UDM Master of Science in Product Development

Vehicle Feature Complexity Matrix Modeling and Management in SysML

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OVERVIEW

- Goals and Objectives
- Importance of the Vehicle Feature Code Matrix (VFCM)
- Contents of the VFCM
- Disadvantages of the current VFCM Format
- Concept design
- SysML Approach to the VFCM Modeling
- Applying Systems Thinking to the VFCM Design
- Next Steps and Further Research Opportunities
- Conclusions

GOALS AND OBJECTIVES

- Present a different approach to creating, maintaining and managing the VFCM
- Develop a “Proof of Concept” using the SysML Modeling approach
- Discuss the advantages of the “Model-based” approach
- Discuss further steps

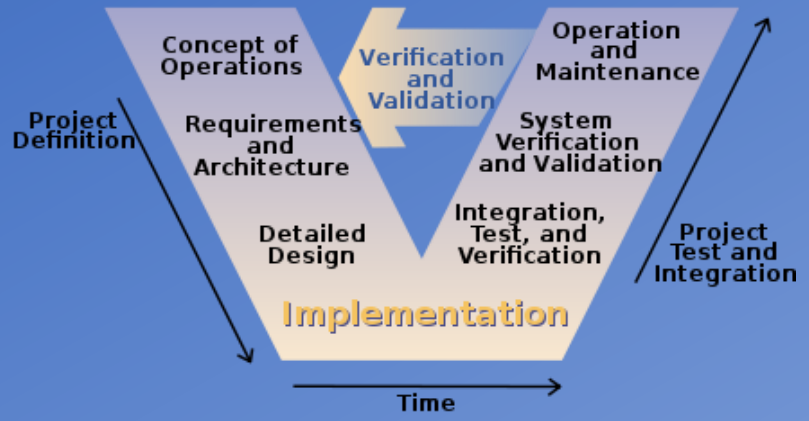
IMPORTANCE OF THE VFCM

- Primary official source of direction for a Vehicle Program
- Documents all the complexity of options that is able to be built (engineered)
- Documents what is going to be built for specific markets or market groupings
- Defines the timing points, Vehicle Series, Standard and Optional content, Plants, Markets, etc.
- Delivers the required codes for Marketing, Finance, Engineering, etc.

IMPORTANCE OF THE VFCM

The VFCM

- is a very active document
- collects and communicates feature deployment information with Engineering and Marketing
- is updated constantly during the Product Development process
- has a significant impact to the PD process



VFCM

CONTENTS OF VFCM

- The current VFCM is a static document published in PDF or MS Excel Format
- Common main tabs of the VFCM consist of but are not limited to the following:
  - Summary
  - Market List
  - Legal and Mandatory Engineering Features by Market
  - Availability and Deployment of the Power packs by Market
  - Features and Options
  - Deployed Features by Market
  - Packages
  - Navigational Data, etc.

DISADVANTAGES OF THE CURRENT VFCM FORMAT

- The VFCM is a static document
  - Requires manual rework to maintain document up-to-date
  - Manual updates cascade
  - Verification of the correct update of all the derivative documentation
- Various tabs contain overlapping information
- Size of the document may become > 100 pages
  - Difficulty of finding data
  - Understanding the directions
  - Difficulty in performing error-proving

NOTE: KEY POTENTIAL ISSUE: the VFCM is 100% manually authored, generated and managed

CONCEPT DESIGN

"The systems engineering processes begin very simply with the identification of a need for a new or improved system" (R. Ian Faulconbridge, 2003)

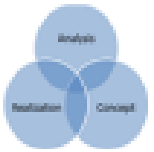
We will consider the VFCM to be the "Product"

Concept Design

Identify Stakeholders

Identify Stakeholder Requirements

Analyze Requirements

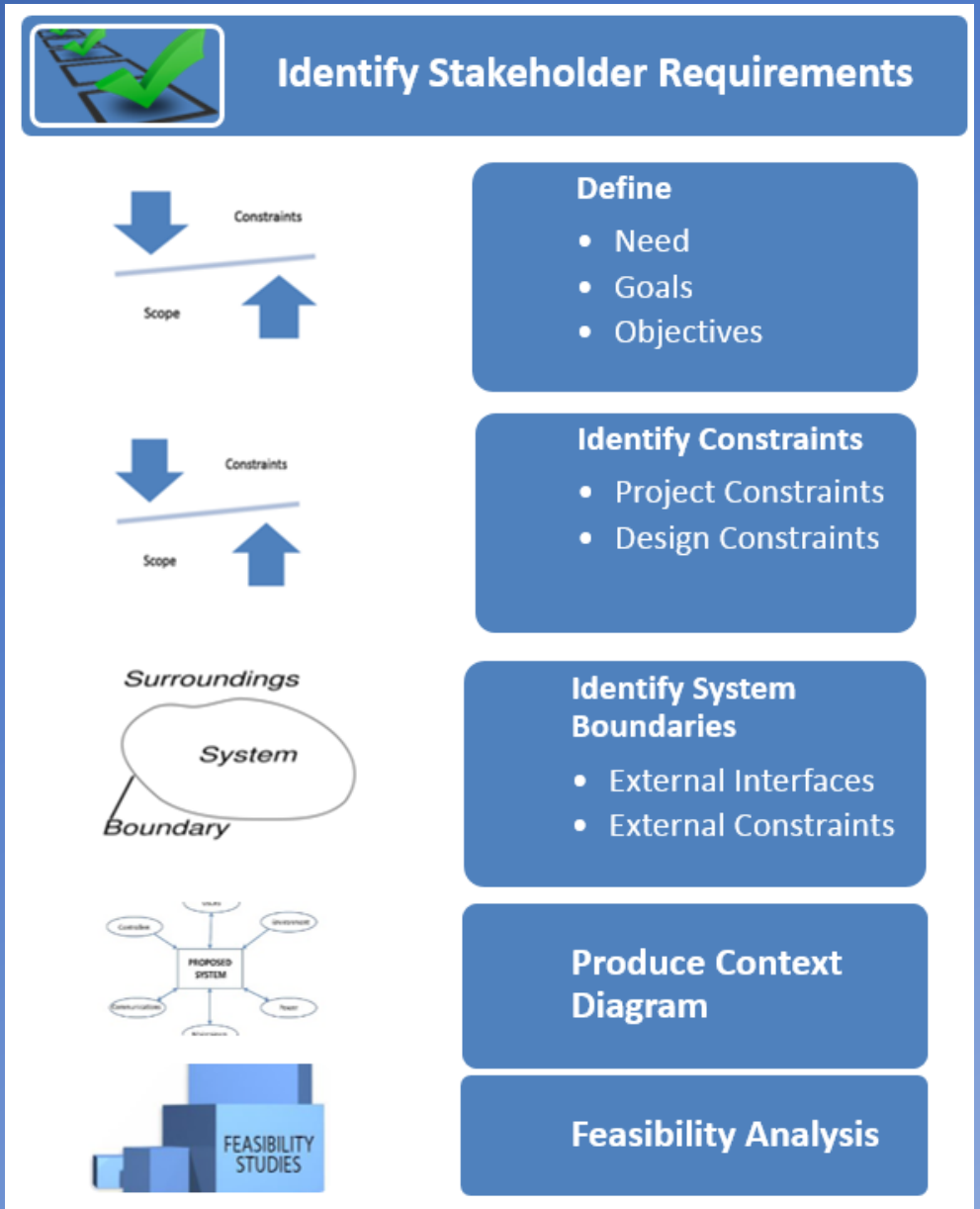


System Design Review

IDENTIFY STAKEHOLDERS AND REQUIREMENTS

Identified Current and Potential Stakeholders

- VFCM Authors
- Program Teams
- Marketing Team
- Purchasing Team
- Finance Team
- Dealers



