Vehicle Feature Complexity Modeling
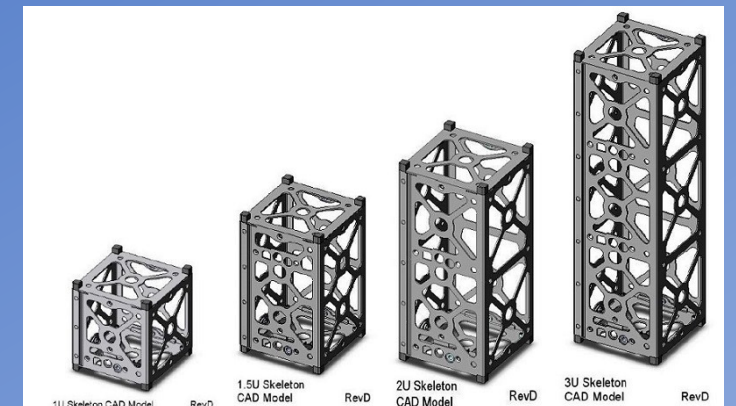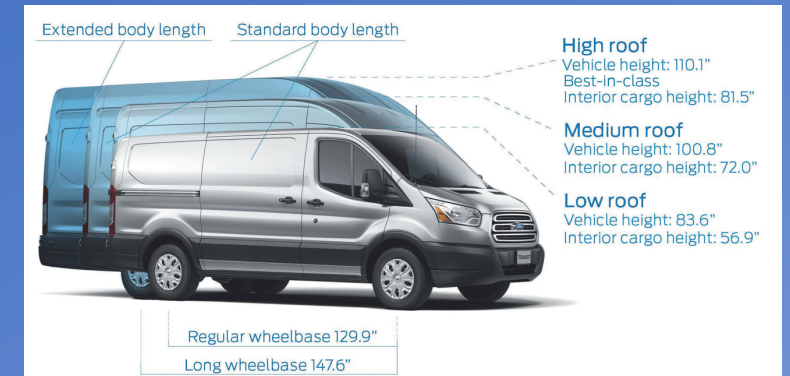
Application in the Automotive Industry

Presented by:

Natalie Matevossyan

Jesus Mata Castañeda

SYSTEM MODELING APPROACH

- **System Model proposed to manage the complexity of vehicle programs in the Automotive Industry**

- **Modeling allows to enhance variants analysis, assessment of changes and improve reliability of the project**

- **This approach would be applicable to manage the complexity on the Cube Sat, to get similar benefits**

COMPLEXITY IN THE AUTOMOTIVE INDUSTRY

- **Diversity of usage profiles and environments**

- **Multiple Target Customers**

- **Market Competition**

- **Government Regulations**

- **Global Deployment**
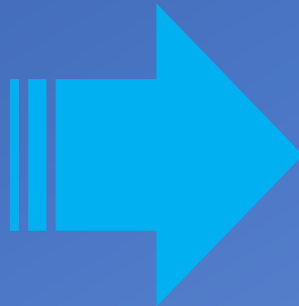
- **Design Variants**

- **Common/shared vehicle architectures (Platforms)**

- **Re-use of components**

- **Customization**

- **Mass Production**
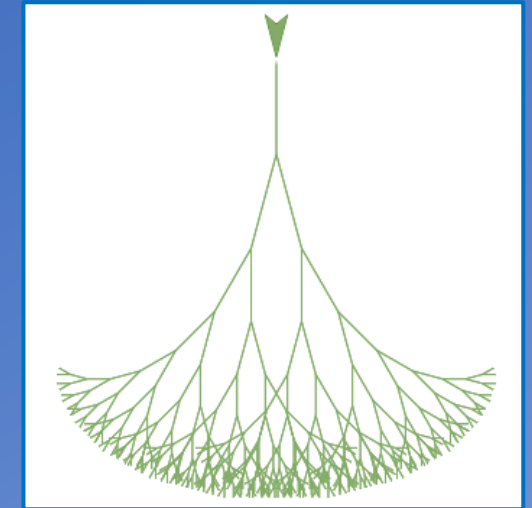

Toyota New Global Architecture

VEHICLE VARIANTS

- **Variants developed to meet customer expectations**
- **Complexity grows as features combine to form new variants**
- **High level vehicle variants include:**
  - Body Style
  - Wheel Base
  - Box Size
  - Trim Levels
  - Packages
  - Body Colors
  - Optional Content

Typical Modern Vehicle

50-70 computers on-board

> 15 million lines of software code

> 1 million pages of specifications

> 10,000 buildable series variants (including ECU variations per vehicle) (1)

(1) Automotive Software Systems Complexity: Challenges and Opportunities, Christopher Davey, INCOSE International Workshop-MBSE Workshop , Jan 26-28th, 2013

VEHICLE FEATURE COMPLEXITY MATRIX

Systems

Features
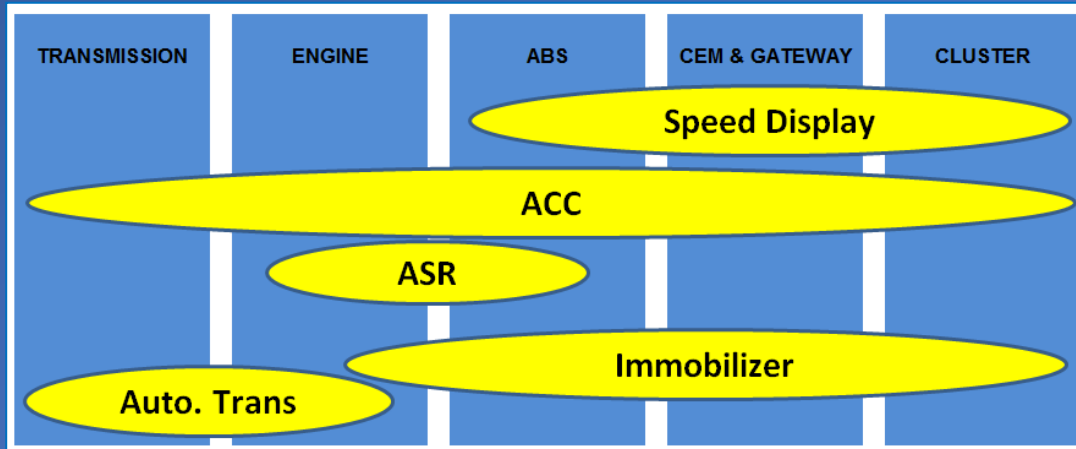
TRANSMISSION	ENGINE	ABS	CEM & GATEWAY	CLUSTER
		Speed Display		
		ACC		
	ASR			
		Immobilizer		
Auto. Trans				

