

UDM Master of Science in Product Development

**Vehicle Feature Complexity
Matrix Modeling and
Management in SysML**

Presented by: Jesus Mata Castaneda, Natalie Matevossyan

Advisor: Michael John Vinarcik

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

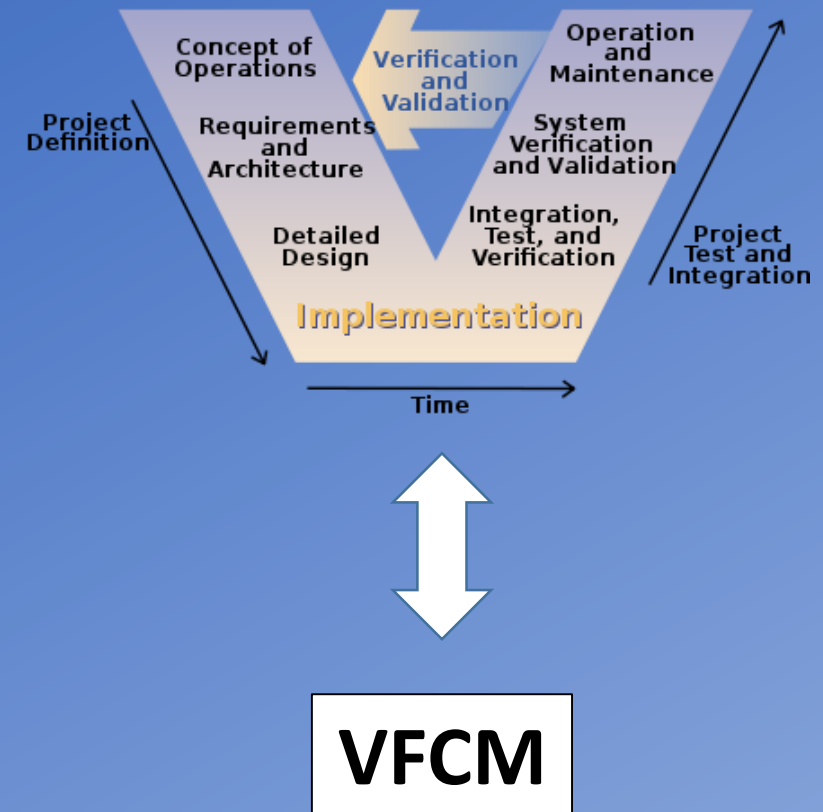
IMPORTANCE OF THE VFCM

- 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



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

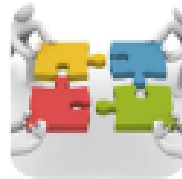
NOTE: KEY POTENTIAL ISSUE: the VFCM is 100% manually authored, generated and managed