IDENTIFY STAKEHOLDER REQUIREMENTS

Needs

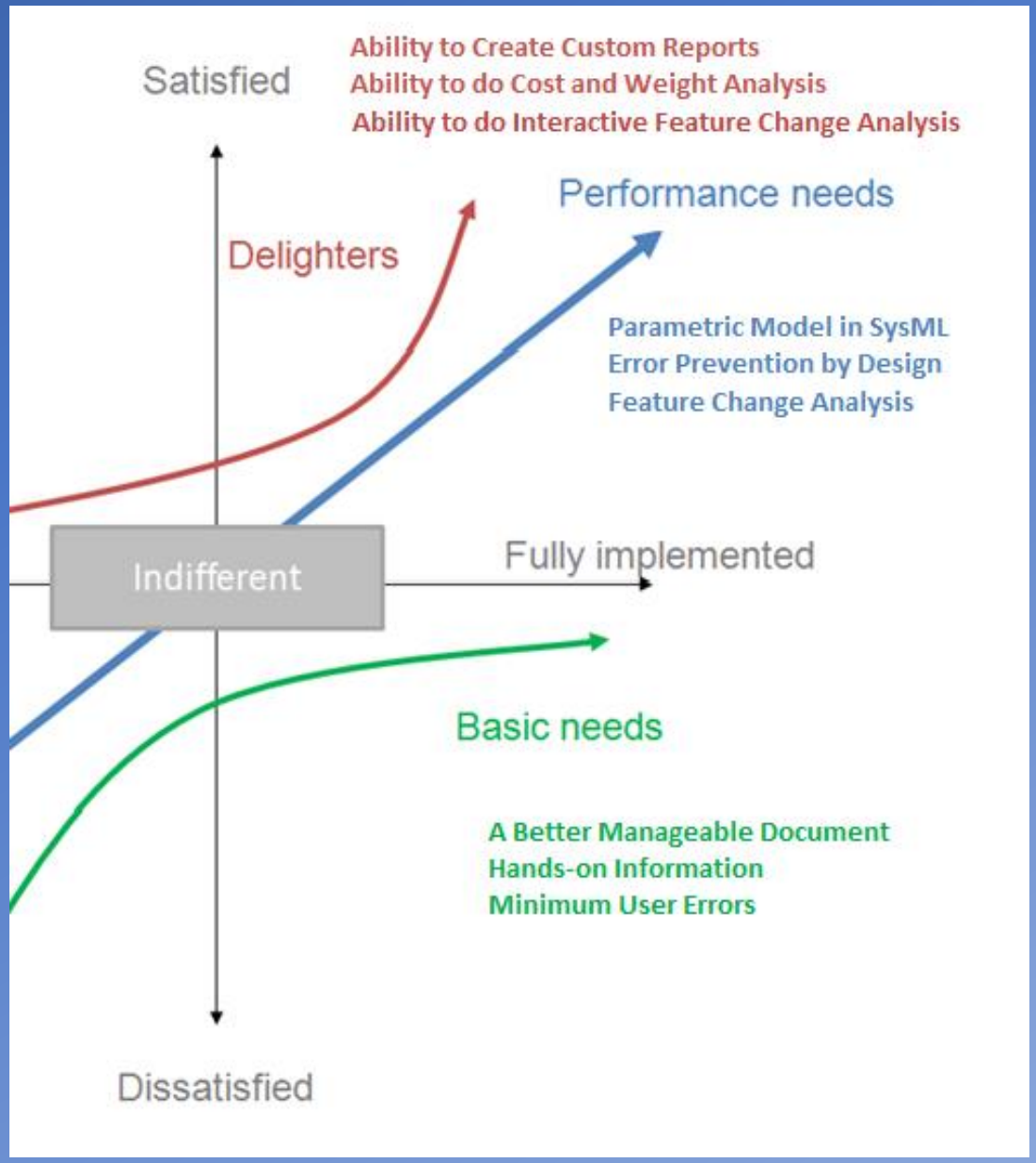
- A better manageable document
- Hands-on information
- Minimum user errors

Goals

- Provide a "Proof of Concept"

Objectives

- Use SysML to create a parametric model of the VFCM
- Use SysML to create error-states and show the way to prevent errors
- Use SysML to create custom reports
- Use SysML to create a Cost Roll-Up



IDENTIFY CONSTRAINTS

Project Constraints

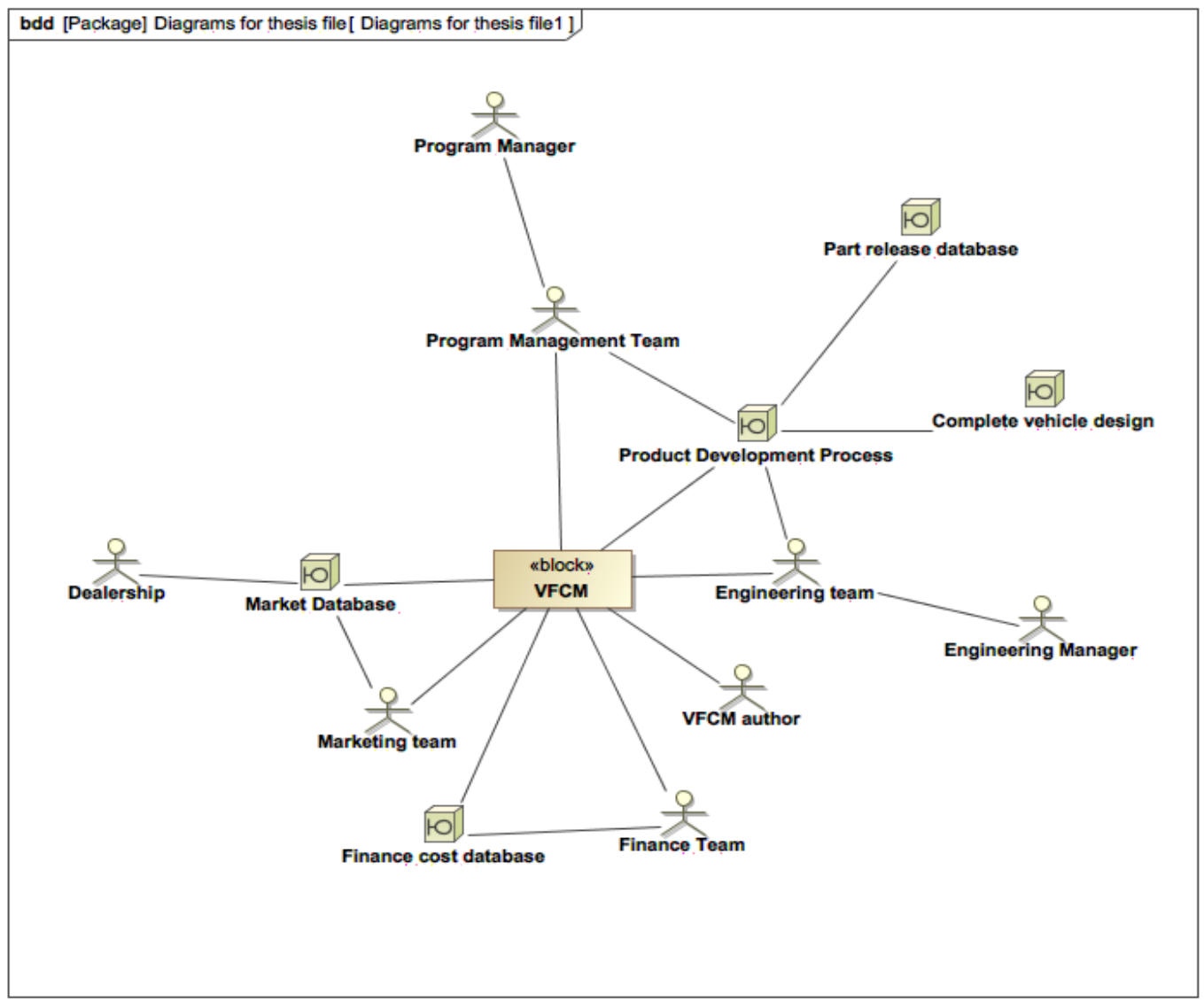
- Unavailability of the source raw data
- Working with highly confidential information