Feature List	Vehicle Variants			
	USA Single Cab Base	USA Double Cab Luxury	...	South America Single Cab Base
Powertrain				
Engine 1	✓	✗	...	✓
Engine 2	O	✓	...	✗
Suspension				
Tire 1	✓	✗	...	✓
Tire 2	✗	✓	...	O
...	...	...	...	...

Features meet specific customer requirements and are formed by multiple systems

VFCM is used to keep track of ALL feature combinations that build the vehicle variants

IMPORTANCE OF THE VFCM

- **Primary official source of direction for a Vehicle Program**

- **Documents all the complexity of options that is able to be built**

- **Documents what is going to be built for specific market**

VFCM

| Engineering | Marketing | Finance | Program Management |
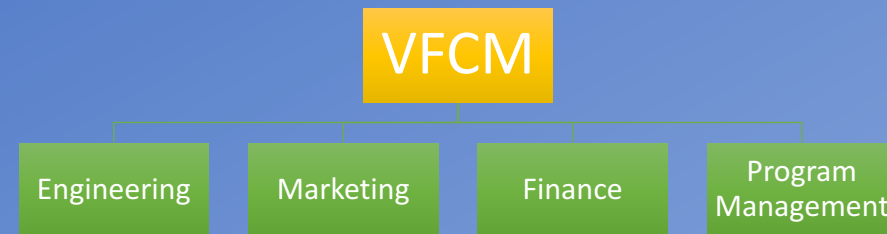
TRADITIONAL APPROACH TO VFCM

- **Document based matrix**

- **Features have relationships with vehicle variants**

- **Relations to other Features**

- **Require / Exclude Features**

- **Complex relationships**

Downsides:

Re-work	Prone to error
Manual updates	Extensive documents
Time	

Feature	Feature Code	Vehicle Variant 1
FR WIPER	FC350	
Contains RR MIRROR 1 (FC184) when {BULKHEAD 2 (FC018), BULKHEAD 3 (FC020), BULKHEAD 5 (FC023)} is not present, and when FIXED RR WINDOW (FC462) is present, and when CAMERA 2 (FC612) is not present		Contains

Feature	Feature Code	Vehicle Variant 1
RR MIRROR	FC184	
Included in FR WIPER (FC350) when {BULKHEAD 2 (FC018), BULKHEAD 3 (FC020), BULKHEAD 5 (FC023)} is not present, and when FIXED RR WINDOW (FC462) is present, and when CAMERA 2 (FC612) is not present		Includes

Feature	Feature Code	Variant 1
RHD	FC443	O*/-
Requires {MARKET GROUP 1 (FC656), MARKET GROUP 2 (FC657), MARKET GROUP 3 (FC658)}		O[1]
HEADLAMP 5	FC624	O*/-
Excludes {MARKET GROUP 2 (FC657), MARKET GROUP 4 (FC659), MARKET GROUP 3(FC658), BULGARIA (FC660), SLOVENIA (FC661), CROATIA (FC662), SLOVAKIA (FC663), MACEDONIA (FC664), ESTONIA (FC665), LATVIA (FC666), LITHUANIA (FC667)}		O[1]

Feature	Feature Code	Variant 1
LESS SIDE DOORS	FC674	S*
Contains LESS 2ND ROW R/H WINDOW (FC675)		C[1]
Contains LESS 2ND ROW L/H WINDOW (FC676)		C[2]
Contains LESS CONFIG UNLOCKING (FC655) when LIFTGATE (FC518) is not present, and when {SPECIAL TRANSPORT PACKAGE (FC669), SPECIAL TRANSPORT PACKAGE 2 (FC671), SPECIAL TRANSPORT PACKAGE 3 (FC673)} is not present		C[3]

VFCM CONTEXT

bdd [Package] Diagrams [Context Diagram]

- Part release database
- Requirements Database
- Complete vehicle design
- Engineering Manager
- Vehicle usage envionment
- Product Development Process
- Engineering team
- Final Customer
- Program Management Team
- «block» Vehicle Feature Complexity Matrix
- Market Database
- Dealership
- Program Manager
- VFCM author
- Marketing team
- Finance cost database
- Finance Team

