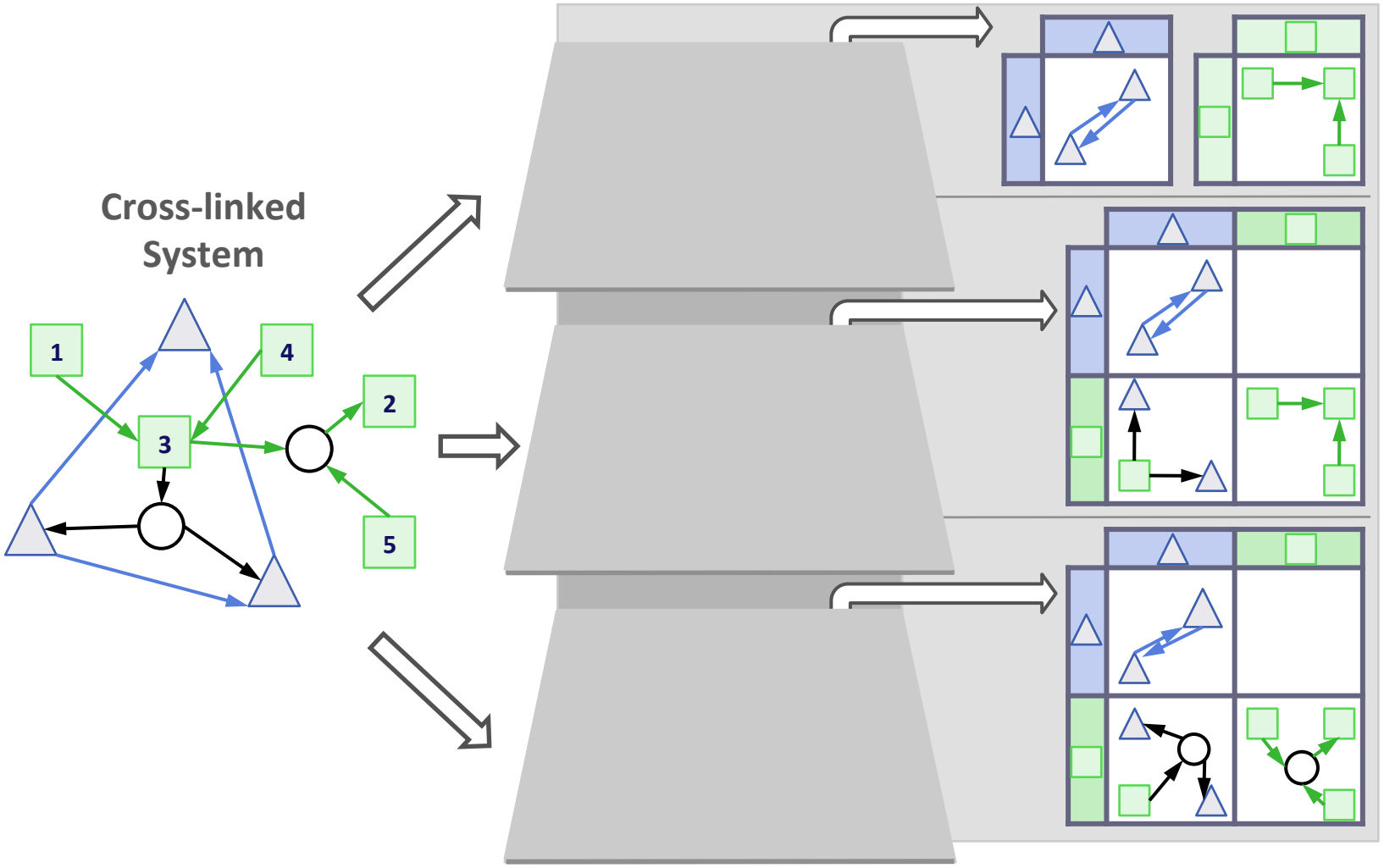
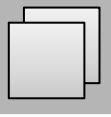
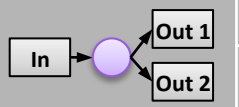
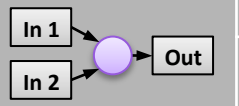
Evolution of matrix based System Modeling