External Constraints

- The VFCM Output Data Compatibility as an input into other systems

"Interface control consists of establishing common understanding of interfaces for all project participants." (Weiss, 2013)

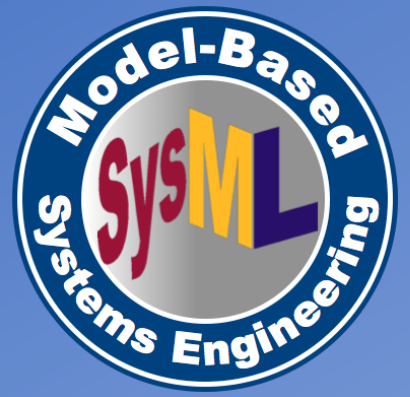
IDENTIFY EXTERNAL INTERFACES



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

SysML MODELING GENERAL OVERVIEW

- Model-based approach so Systems Engineering proposes to create an “integrated, coherent, and consistent System Model, created by using a systems model tool” (Delligatti, 2013)
- Traditional document VFCM text can be represented as model elements with a set of relationships between them.
- SysML is a “modeling language” that can be understood as a graphical language
- The model has the purpose of facilitate visualization and communication of a system’s design among stakeholders.
- The system modeling tool used in this project was Magic Draw by NoMagic



APPLYING SYSTEMS THINKING TO VFCM

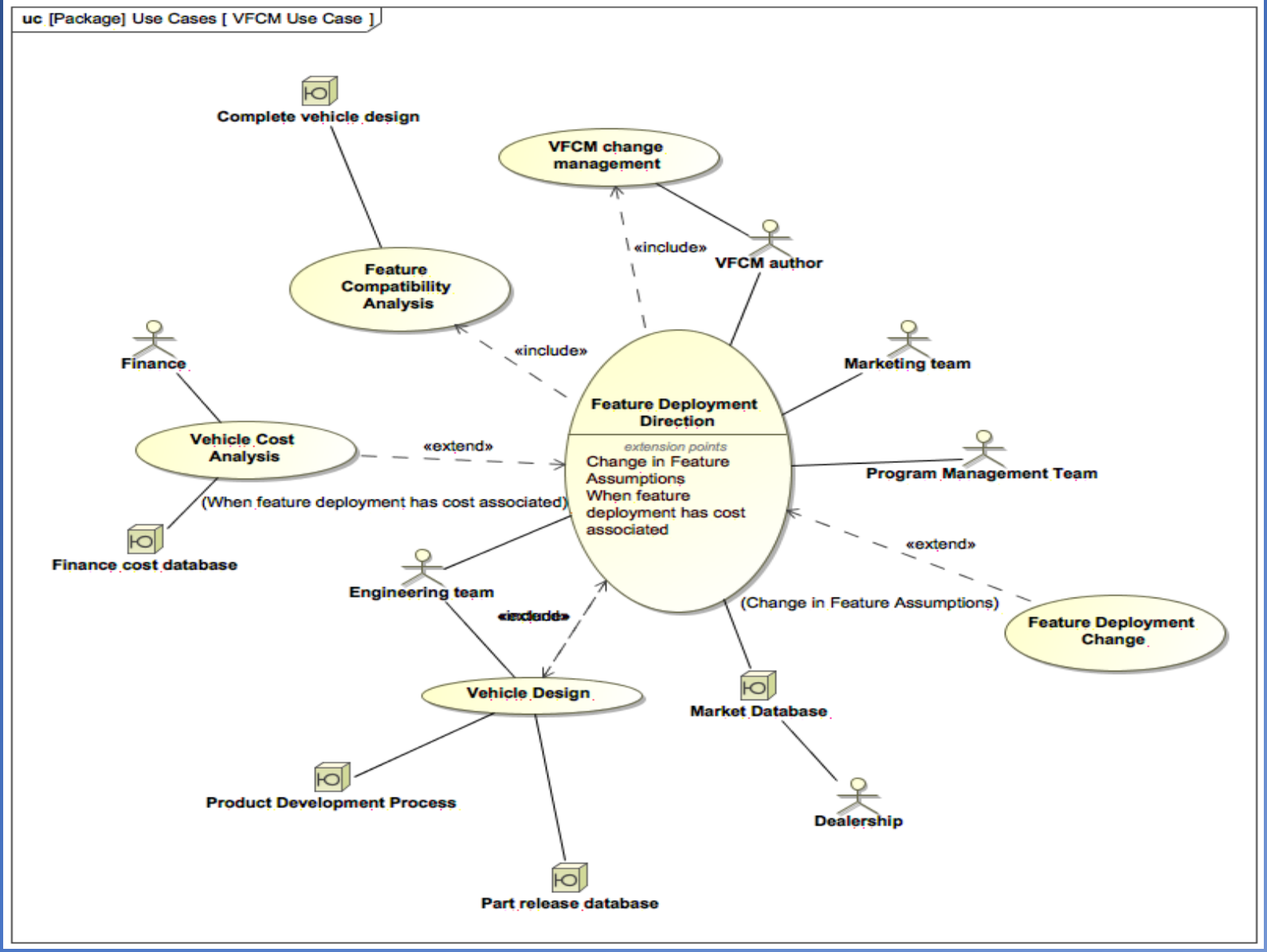
Consideration: The VFCM is a very complex system with a multiplicity of elements and complex relations between them.

Crawley's approach to Systems Thinking suggests the development of a system model which can be structured and done in an ordered manner, following the next four stages:

- **Identify the System**
- **Identify the Entities**
- **Identify the Relationships Among Entities**
- **Analyze Emergence**

Input Data Used: "Features & Options" Template

IDENTIFY THE SYSTEM



Main Use Case: Feature Deployment Direction

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

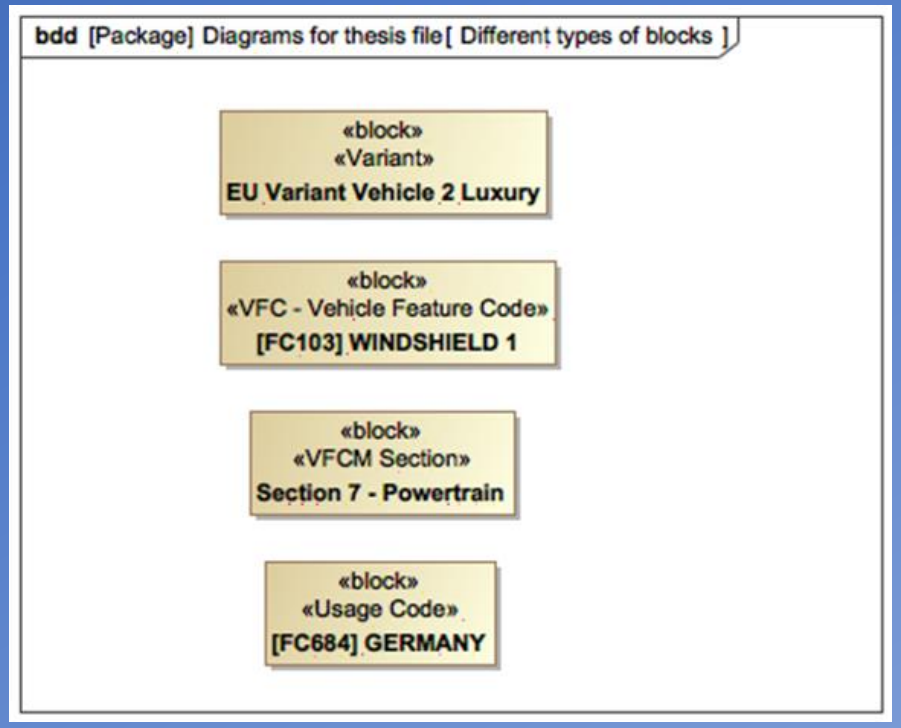
IDENTIFY THE SYSTEM

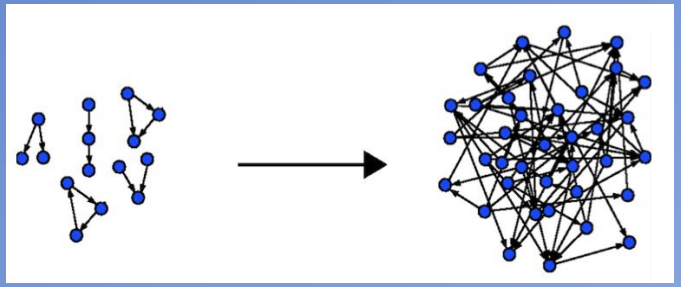
Selected section of the VFCM to develop the “Proof of Concept” model: Features & Options