- **Interfaces with stakeholders:**
  - **Engineering**
  - **Marketing**
  - **Finance**
  - **Management**
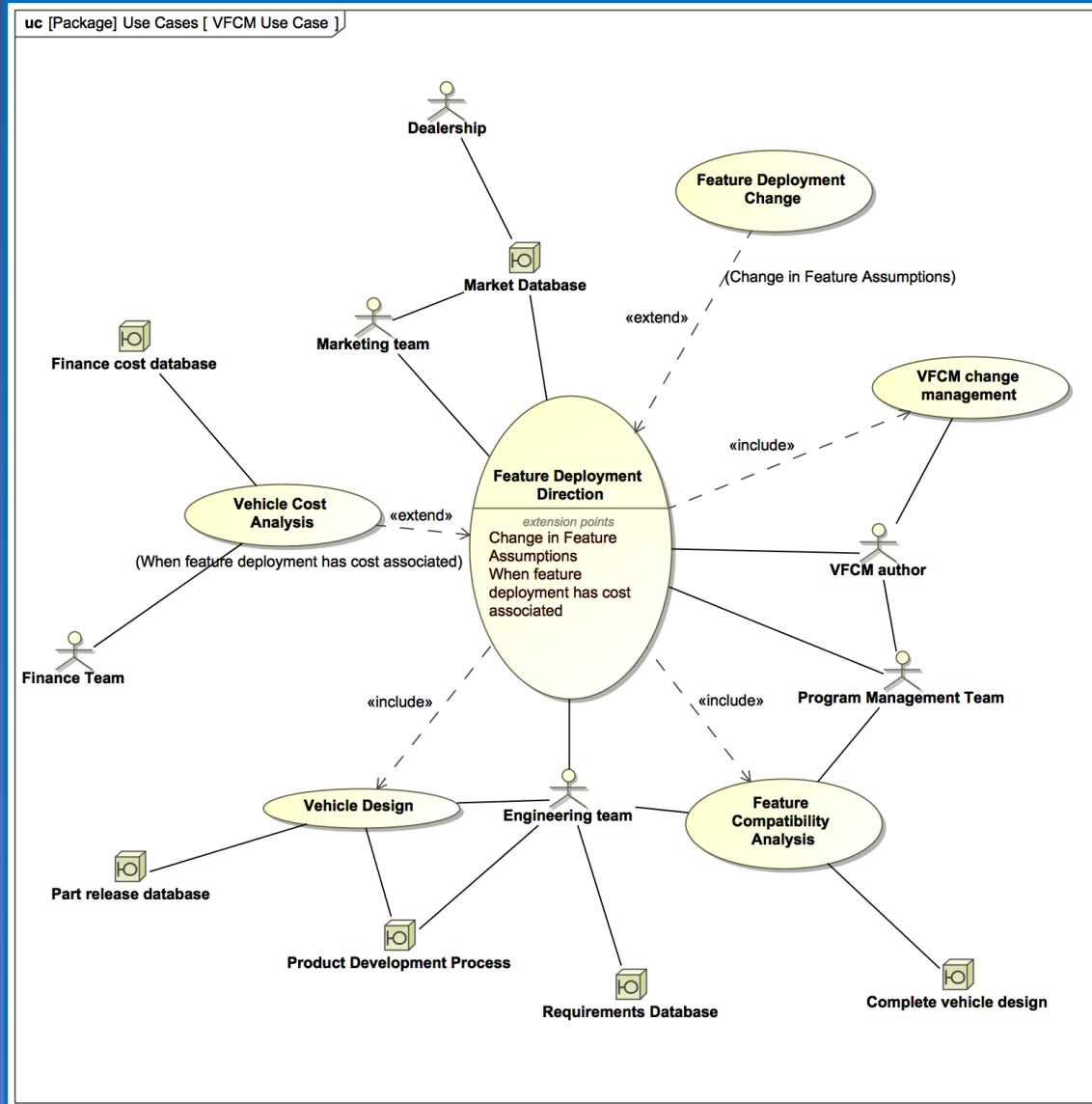 - **Dealership**
  - **Final Customer**
- **Interfaces with boundary systems**
  - **PD Process**
  - **Part release system**
  - **Requirements database**
  - **Complete vehicle design**
  - **Market database**
  - **Finance Cost database**

Vehicle Usage Environment

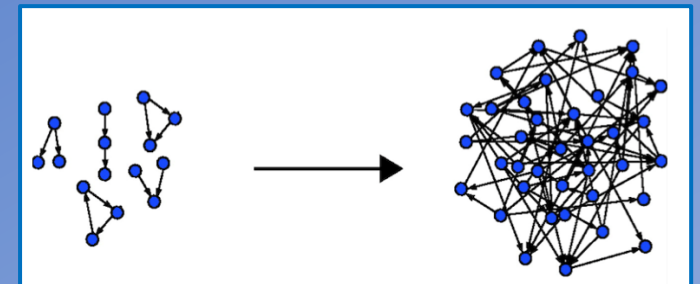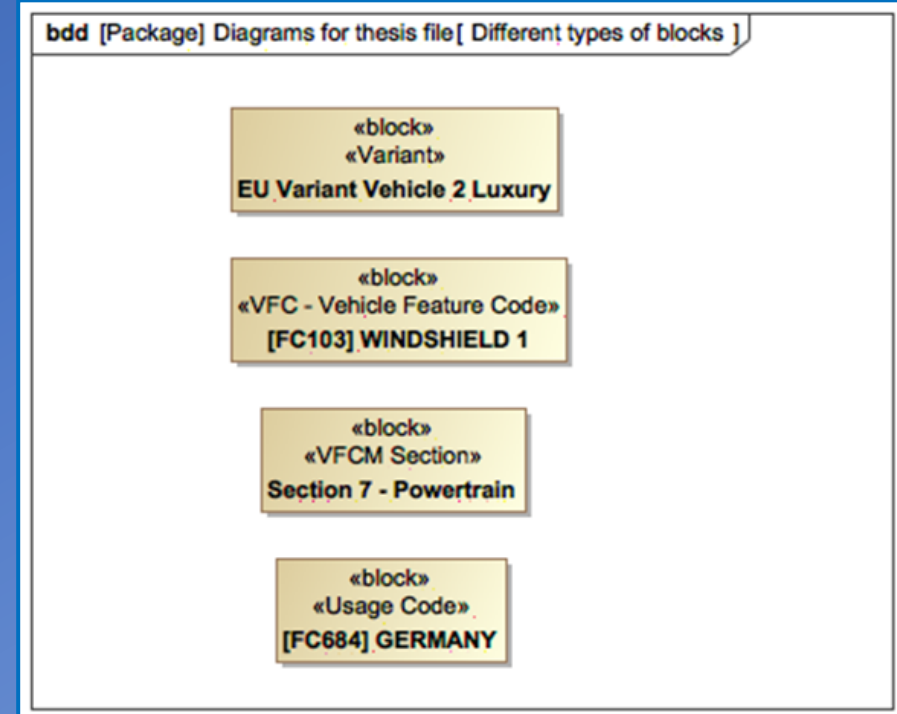# SYSTEM USE CASES

Main Use Case: Feature Deployment Direction

- **Include**
  - **Vehicle Design**
  - **VFCM change management**
  - **Feature compatibility analysis**
- **Extend**
  - **Feature Deployment Change**
  - **Vehicle Cost Analysis**