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



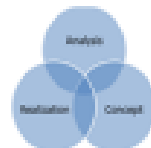
Identify Stakeholders



Identify Stakeholder Requirements



Analyze Requirements



System Design Review

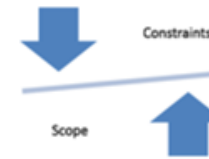
IDENTIFY STAKEHOLDERS AND REQUIREMENTS

Identified Current and Potential Stakeholders

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

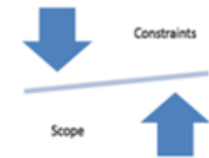


Identify Stakeholder Requirements



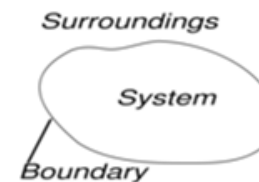
Define

- Need
- Goals
- Objectives



Identify Constraints

- Project Constraints
- Design Constraints



Identify System Boundaries

- External Interfaces
- External Constraints



Produce Context Diagram



Feasibility Analysis

IDENTIFY STAKEHOLDER REQUIREMENTS



Needs

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



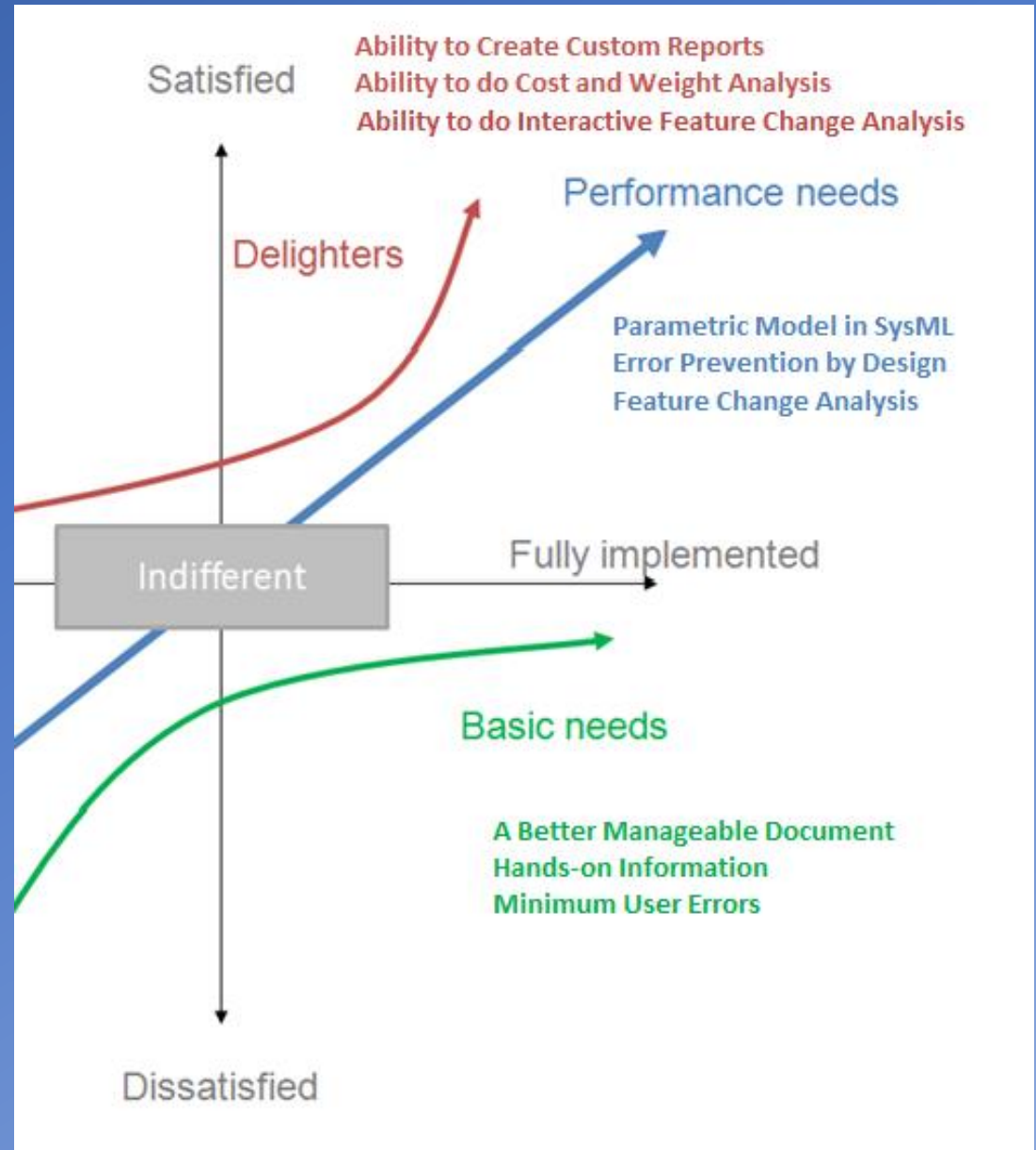
Goals

- 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

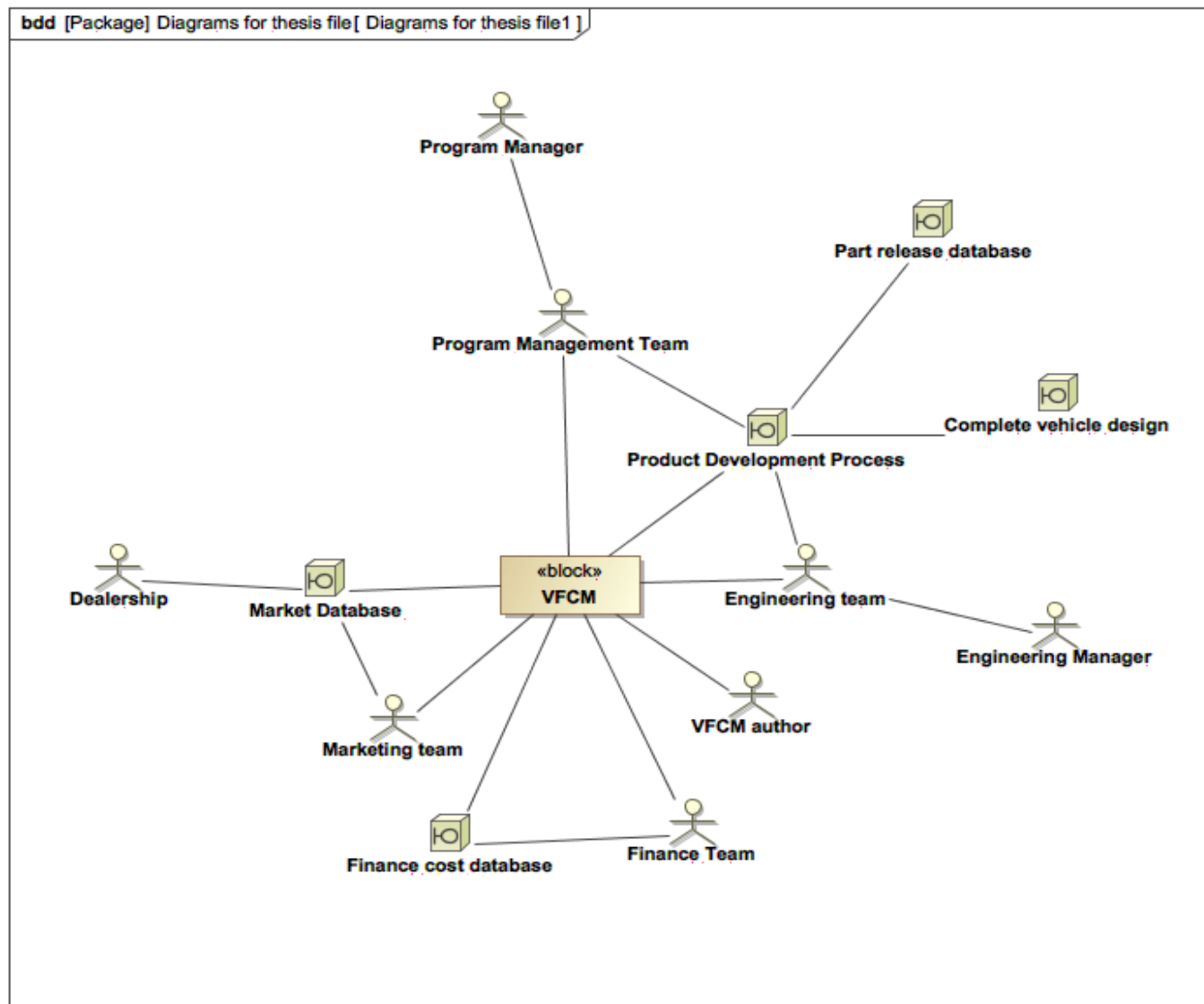
- Unavailability of the source raw data
- Working with highly confidential information

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

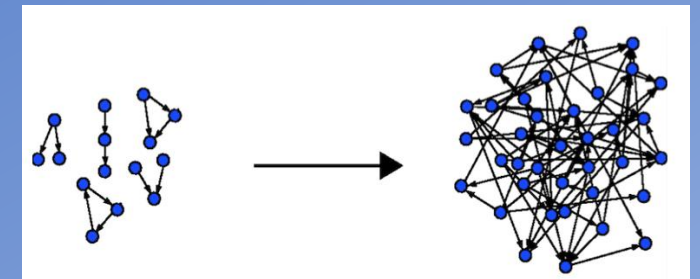
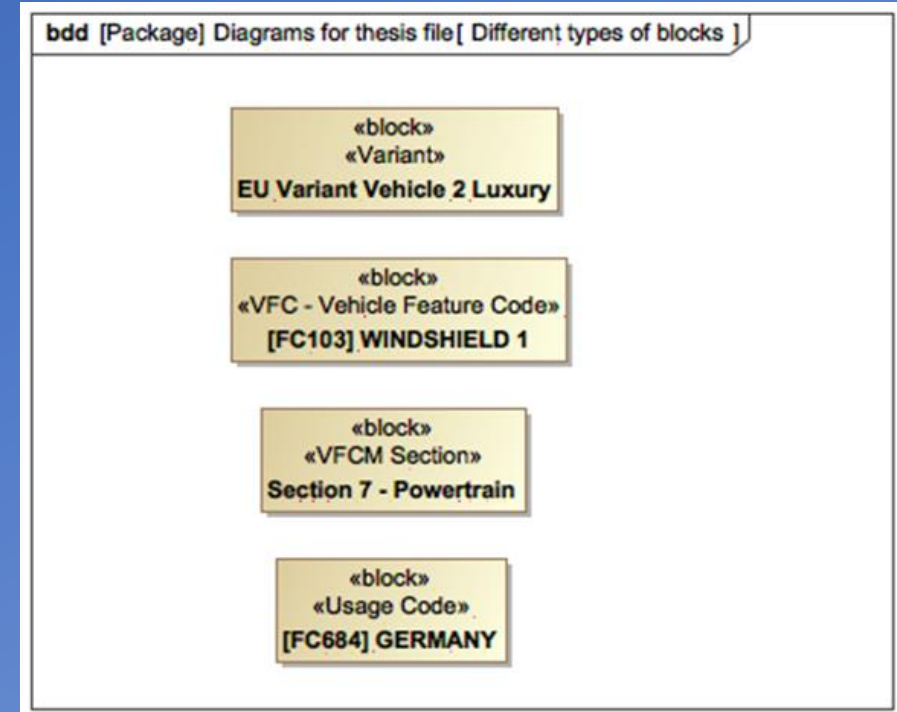
IDENTIFY THE SYSTEM