	Vehicle Variants			
Feature List	USA Single Cab Base	USA Double Cab Luxury	…	South America Single Cab Base
Section. Suspension				
Tire 1				
Tire 2				
…				
Section. Powertrain				
Engine 1				
Engine 2				
…				

IDENTIFY THE ENTITIES

- The base entities in the VFCM are **Features** which are identified with a Feature Code
- Each Feature can be understood as a Model Block
- Each code has a series of relationships with other codes and this group of relations communicates the feature deployment direction
- The mount of relationships between feature codes is very high which makes the system really complex and hard to be shown in a simple matrix or table



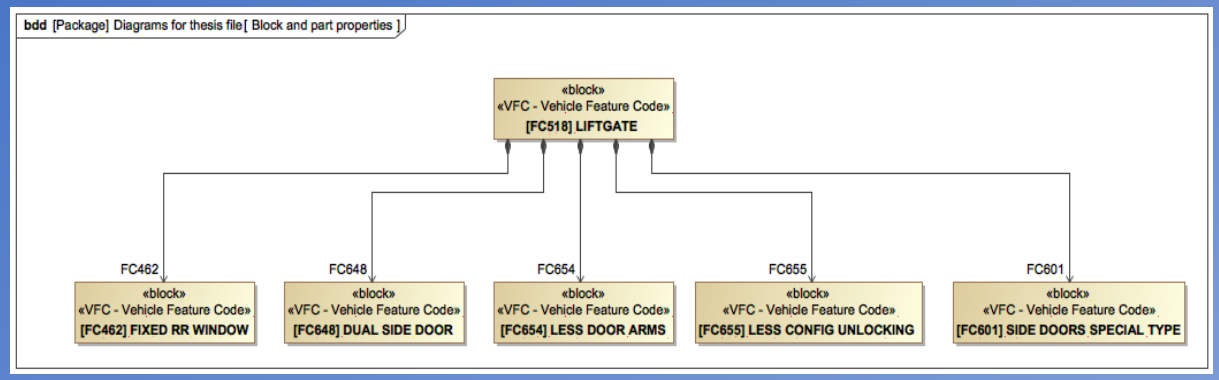


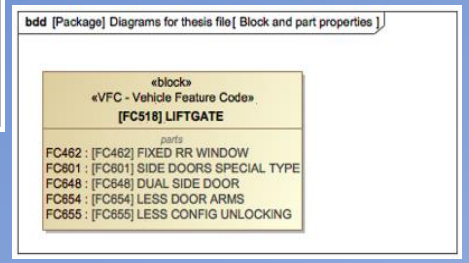
IDENTIFY THE RELATIONSHIPS AMONG ENTITIES

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
- Model diagram representation can replace complex and repetitive text relation descriptions
- Part Properties to represent Packages and VFCM “Contains” / “Includes”.
- In the model the Owner is truly connected with its parts.



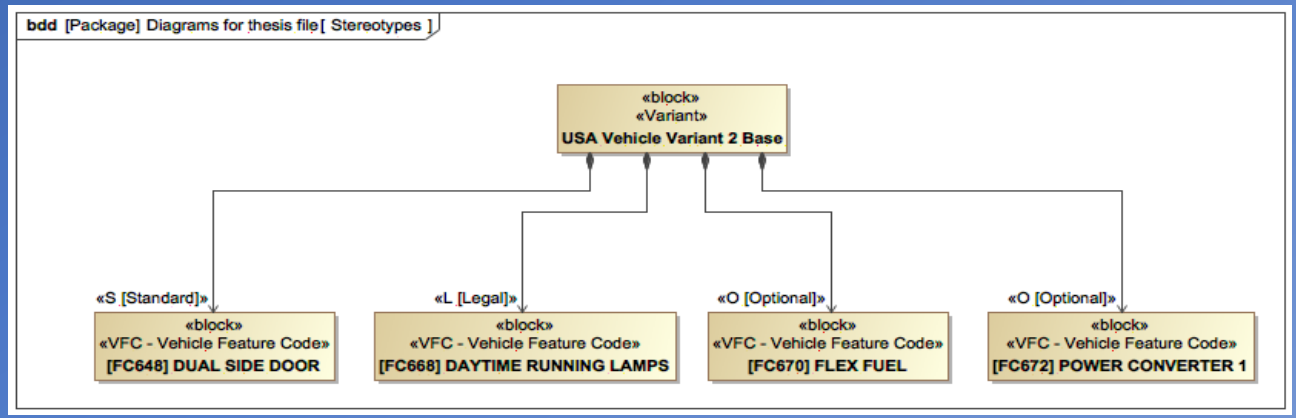


IDENTIFY THE RELATIONSHIPS AMONG ENTITIES

Optionality

This is type of relationship connecting the Vehicle Variant with the Feature Blocks

- **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



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

IDENTIFY THE RELATIONSHIPS AMONG ENTITIES

Feature Constraints

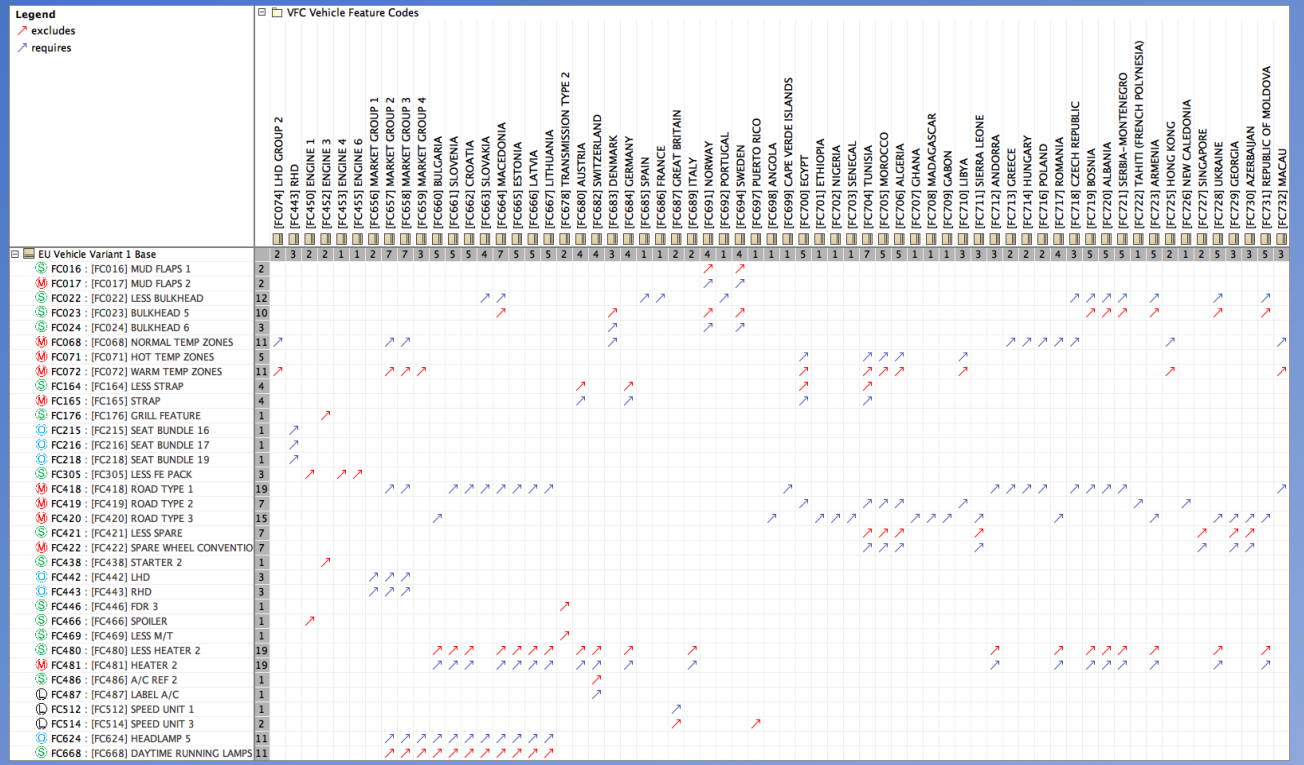
Features in VFCM can have constraints that specify the way in which the features are connected