VFCM SYSTEM MODELING

- **Base entities in VFCM are Features with a Feature Code**

- **Feature = Model Block**

- **Block Stereotype differentiate features / variants, etc....**

- **Blocks connected to each other represent the Features relationships**

- **High complexity of Feature relationships are managed by the System Model**

bdd [Package] Diagrams for thesis file [Different types of blocks]

«block»
«Variant»
EU Variant Vehicle 2 Luxury

«block»
«VFC - Vehicle Feature Code»
[FC103] WINDSHIELD 1

«block»
«VFCM Section»
Section 7 - Powertrain

«block»
«Usage Code»
[FC684] GERMANY

RELATIONSHIPS AMONG ENTITIES

Part Properties

Owner	Feature Code
LIFTGATE Contains SIDE DOORS SPECIAL TYPES (FC601) Contains available DUAL SIDE DOOR (FC648) Contains LESS DOOR ARMS (FC654) Contains FIXED RR WINDOW (FC462) Contains LESS CONFIG UNLOCKING (FC655)	FC518
Parts	**Feature Code**
SIDE DOORS SPECIAL TYPES Included in LIFTGATE (FC518)	FC601
DUAL SIDE DOOR Included in LIFTGATE (FC518)	FC648
LESS DOOR ARMS Included in LIFTGATE (FC518)	FC654
FIXED RR WINDOW Included in LIFTGATE (FC518)	FC462
LESS CONFIG UNLOCKING Included in LIFTGATE (FC518)	FC655

- **Model Part Properties convey ownership (true connection)**

- **Diagrams replace complex and repetitive text relation descriptions**

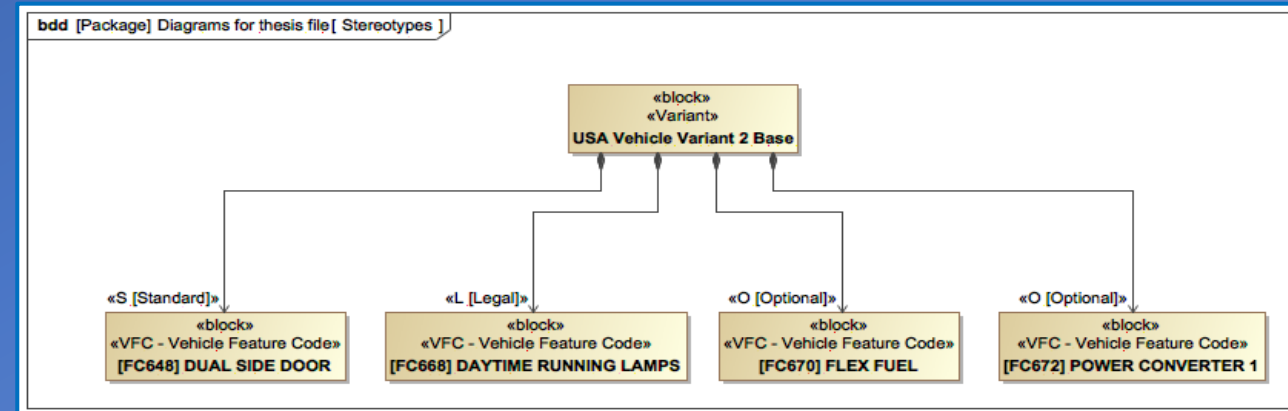- **Part Properties represent feature packages**
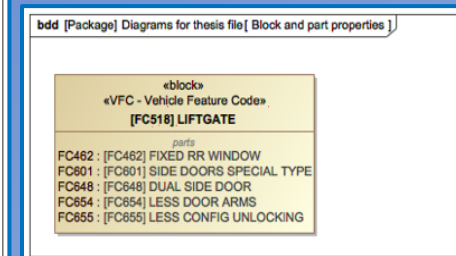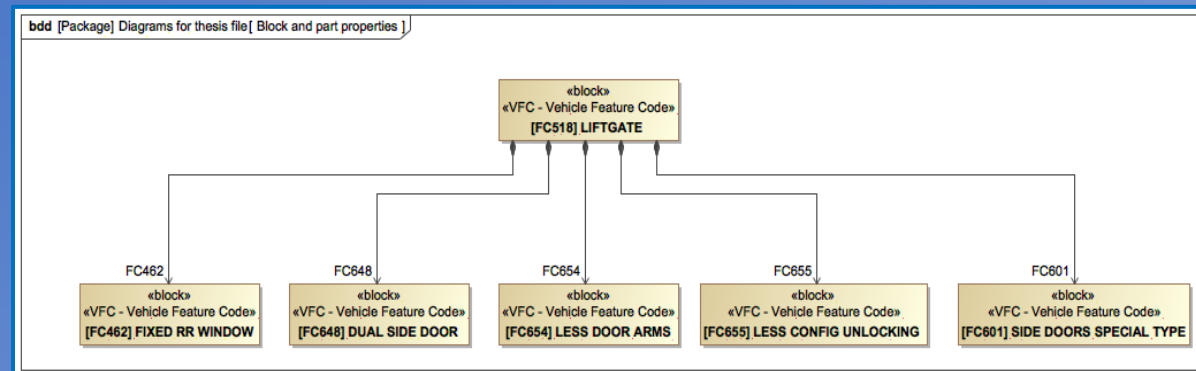
RELATIONSHIPS AMONG ENTITIES

Optionality

Optionality is modeled as a part property with stereotypes

- **Standard** – Always present

- **Optional** – Optional can be or not be present depending on customer selection

- **Legal** – Obligatory by legal requirements usually associated with specific markets legislation

- **Mandatory** – Obligatory based on a strong market need or an engineering performance reason