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

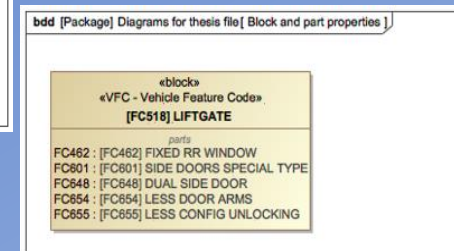
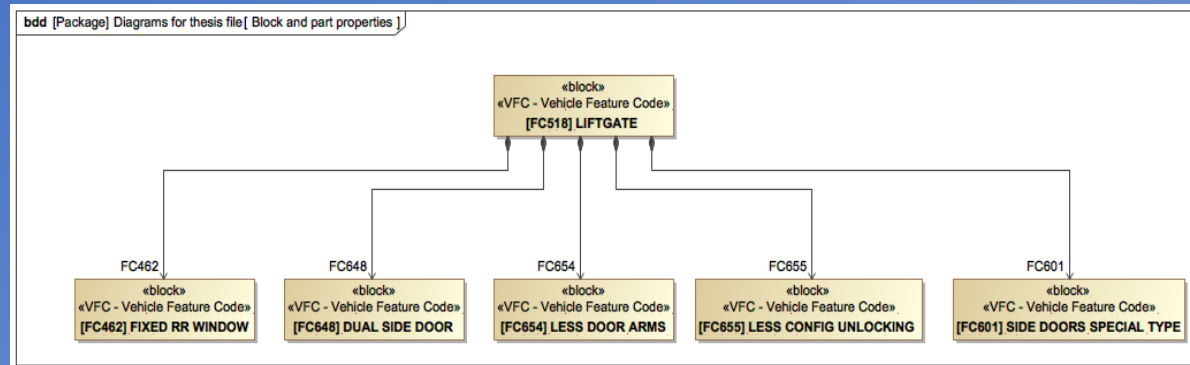


IDENTIFY THE RELATIONSHIPS AMONG ENTITIES

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.

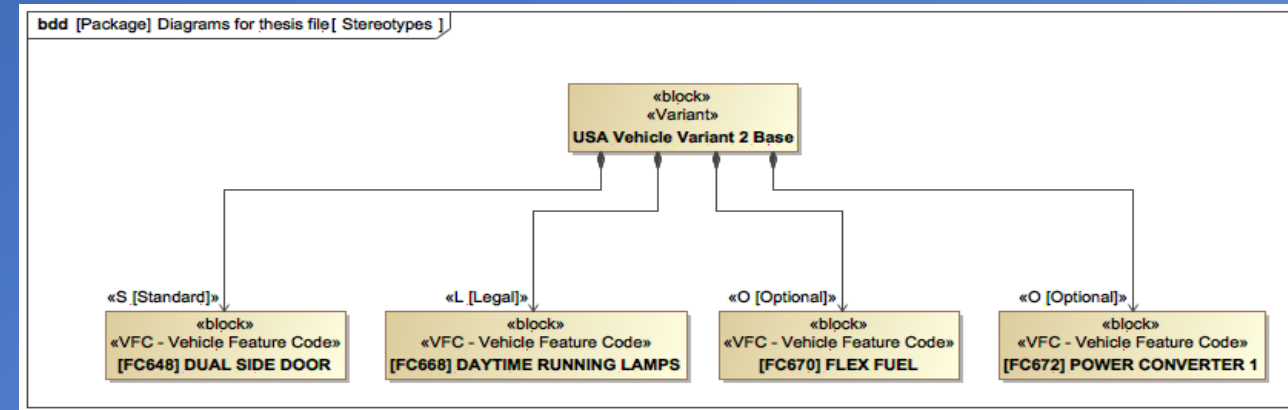


IDENTIFY THE RELATIONSHIPS AMONG ENTITIES

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



Feature List	Vehicle Variants			
	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

