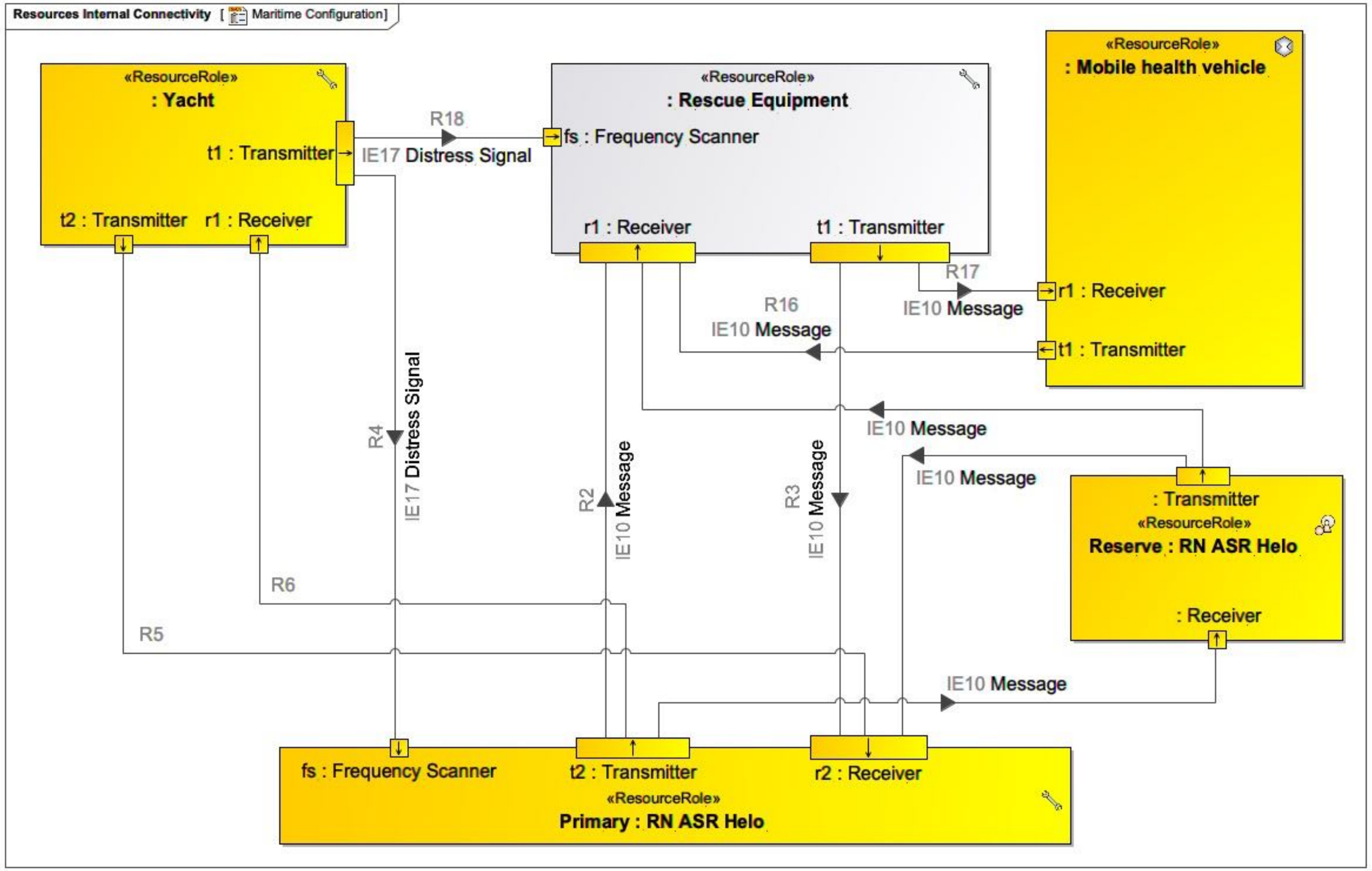
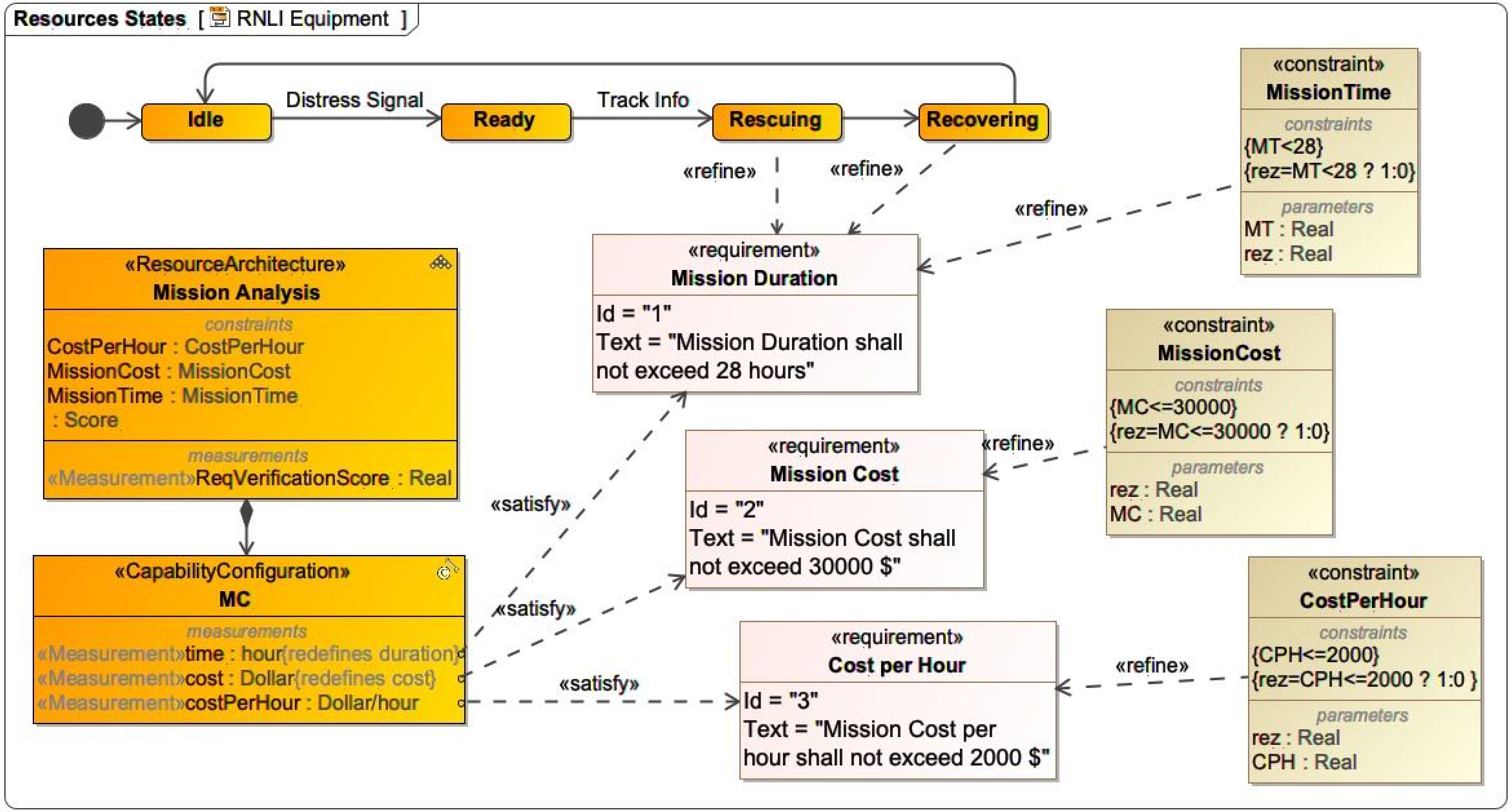
Case Study:
System of Systems Engineering Domain