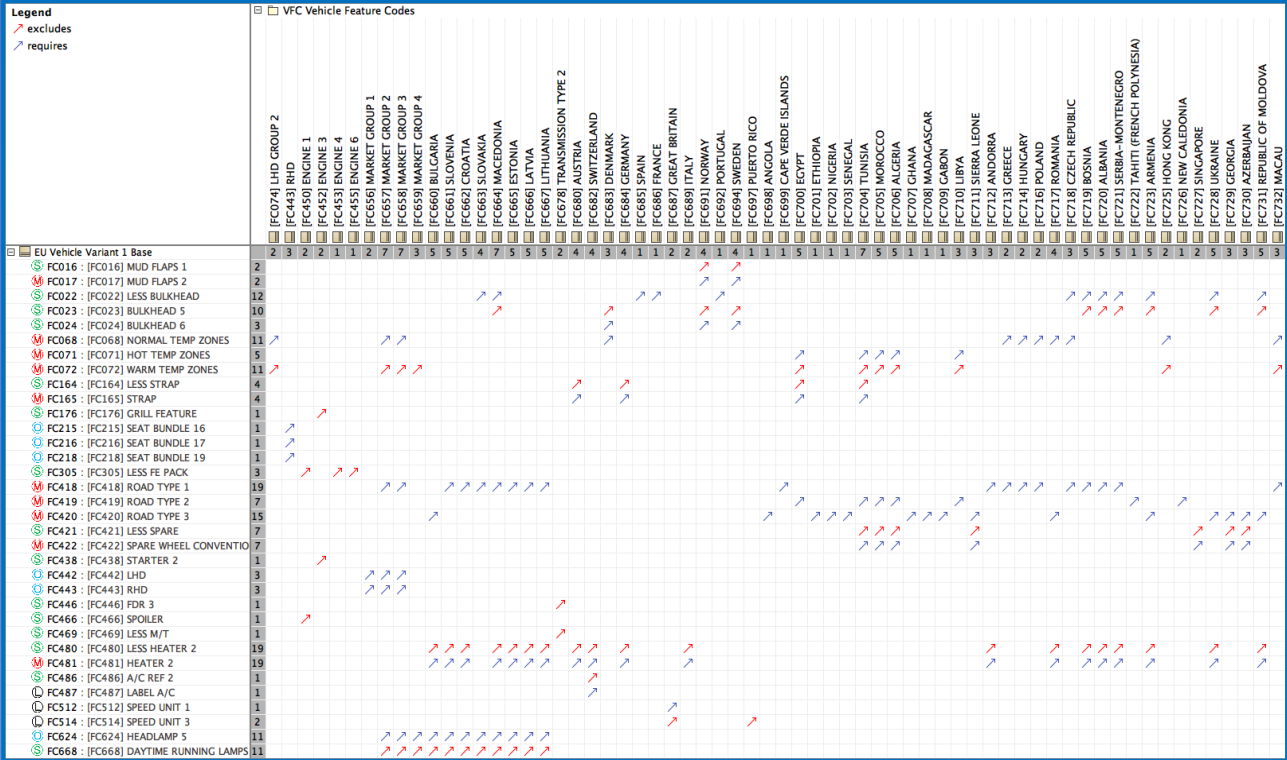# RELATIONSHIPS AMONG ENTITIES

Feature Constraints

Traditional VFCM represents constraints with text:

- *Requires*: One feature/block needs other in order to be deployed

- *Excludes*: Certain feature/block is not deployed when other is present

Constraints modeled as dependency relations

Customizable matrixes allow to track dependencies

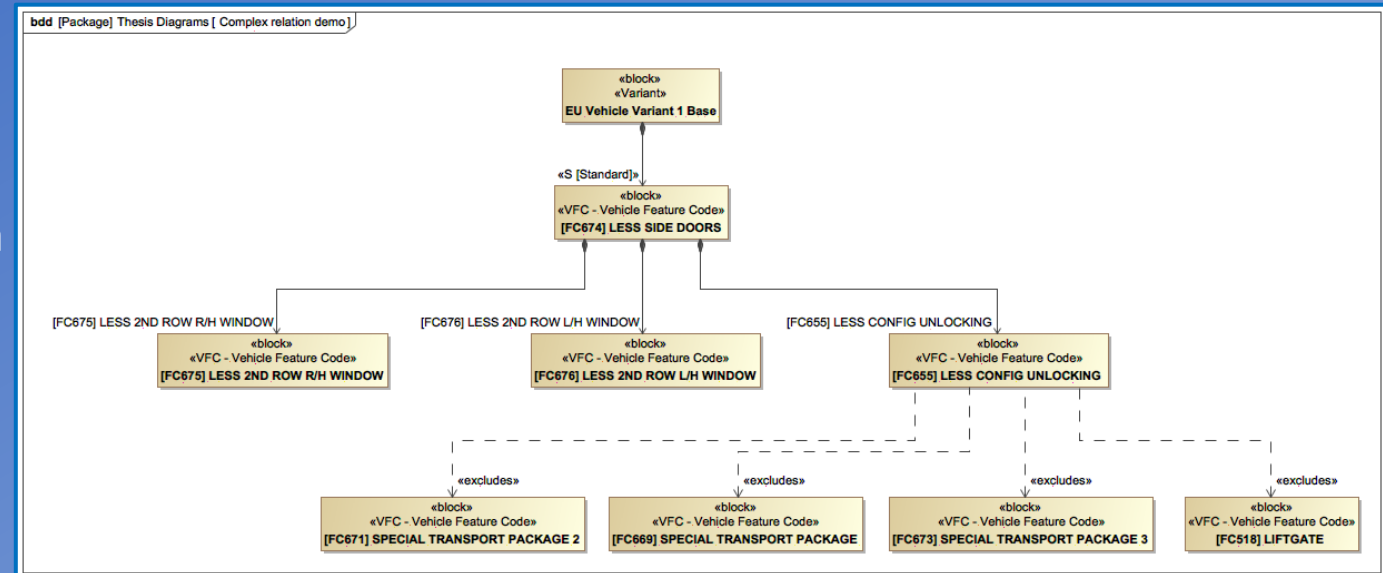| Feature	Feature Code	Variant 1
RHD	FC443	O*/-
Requires {MARKET GROUP 1 (FC656), MARKET GROUP 2 (FC657), MARKET GROUP 3 (FC658)}		O[1]
HEADLAMP 5	FC624	O*/-
Excludes {MARKET GROUP 2 (FC657), MARKET GROUP 4 (FC659), MARKET GROUP 3(FC658), BULGARIA (FC660), SLOVENIA (FC661), CROATIA (FC662), SLOVAKIA (FC663), MACEDONIA (FC664), ESTONIA (FC665), LATVIA (FC666), LITHUANIA (FC667)}		O[1]

RELATIONSHIPS AMONG ENTITIES

Feature Constraints

Compatibility is modeled using part properties stereotypes

Compatibility between features is easier to understand graphically

- **Compatibility**: Feature available depending on deployment of other features.