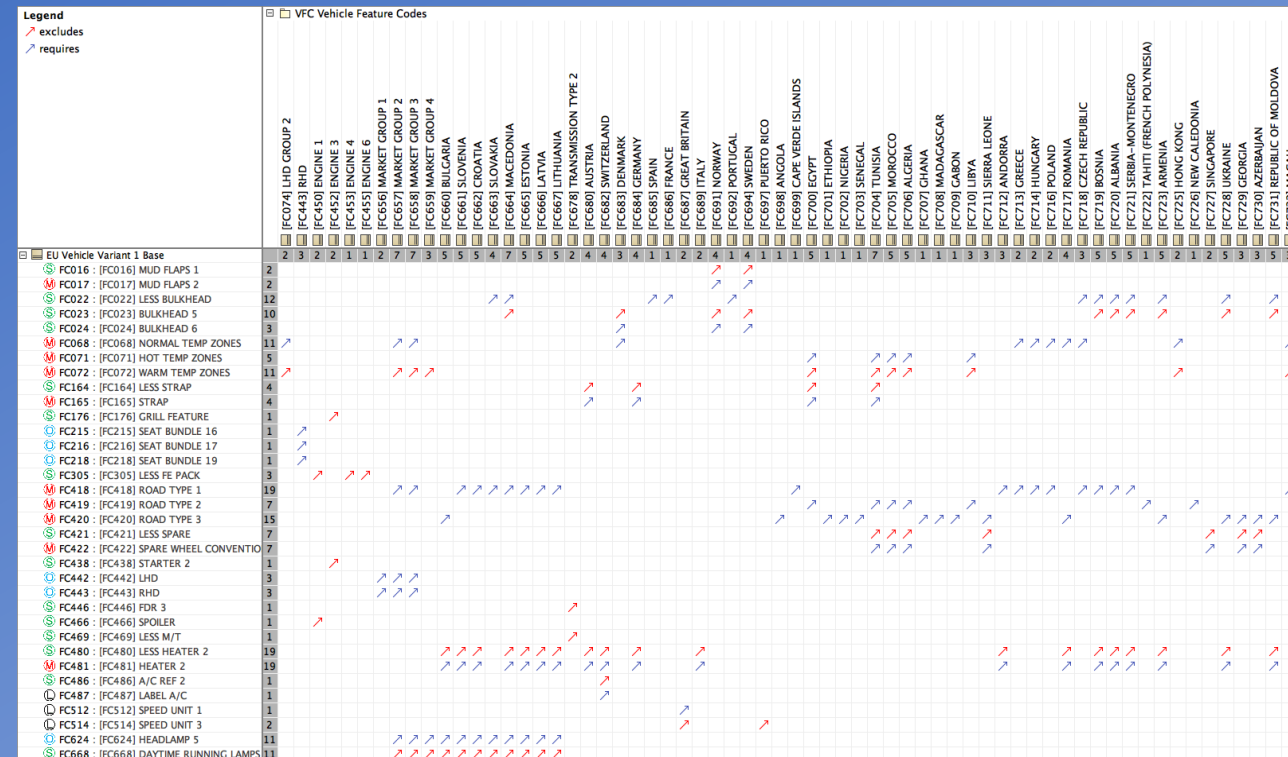
Features in VFCM can have constraints that specify the way in which the features are connected