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**

NOTE: In the SysML Model those are represented as Dependency Relations

Feature	Feature Code	Variant 1
RHD Requires {MARKET GROUP 1 (FC656), MARKET GROUP 2 (FC657), MARKET GROUP 3 (FC658)}	FC443	O*/- O^1
HEADLAMP 5 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)}	FC624	O*/- O^1



IDENTIFY THE RELATIONSHIPS AMONG ENTITIES

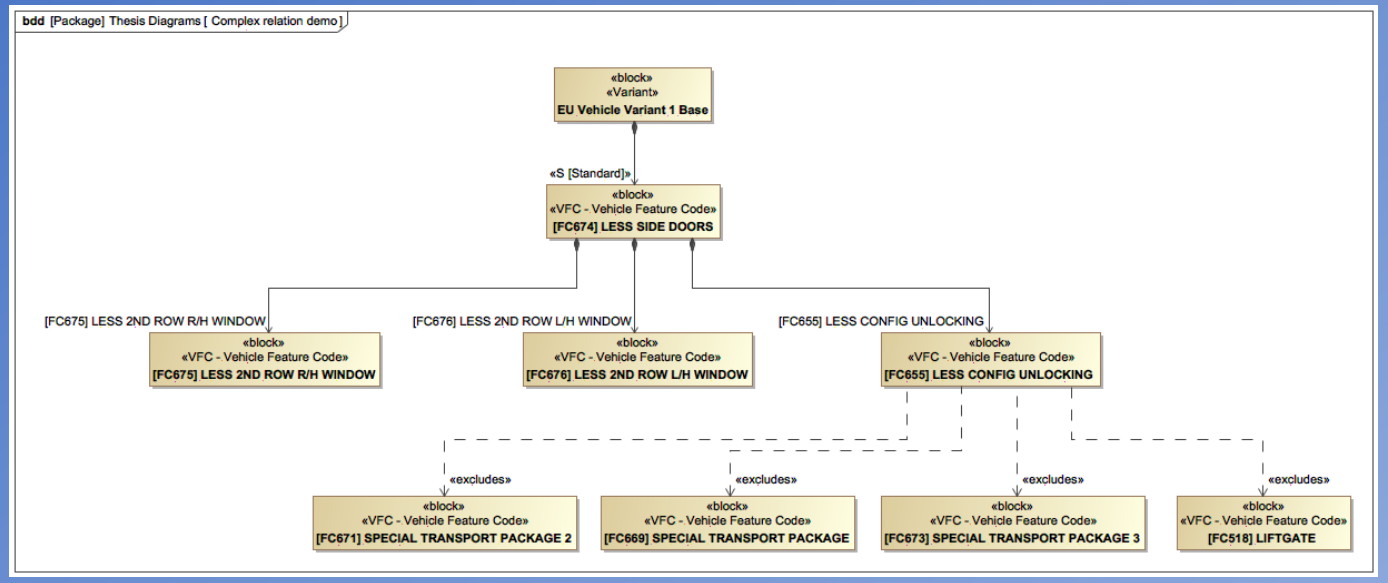
Feature Constraints

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

Traditional VFCM represent constraints with text and logic connectors:

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

NOTE: This is represented with the Part Properties and Dependency Relations



"The whole is more than the sum of the parts" ***Aristotle, Metaphysics***

ANALYZE EMERGENCE

Crawley: "The essential aspect of a system is that some new functions emerge"

Analysis of Emergence in the Model according to Elegant Systems characteristics (Griffin, 2010)

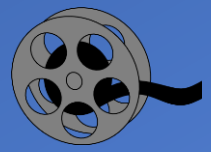
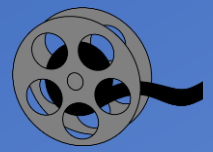
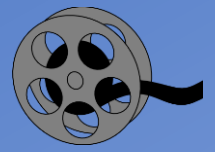
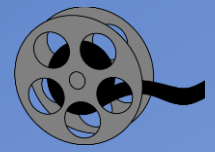
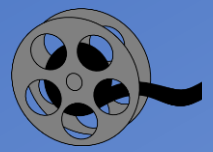
- **Meet Function**
  - Every block is unique, all its properties reside in the containment tree
  - Model diagrams are representations of the block.
  - Capability of block analysis to find all the other elements connected to it, and assess impact of VFCM changes
- **Robustness**
  - Changes are automatically updated in all the model
  - Minimization of errors and inconsistency
  - Ability to create custom error proof tools using "Custom Properties"

ANALYZE EMERGENCE

Analysis of the Model according Elegant Systems characteristics

- **Efficiency**
  - Changes are done in one model with low effort
  - 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
  - Manages Complexity of the VFCM, and can customize scope of the analysis

MODEL FUNCTIONALITY EXAMPLES

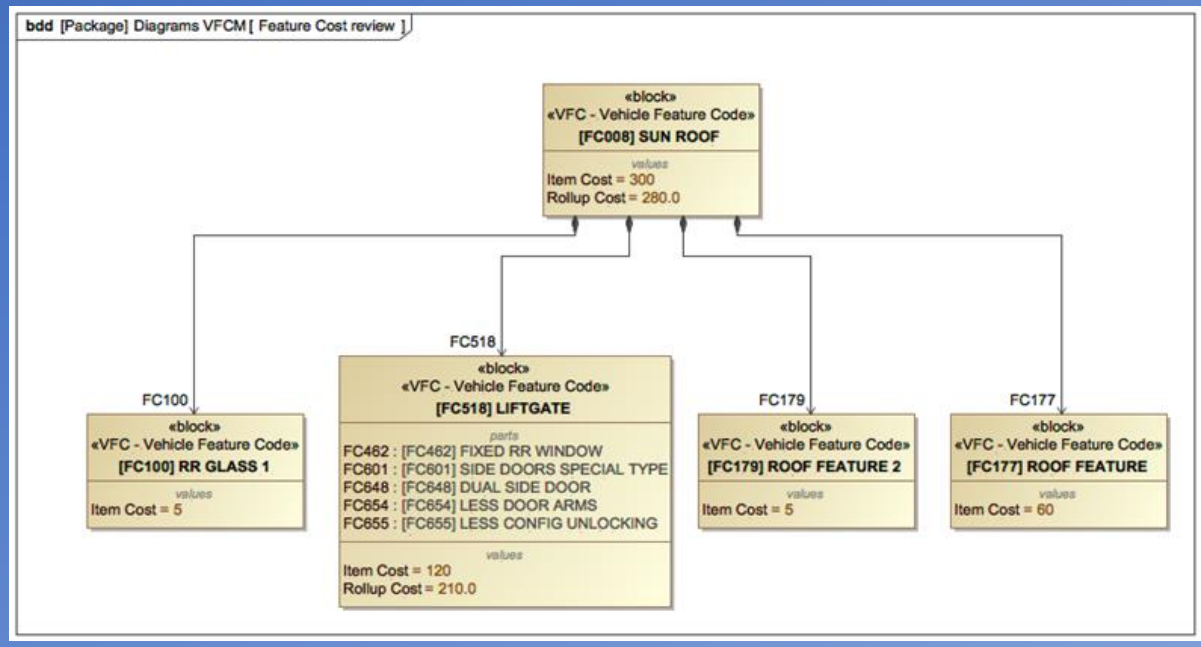
- Feature Change Analysis
  - Block Specifications 
  - “Used By” Function 
  - “Display Related Elements” function  
- Generic Tables 