Feature	Feature Code	Variant 1
LESS SIDE DOORS	FC674	S*
Contains LESS 2ND ROW R/H WINDOW (FC675)		C^1
Contains LESS 2ND ROW L/H WINDOW (FC676)		C^2
Contains LESS CONFIG UNLOCKING (FC655) when LIFTGATE (FC518) is not present, and when {SPECIAL TRANSPORT PACKAGE (FC669), SPECIAL TRANSPORT PACKAGE 2 (FC671), SPECIAL TRANSPORT PACKAGE 3 (FC673)} is not present		C^3

COMPLEXITY OF FEATURE RELATIONS

VFCM model contains highly complex relations between Features

Analysis can be customized to define levels of depth
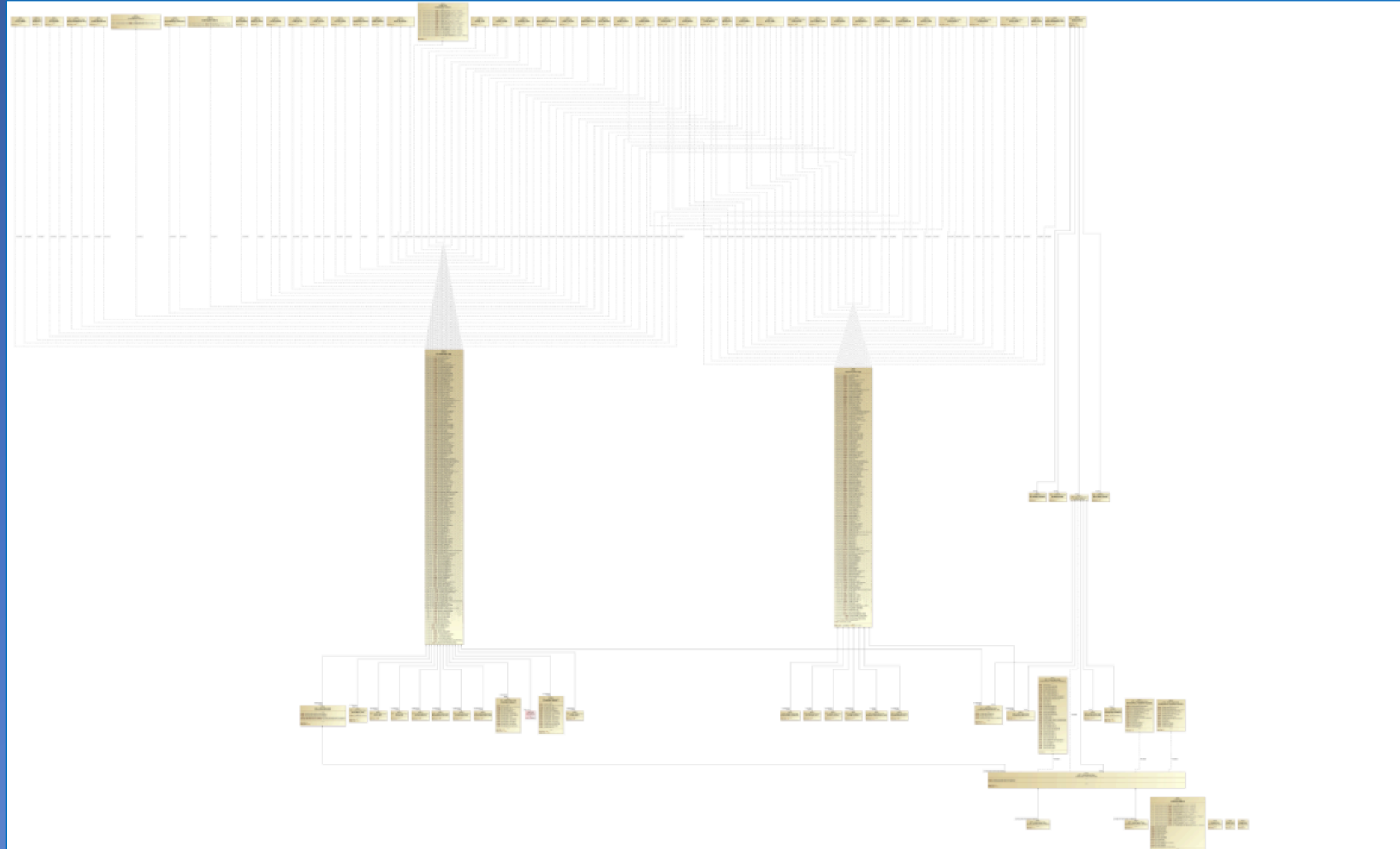
ERROR CHECK TOOL