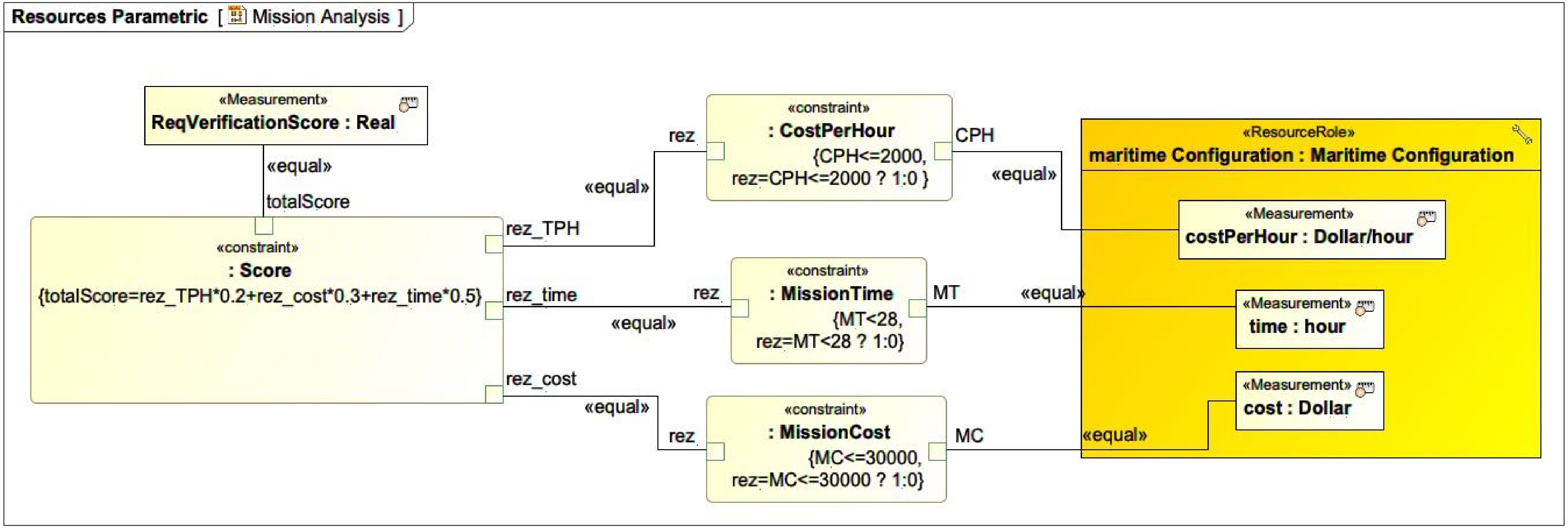
UAF-based Case Study: MSR



UAF-based Case Study: MSR



UAF-based Case Study: MSR



UAF-based Case Study: MSR

#	Name	..operationCostPerHour	.costPerHour	CostPerHour	.time	MissionTime	.cost	MissionCost	ReqVerificationScore
1	SaveByBoat	1147	998.8	pass	25	pass	24970	pass	1
2	SaveByHelicopter	4910	2164.6154	fail	13	pass	28140	pass	0.8

Conclusions

- Research described in this paper leads us to the following conclusions:
  - Automated dynamic requirements verification is a new field of study enabled by the MBSE environment. We have demonstrated the approach with SysML state machine models; however, there are also activity and interaction models that could also be taken into consideration in future research.
  - We extend the static requirements verification approach to support dynamic requirement verification by using SysML state machine models. We propose an extension that can be used to automatically verify system requirements and be used as evaluation criteria in automated trade-study analysis.
  - We demonstrate the versatility of SysML allowing us to define analysis approaches applicable to its extensions. In this particular case, UAFP allows us to apply SysML based approaches to the SoS engineering domain to verify, for example, capability requirements.
  - The whole approach is scalable and can be used for large sets of requirements or system variants.

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