COST ROLL-UP

Artificial Cost Information was added to the blocks

#	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

Cost Roll-up macro Execution Result



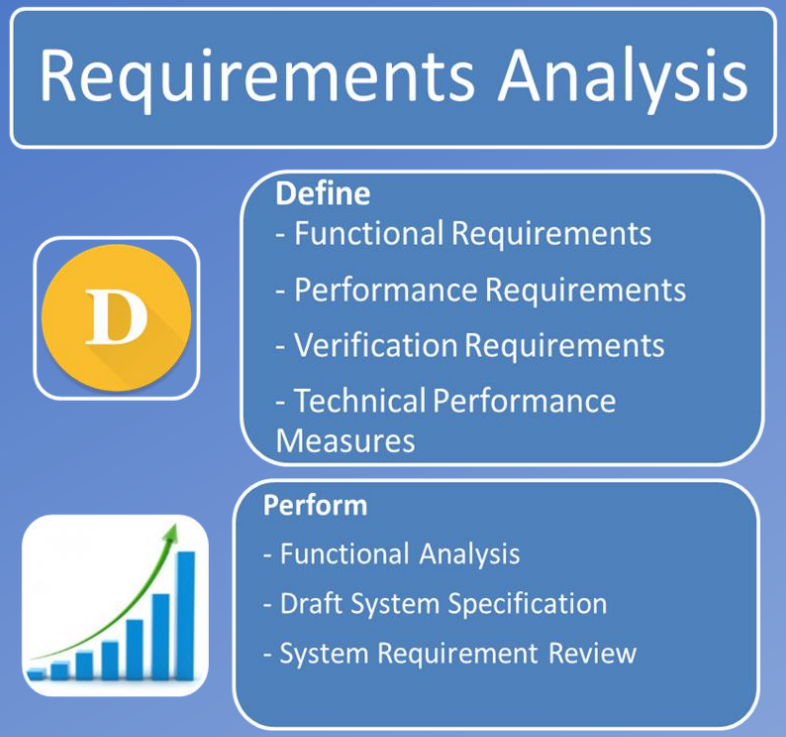
#	Owner	Default Value	Type
1	USA Vehicle Variant 2 Base	16570.0	cost [dollars]
2	USA Vehicle Variant 1 Luxury	19766.0	cost [dollars]
3	EU Variant Vehicle 2 Luxury	19598.0	cost [dollars]
4	EU Vehicle Variant 1 Base	10186.0	cost [dollars]

USAGE POSSIBILITIES

- Vehicle Systems Architecture
- Electrical Systems Topology
- Electrical System Error-States Analysis
- Costing Models
- Weight Calculation Models

NEXT STEPS

- Widen the scope of the model to add specific model analysis tools to engineering teams like Powertrain or Electrical Systems
- Research among diverse OEMs formats and compile a database of necessary inputs to the model
- Define more accurate requirements and perform Requirement Model Analysis
- Research and develop new output tables and reports to satisfy the needs of the stakeholders



CONCLUSIONS

The VFCM model can:

- Improve the consistency of the information
- Reduce the amount of time and resources to maintain and update the VFCM
- Provide a greater capability to display information in more customizable way and make timely and more informed decisions
- Increase the efficiency, robustness and minimize the undesired behaviors present in the current VFCM
- Be expanded to different functional areas of the Product Development

CONCLUSIONS

The MagicDraw proved to:

- Be very capable and robust to manage big and complex networks of highly interconnected blocks
- Have a capability to be extrapolated to a larger scale to VFCM models in real life automotive vehicle programs
- Be highly customizable

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

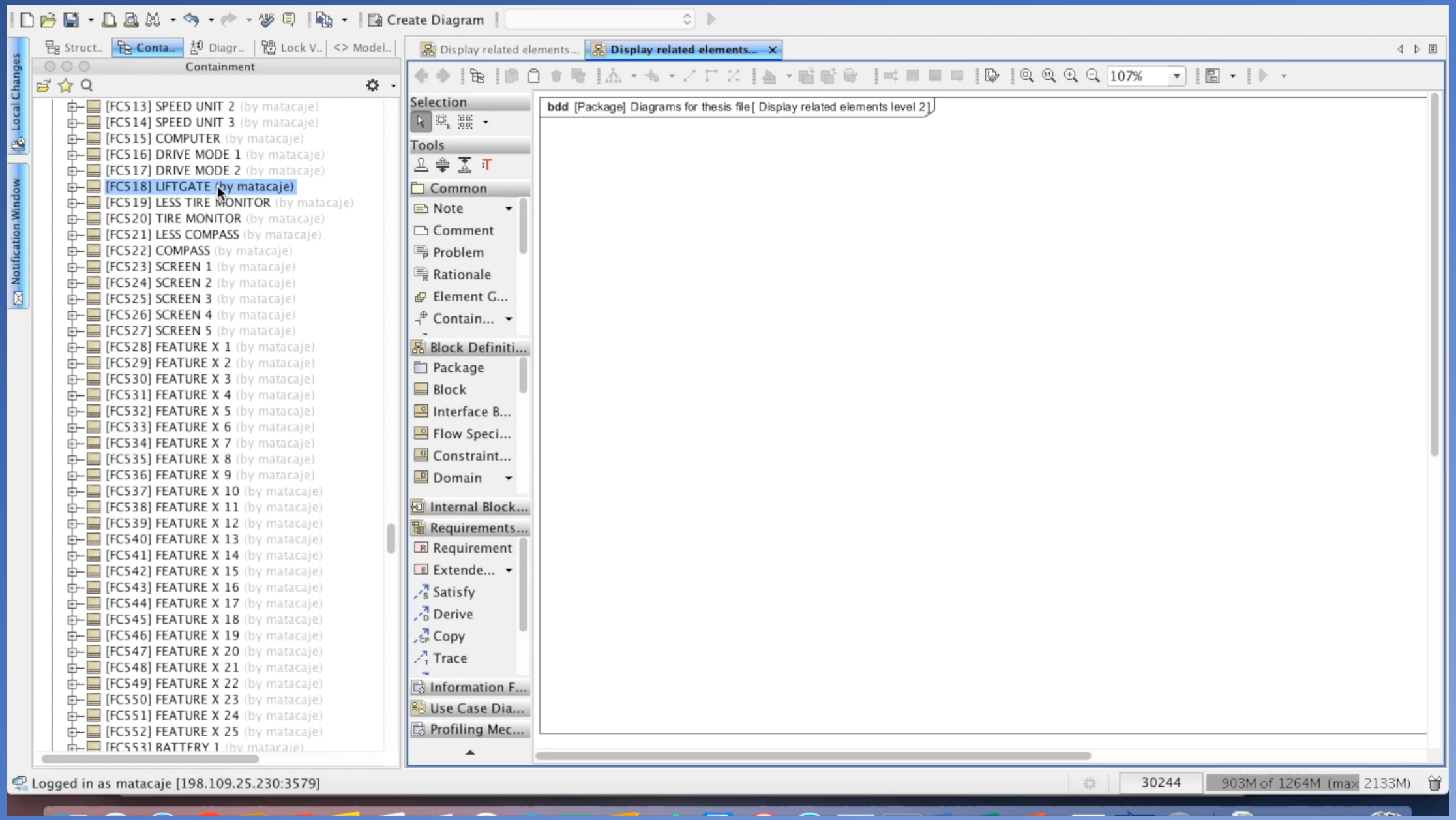
ACKNOWLEDGEMENTS

THANK YOU TO OUR ADVISOR MICHAEL VINARCIK FOR ALL THE HELP, ENTHUSIASM AND GUIDANCE!