Custom Analysis tables can be developed easily

Errors and inconsistencies in the model can be minimized

COST ROLL-UP

Each feature is assigned with a cost

#	Owner	Default Value	Feature Cost [Dollars]
70	[FC041] GVW 3	0	0
71	[FC440] EMISSIONS PACK 2	600	600
72	[FC632] LIGHT FEATURE 1	5	5
73	[FC219] SEAT BUNDLE 20	220	220
74	[FC084] REPAIR KIT	5	5
75	[FC166] LESS GRAB HANDLE	0	0
76	[FC451] ENGINE 2	3000	3000
77	[FC125] CUP HOLDER	8	8
78	[FC149] LESS HOOK	0	0
79	[FC535] FEATURE X 8	100	100
80	[FC343] DOOR LOCKS 5	10	10
81	[FC248] SEAT BUNDLE 49	300	300
82	[FC146] DOOR HANDLE 2	20	20
83	[FC003] TRIM 2	5	5
84	[FC417] LUG NUT 2	5	5
85	[FC284] LESS RR ROW 3	0	0
86	[FC523] SCREEN 1	0	0
87	[FC053] UPGRADE FEATURE P...	250	250
88	[FC117] GLOVE BOX 1	0	0
89	[FC283] RR ROW 2	10.0	10.0
90	[FC202] SEAT BUNDLE 3	320	320
91	[FC445] FDR 2	5	5
92	[FC311] DOOR HANDLE 3	5	5
93	[FC273] LESS SEAT FEATURE 3	0	0
94	[FC470] M/T	2000	2000
95	[FC193] MIRROR COLOR 2	5	5
96	[FC446] FDR 3	5	5
97	[FC352] JETS	20	20
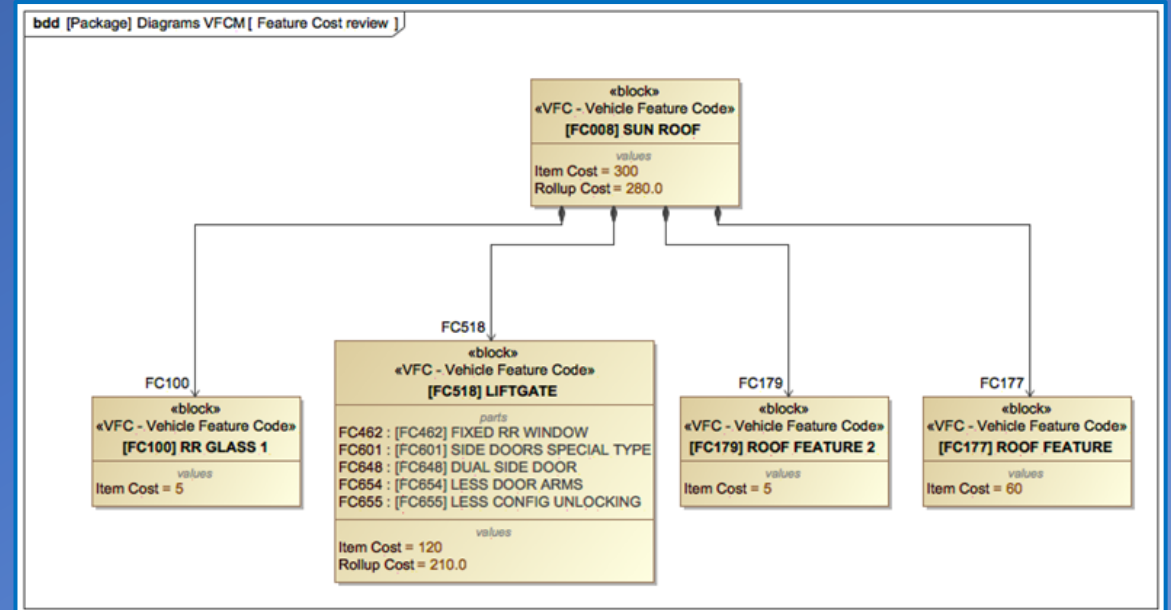
#	Owner	Default Value	Type
1	USA Vehicle Variant 2 Base	16570.0	cost [dollars]
2	USA Vehicle Variant 1 Luxury	19766.0	cost [dollars]
3	EU Variant Vehicle 2 Luxury	19598.0	cost [dollars]
4	EU Vehicle Variant 1 Base	10186.0	cost [dollars]

Cost rolls up to higher level blocks

A change in any feature is reflected automatically at all levels of the model

MODELING ADVANTAGES TO MANAGE COMPLEXITY AUTOMOTIVE

- **Meet Function**
  - **Every block is unique, all its properties and connections reside in it.**
  - **All Diagrams are just representations of blocks**
  - **Block relationships can be analyzed graphically**
  - **Model replaces multiple documents with complexity specifications**

- **Robustness**
  - **Changes are automatically updated in all the model**
  - **Minimization of errors and inconsistency**
  - **Ability to create custom error proof tools using "Custom Properties"**

MODELING ADVANTAGES TO MANAGE COMPLEXITY AUTOMOTIVE

- **Efficiency**
  - **Changes are done in one model with lower effort, and in a fraction of the time**
  - **Multiple & customizable diagrams to show the information to improve communication to users**
  - **Easier to visualize information and make decisions**
  - **Compatibility with MS Excel allows to import/export large amounts of data**