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

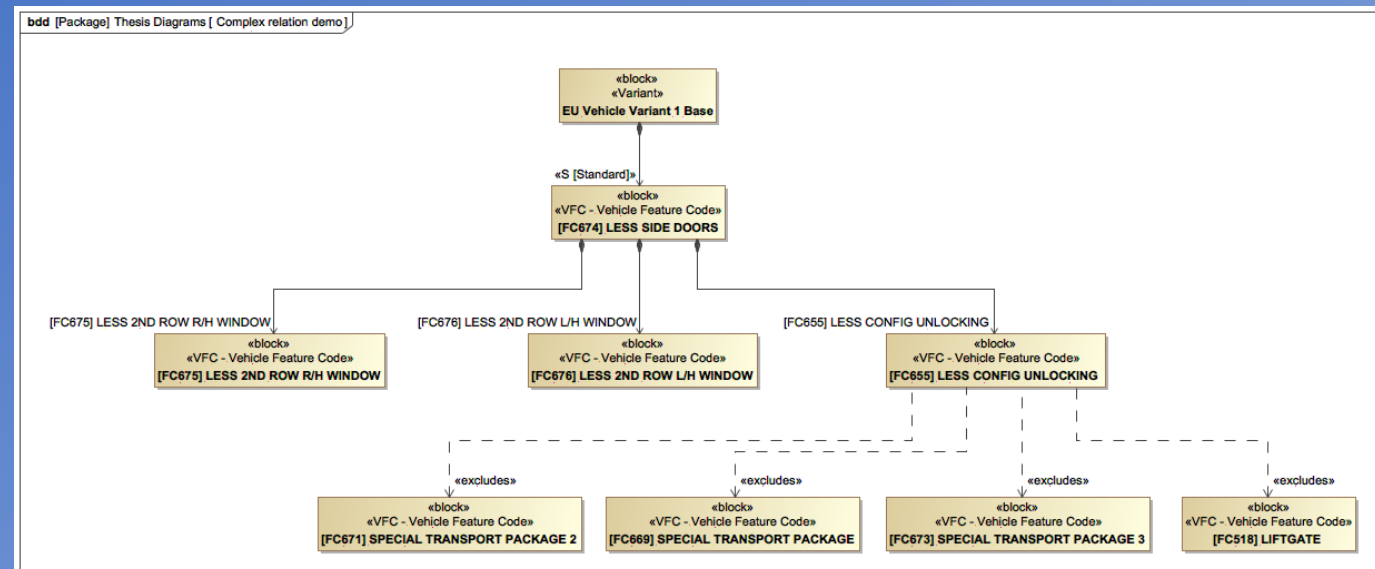
Feature Constraints

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

Feature	Feature Code	Variant 1
LESS SIDE DOORS Contains LESS 2ND ROW R/H WINDOW (FC675) Contains LESS 2ND ROW L/H WINDOW (FC676) 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	FC674	S* C ¹ C ² C ³



“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

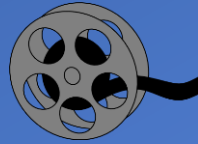
Analysis of the Model according Elegant Systems characteristics

- **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

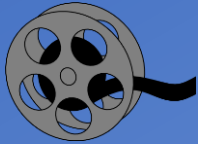
MODEL FUNCTIONALITY EXAMPLES

- Feature Change Analysis

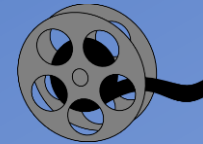
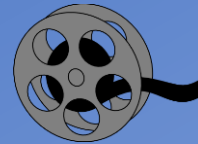
- Block Specifications



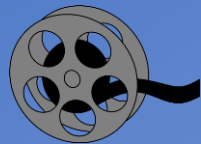
- “Used By” Function



- “Display Related Elements” function



- Generic Tables

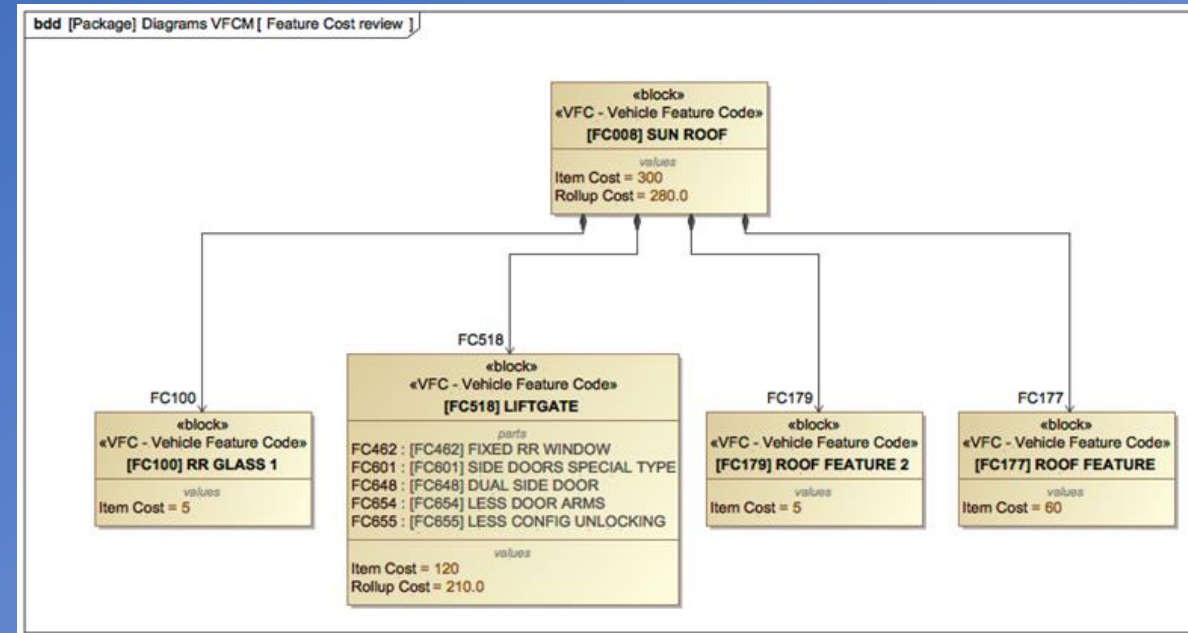


COST ROLL-UP

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

Requirements Analysis



Define

- Functional Requirements
- Performance Requirements
- Verification Requirements
- Technical Performance Measures



Perform

- Functional Analysis
- Draft System Specification
- System Requirement Review

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

The screenshot displays a software development tool interface, likely for UML modeling. The left sidebar contains a 'Local Changes' panel and a 'Notification Window'. The main area is divided into three panes:

- Containment:** A tree view listing various features, including 'SPEED UNIT 2', 'SPEED UNIT 3', 'COMPUTER', 'DRIVE MODE 1', 'DRIVE MODE 2', 'LIFTGATE', 'LESS TIRE MONITOR', 'TIRE MONITOR', 'LESS COMPASS', 'COMPASS', 'SCREEN 1', 'SCREEN 2', 'SCREEN 3', 'SCREEN 4', 'SCREEN 5', 'FEATURE X 1' through 'FEATURE X 25', and 'BATTERY 1'. The 'LIFTGATE' feature is currently selected.
- Selection:** A panel showing the selected element and its properties. It includes a 'Tools' section with icons for selection, zoom, and other actions. Below this is a 'Common' section with a list of elements: Note, Comment, Problem, Rationale, Element G..., Contain..., Block Definiti..., Package, Block, Interface B..., Flow Speci..., Constraint..., Domain, Internal Block..., Requirements..., Requirement, Extende..., Satisfy, Derive, Copy, Trace, Information F..., Use Case Dia..., and Profiling Mec...
- Diagram:** A large area for editing the diagram. It shows a single element labeled 'bdd [Package] Diagrams for thesis file [Display related elements level 2]'. The diagram is currently empty.

The bottom status bar indicates the user is logged in as 'matacaje' with IP address '198.109.25.230:3579'. It also shows the current page number '30244' and the total number of pages '903M of 1264M (max 2133M)'.

Feature Change Analysis. “Used By” Function

The screenshot displays a software interface for feature change analysis. On the left, a 'Containment' tree lists various features, with '[FC518] LIFTGATE (by matacaje)' selected. The main workspace shows a diagram titled 'bdd [Package] Diagrams for thesis file [Display related elements level 2]'. A yellow box represents the selected feature, containing a list of parts and their associated values.

«block» «VFC - Vehide Feature Code» [FC518] LIFTGATE	
parts	FC462 : [FC462] FIXED RR WINDOW FC601 : [FC601] SIDE DOORS SPECIAL TYPE FC648 : [FC648] DUAL SIDE DOOR FC654 : [FC654] LESS DOOR ARMS FC655 : [FC655] LESS CONFIG UNLOCKING
values	Item Cost = 120 Rollup Cost = 210.0

At the bottom, a status bar indicates 'Block [FC518] LIFTGATE (534, 162)' and system resources: '30301' and '918M of 1268M (max 2133M)'.

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

The screenshot displays a software development tool interface for feature change analysis. The left pane, titled 'Containment', lists a hierarchy of features. The feature '[FCS18] LIFTGATE (by matacaje)' is selected and highlighted. The right pane, titled 'Display related elements...', shows a diagram area with a toolbar and a 'Selection' tool. The bottom status bar indicates the user is logged in as 'matacaje' with IP address [198.109.25.230:3579].

Feature List (Left Pane):

- [FCS08] HEATER TYPE 3 (by matacaje)
- [FCS09] CLUSTER 1 (by matacaje)
- [FCS10] CLUSTER 2 (by matacaje)
- [FCS11] CLUSTER 3 (by matacaje)
- [FCS12] SPEED UNIT 1 (by matacaje)
- [FCS13] SPEED UNIT 2 (by matacaje)
- [FCS14] SPEED UNIT 3 (by matacaje)
- [FCS15] COMPUTER (by matacaje)
- [FCS16] DRIVE MODE 1 (by matacaje)
- [FCS17] DRIVE MODE 2 (by matacaje)
- [FCS18] LIFTGATE (by matacaje)**
- [FCS19] LESS TIRE MONITOR (by matacaje)
- [FCS20] TIRE MONITOR (by matacaje)
- [FCS21] LESS COMPASS (by matacaje)
- [FCS22] COMPASS (by matacaje)
- [FCS23] SCREEN 1 (by matacaje)
- [FCS24] SCREEN 2 (by matacaje)
- [FCS25] SCREEN 3 (by matacaje)
- [FCS26] SCREEN 4 (by matacaje)
- [FCS27] SCREEN 5 (by matacaje)
- [FCS28] FEATURE X 1 (by matacaje)
- [FCS29] FEATURE X 2 (by matacaje)
- [FCS30] FEATURE X 3 (by matacaje)
- [FCS31] FEATURE X 4 (by matacaje)
- [FCS32] FEATURE X 5 (by matacaje)
- [FCS33] FEATURE X 6 (by matacaje)
- [FCS34] FEATURE X 7 (by matacaje)
- [FCS35] FEATURE X 8 (by matacaje)
- [FCS36] FEATURE X 9 (by matacaje)
- [FCS37] FEATURE X 10 (by matacaje)
- [FCS38] FEATURE X 11 (by matacaje)
- [FCS39] FEATURE X 12 (by matacaje)
- [FCS40] FEATURE X 13 (by matacaje)
- [FCS41] FEATURE X 14 (by matacaje)
- [FCS42] FEATURE X 15 (by matacaje)
- [FCS43] FEATURE X 16 (by matacaje)
- [FCS44] FEATURE X 17 (by matacaje)
- [FCS45] FEATURE X 18 (by matacaje)
- [FCS46] FEATURE X 19 (by matacaje)
- [FCS47] FEATURE X 20 (by matacaje)
- [FCS48] FEATURE X 21 (by matacaje)