THANK YOU TO DR. WEAVER AND DR. KLEINKE FOR ALL THE KNOWLEDGE WE GAINED THROUGHOUT THE PROGRAM AND USED IN THIS THESIS!

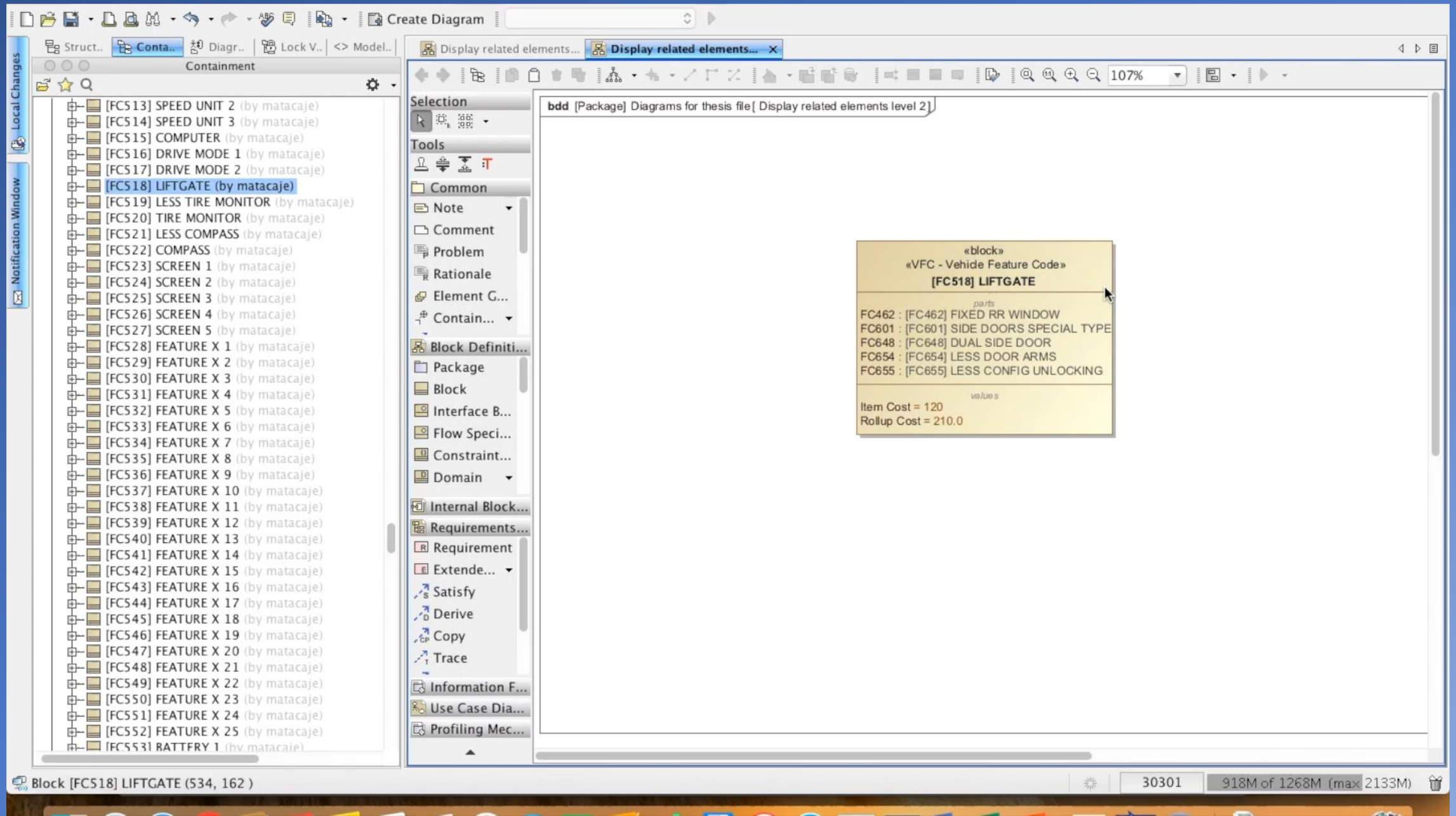
BACKUP

Feature Change Analysis. Block Specifications



Return

Feature Change Analysis. “Used By” Function



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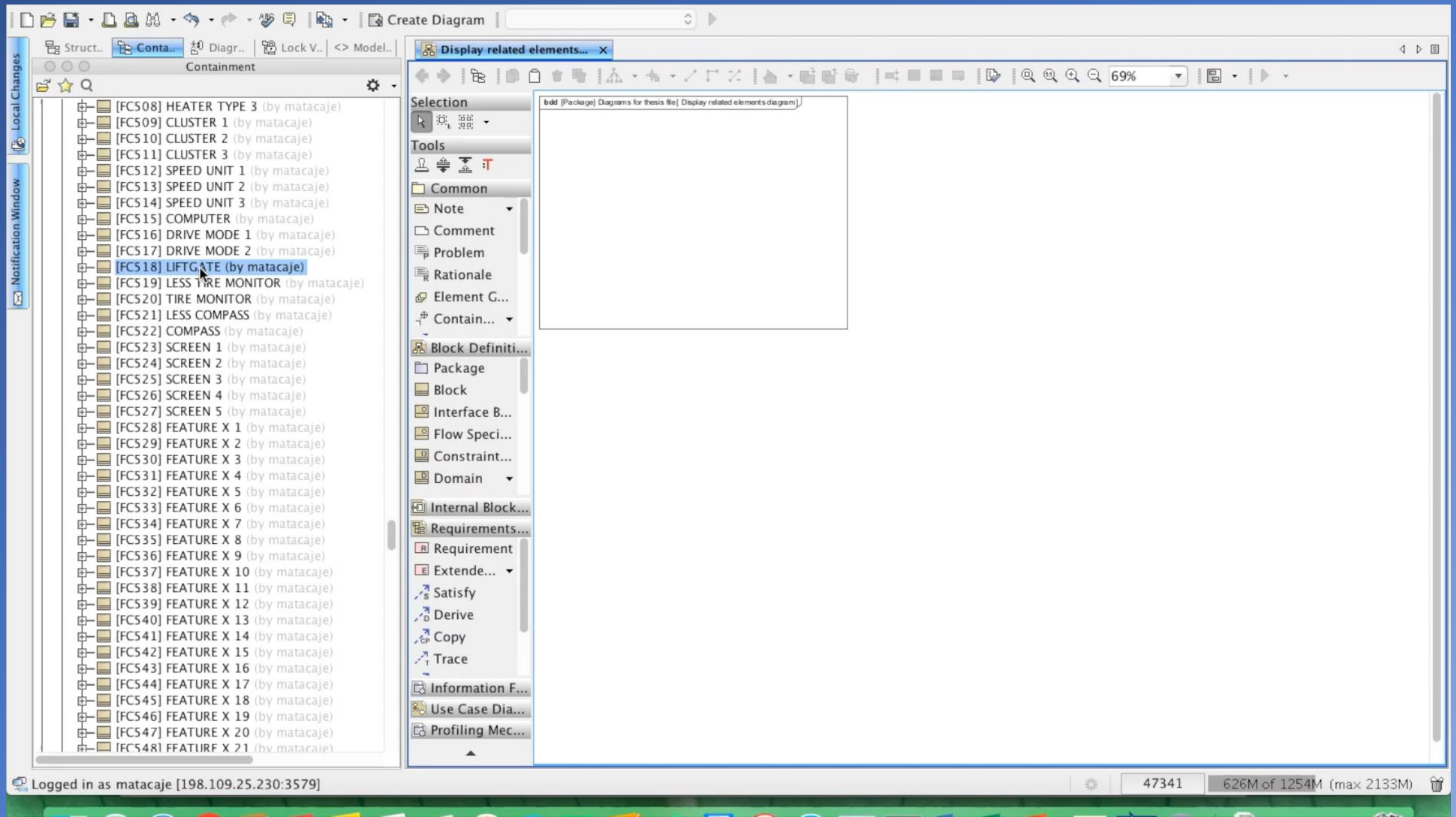
Feature Change Analysis. “Display Related Elements” function 1 level