- **Minimization of unintended behavior**
  - **Avoids inconsistency and contradictions in feature deployment**
  - **Prevent re-work**
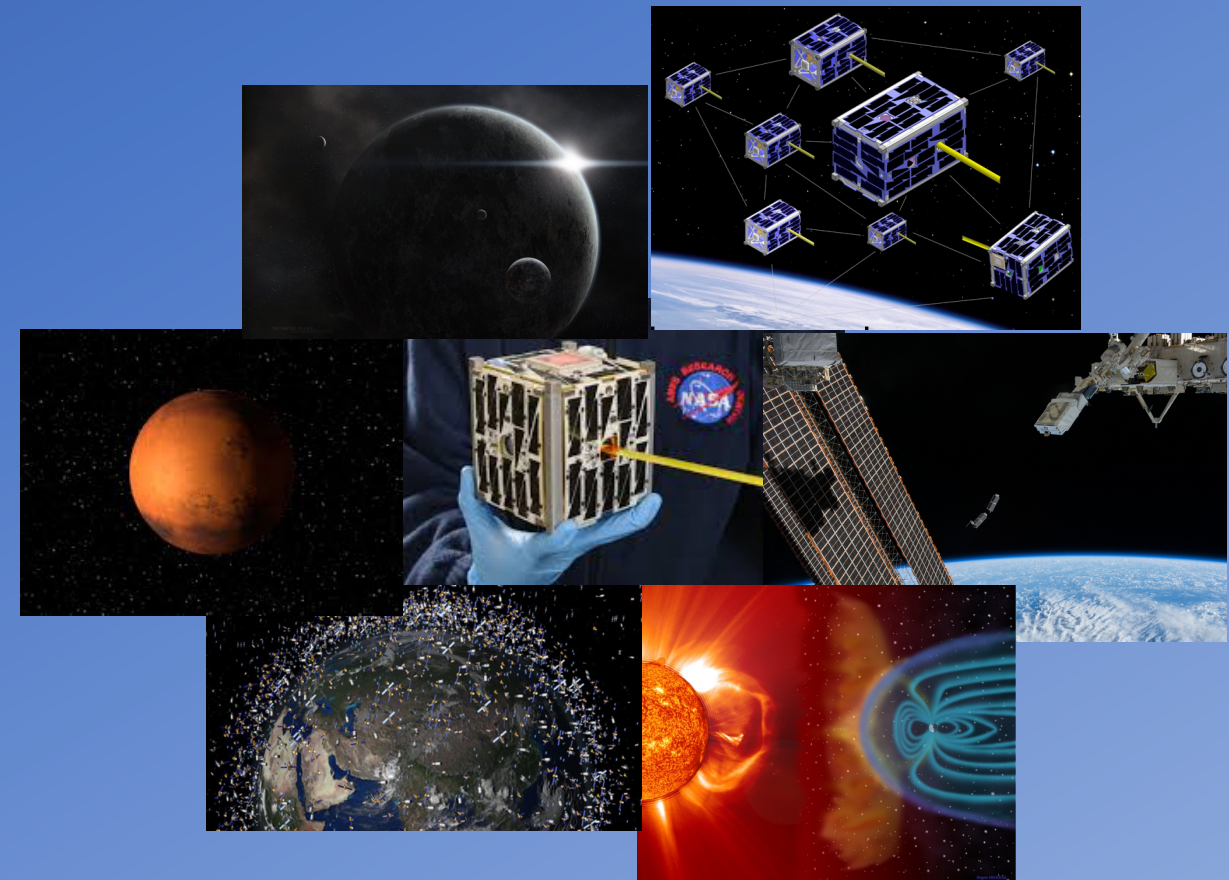 - **Manages Complexity of the VFCM, and can customize scope of the analysis**

EXPOSED TO THE UNKNOWN

Automotive

CubeSats
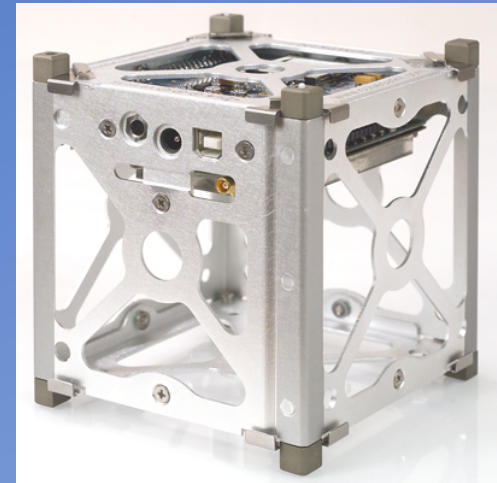
COMMONALITIES

- **Architecture**
  - Modular vs. Platform
- **Requirements**
  - Size
  - Weight/Mass
  - Cost
  - Buildability
  - Power
- **Failure Modes**
- **Cost Reduction**
- **Design and Development Improvements**

Requirements Failure Modes
Missing
Incomplete
Inconsistent
Incorrect content
Incorrect version
Inappropriate design
Incorrect Configuration
Un-accessible
Non-validated

MODELING CAN LOWER CUBE SAT COST

- **Enhance reusability of technology**

- **Reduce effort and time to run complexity analysis**

- **More frequent less costly reviews**

- **Cost Rollup Analysis can help to to make deployment of features more cost effective**

- **Variant complexity analysis can aid to find opportunities to combine validation and reduce cost.**

- **Weight rollup analysis can help to reduce weight (cost)**

¨a single major review of the Earth Observing System Data and Information System (EOSDIS) core system being built for NASA produced over 5,000 pages of material at a cost of several person-years of effort.¨

TRW estimates that the Critical Design Review for the Total Ozone Mapping Sensor, now in orbit as part of the Earth Probes program, required 10 person-years of effort. ¨ (2)

(2) The role of small satellites in NASA and NOAA Earth observation programs, Committee on Earth Studies Space Studies Board Commission on Physical Sciences, Mathematics, and Applications National Research Council, National Academy Press, Washington DC, 2000.

MODELING CAN IMPROVE CUBE SAT ROBUSTNESS

- **Risk Management improvement**

- **More informed and quicker decisions to minimize risk to missions**

- **Reduce likelihood of errors or outdated information from document to document**

- **Model Error-proofing tools can locate early possible contradictions in Cube Sat variants**

- **Ad-Hoc and What If analysis**
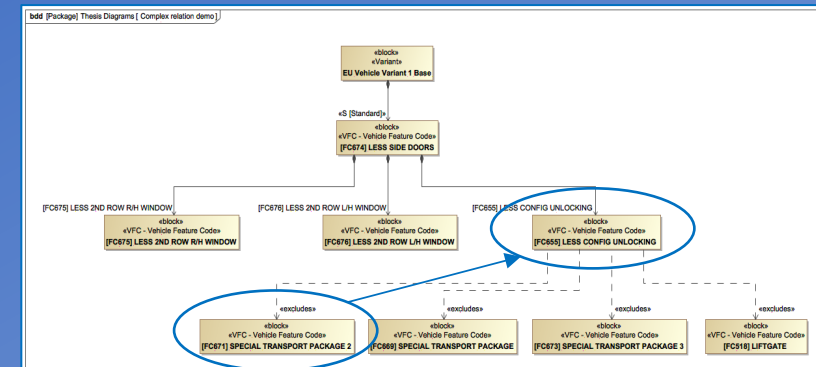
CONCLUSIONS

This system modeling approach:

- **Improved the consistency of the information, and reduced the amount of resources to manage the changes**

- **Provided a greater capability to display information in more customizable way and make timely and more informed decisions**

- **Increased the efficiency, robustness and minimize the undesired behaviors**

- **Can be expanded to different functional areas of any Product Development, at the desired level of detail**

SysML Approach creates a very Elegant Solution which is game-changer for the Automotive Industry