Diagram Area (Right Pane):

The diagram area is titled 'bdd [Package] Diagrams for thesis file [Display related elements diagram]'. It contains a toolbar with various icons for diagram manipulation and a 'Selection' tool. The 'Selection' tool is currently active, showing a list of elements to be displayed.

Tools (Right Pane):

- Common
 - Note
 - Comment
 - Problem
 - Rationale
 - Element G...
 - Contain...
- Block Definiti...
- Package
- Block
- Interface B...
- Flow Speci...
- Constraint...
- Domain
- Internal Block...
- Requirements...
- Requirement
- Extende...
- Satisfy
- Derive
- Copy
- Trace
- Information F...
- Use Case Dia...
- Profiling Mec...

Status Bar:

Logged in as matacaje [198.109.25.230:3579] 47341 626M of 1254M (max 2133M)

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

The screenshot displays a software development tool interface for feature change analysis. The left pane, titled "Containment", lists various features, with [FCS18] LIFTGATE (by matacaje) selected. The right pane, titled "Display related elements...", shows a detailed view of the selected feature. The view is organized into sections: "parts" and "values".

parts

- FC462 : [FC462] FIXED RR WINDOW
- FC601 : [FC601] SIDE DOORS SPECIAL TYPE
- FC648 : [FC648] DUAL SIDE DOOR
- FC654 : [FC654] LESS DOOR ARMS
- FC655 : [FC655] LESS CONFIG UNLOCKING

values

- Item Cost = 120
- Rollup Cost = 210.0

The status bar at the bottom indicates the current block is [FCS18] LIFTGATE (582, 188) and shows memory usage: 30244 / 701M of 1261M (max 2133M).

Generic Table. Part Properties

The screenshot shows a software interface with a project tree on the left and a table on the right. The project tree is titled 'Model (by matacaje)' and contains various sub-items. The table on the right is titled 'Block relationship inves...' and has a filter applied. The table is empty and has a message at the bottom: 'Filter is not applied. 0 rows are displayed in the table.'

Project Tree (Left):

- Model (by matacaje)
 - Relations
 - Cost Rollup (by matacaje)
 - Diagrams for thesis file (by matacaje)
 - Block and part properties (by matacaje)
 - Block relationship investigation (by matacaje)
 - Dependency relations (by matacaje)
 - Diagrams for thesis file (by matacaje)
 - Diagrams for thesis file1 (by matacaje)
 - Different types of blocks (by matacaje)
 - Display related elements diagram (by matacaje)
 - Display Related elements example (by matacaje)
 - Display related elements level 2
 - Example Matrix (by matacaje)
 - Example Related Elements Analysis (by matacaje)
 - Example Related Elements Analysis 2 (by matacaje)
 - Features Summary table (by matacaje)
 - Part Property import example (by matacaje)
 - Relation Map (by matacaje)
 - Rollup Cost Summary (by matacaje)
 - Stereotypes (by matacaje)
 - VFC Cost Database (by matacaje)
 - Diagrams VFCM (by matacaje)
 - MacroEngine (by matacaje)
 - Rollup Test (by matacaje)
 - Usage Codes (by matacaje)
 - Use Cases (by matacaje)
 - Variants (by matacaje)
 - EU Variant Vehicle 2 Luxury (by matacaje)
 - EU Vehicle Variant 1 Base (by matacaje)
 - USA Single Cab Luxury (by matacaje)
 - USA Vehicle Variant 1 Luxury (by matacaje)
 - USA Vehicle Variant 2 Base (by matacaje)
 - SmartPackage [Comment, Package]
 - VFC Database (by matacaje)
 - VFC Vehicle Feature Codes (by matacaje)
 - VFCM Sections (by matacaje)
 - VFCM Sections as Blocks (by matacaje)
 - VFC Profile (by matacaje)
 - Excludes (by matacaje)
 - Requires Exclude Error Finder (by matacaje)

Table (Right):

Criteria: Element Type: Block, Part Property Scope (optional): Drag elements from the M... Filter: Q-

#	Name	Type
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Filter is not applied. 0 rows are displayed in the table.

Logged in as matacaje [198.109.25.230:3579] DUMMY_TASK 146644 867M of 1475M (max 2133M)