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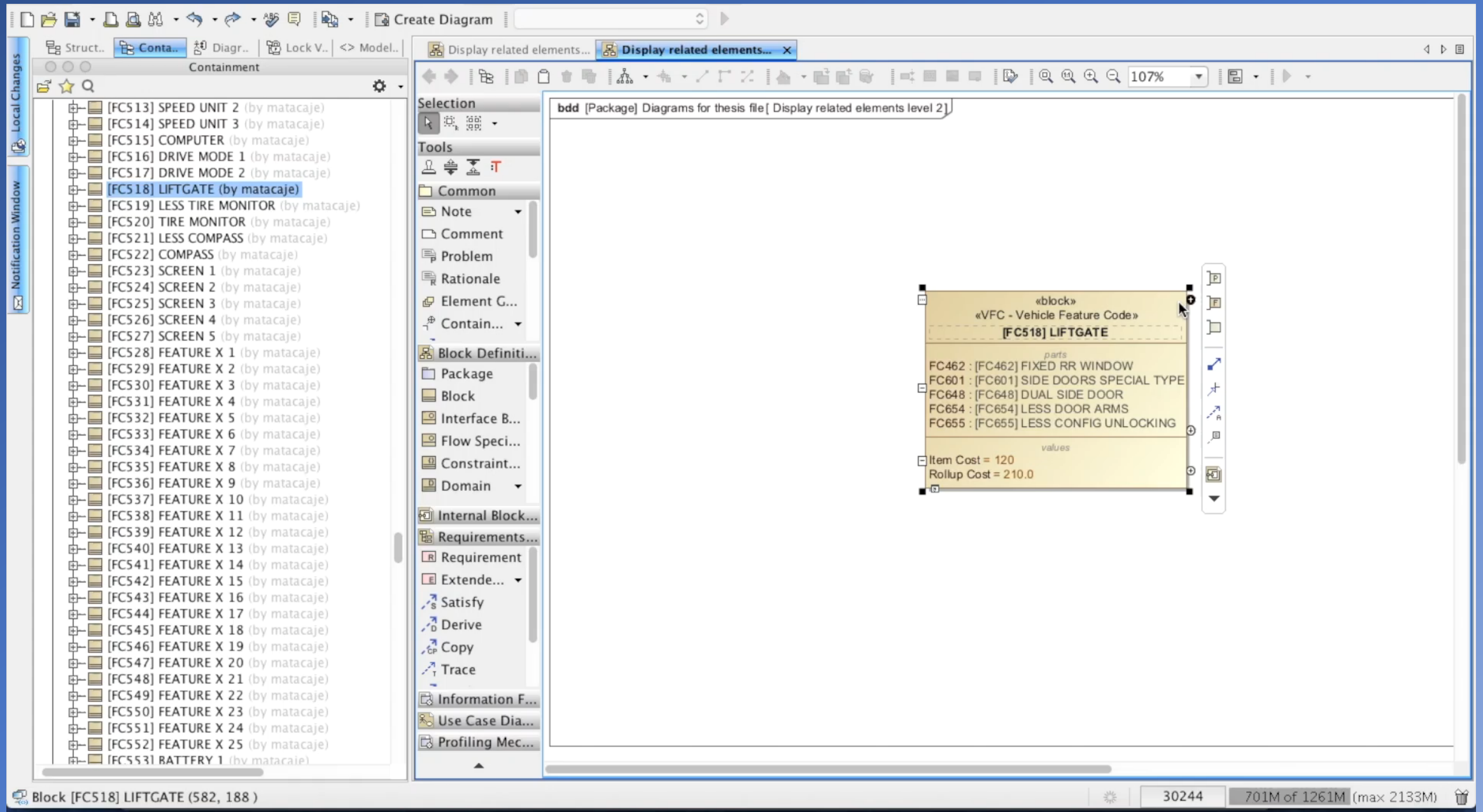
Feature Change Analysis. “Display Related Elements” function 3-level



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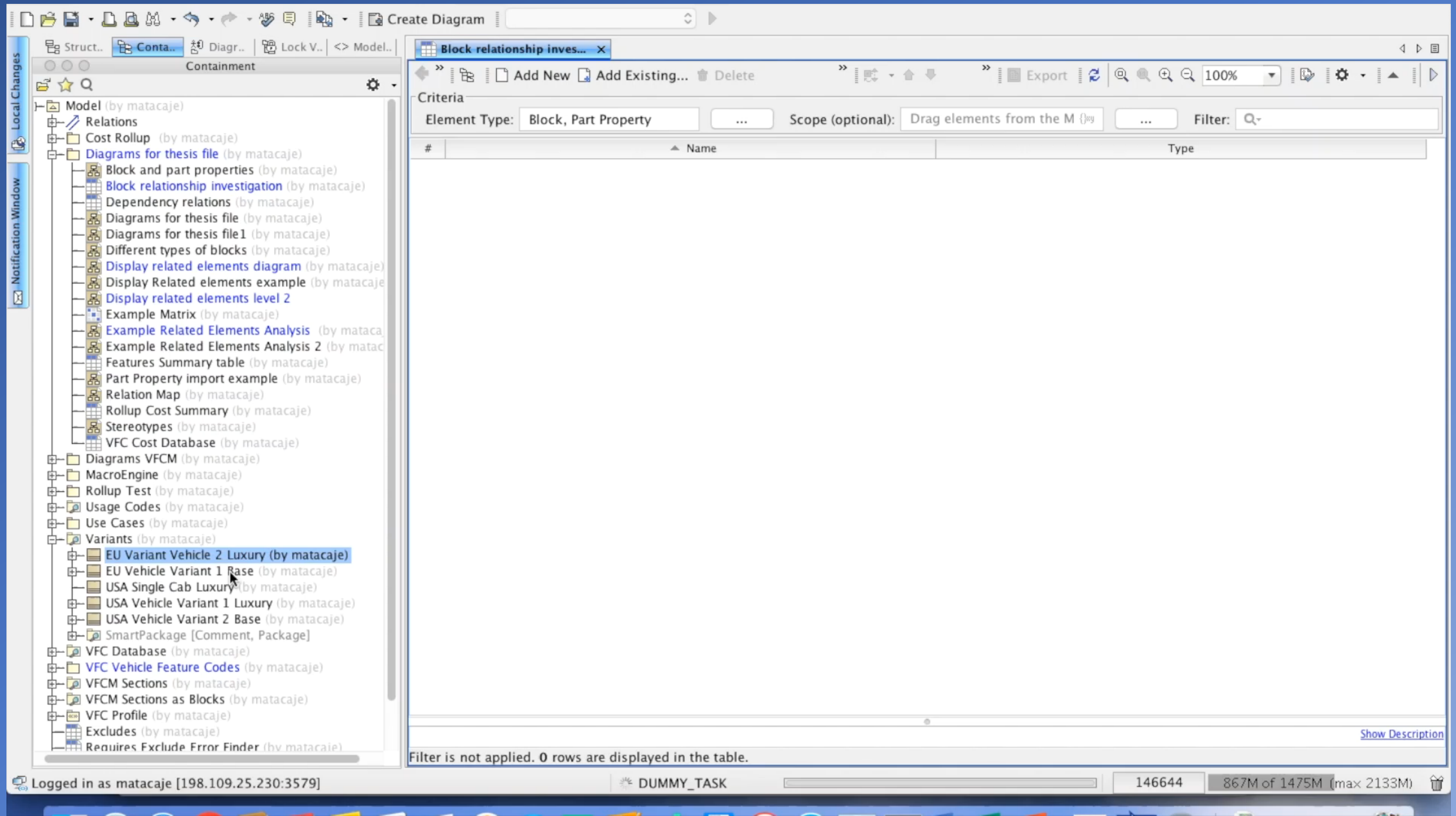
Generic Table. Part Properties



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