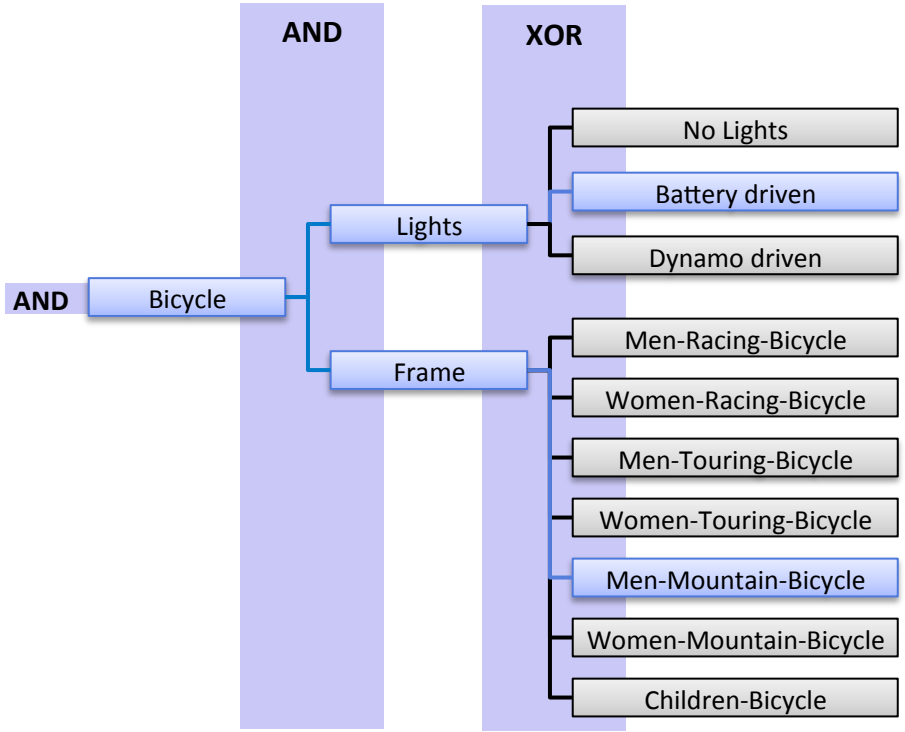
Appearance of Boolean Operators in MDM

			Boolean Operators in MDM		
			Within one subset 	Connecting different subsets 	Accross superimposed subsets 
Logical connectives	Split 	AND	✓	✓	✗
		OR	✓	✓	✗
		XOR	✓	✓	✗
	Join 	AND	✓	✓	✓
		OR	✓	✓	✓
		XOR	✓	✓	✓

Boolean Operators in Variants

Decision Tree

- Vertical AND-Split and XOR-Split;
- Horizontal AND-Chain



Variant Characteristics Matrix

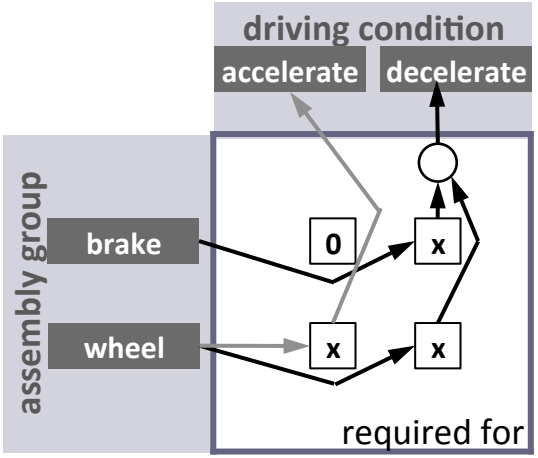
- Domains connected via AND
  Nodes within domains connected via XOR
- Edges in rows connected via AND

AND		Frame						Lights		
XOR		Men-Racing-Bicycle	Women-Racing-Bicycle	Men-Touring-Bicycle	Women-Touring-Bicycle	Men-Mountain-Bicycle	Women-Mountain-Bicycle	Children-Bicycle	No Lights	Battery driven	Dynamo driven
	Variant 1	x							x		
	Variant 2			x							x
	Variant 3					x			x		
AND	Variant 4					x				x	
	Variant 5		x						x		
	Variant 6				x						x
	Variant 7						x			x	
	Variant 8						x				x
	Variant 9							x			x

Boolean operators in Multiple Domain Matrix

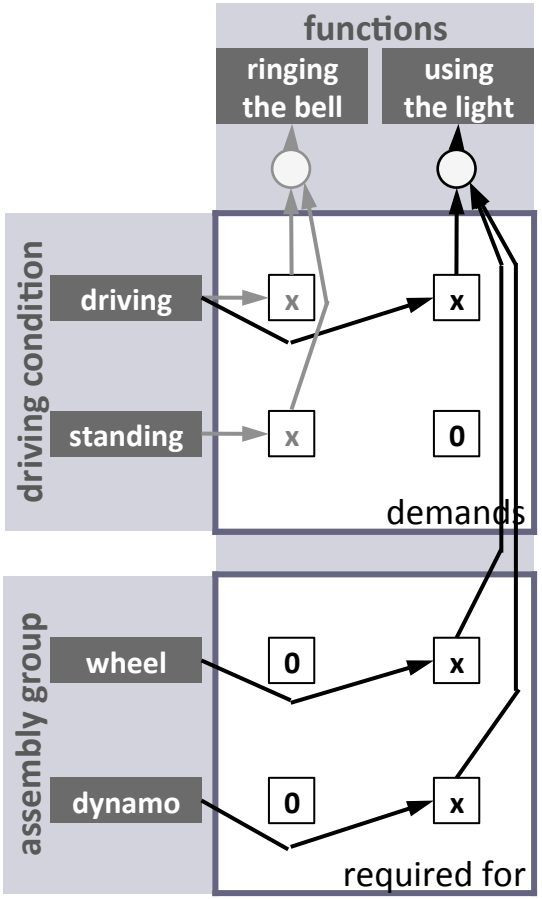
Within one subset

Dependencies between edges
in one subset
with one node in common



Boolean operators in Multiple Domain Matrix

Connecting different subsets

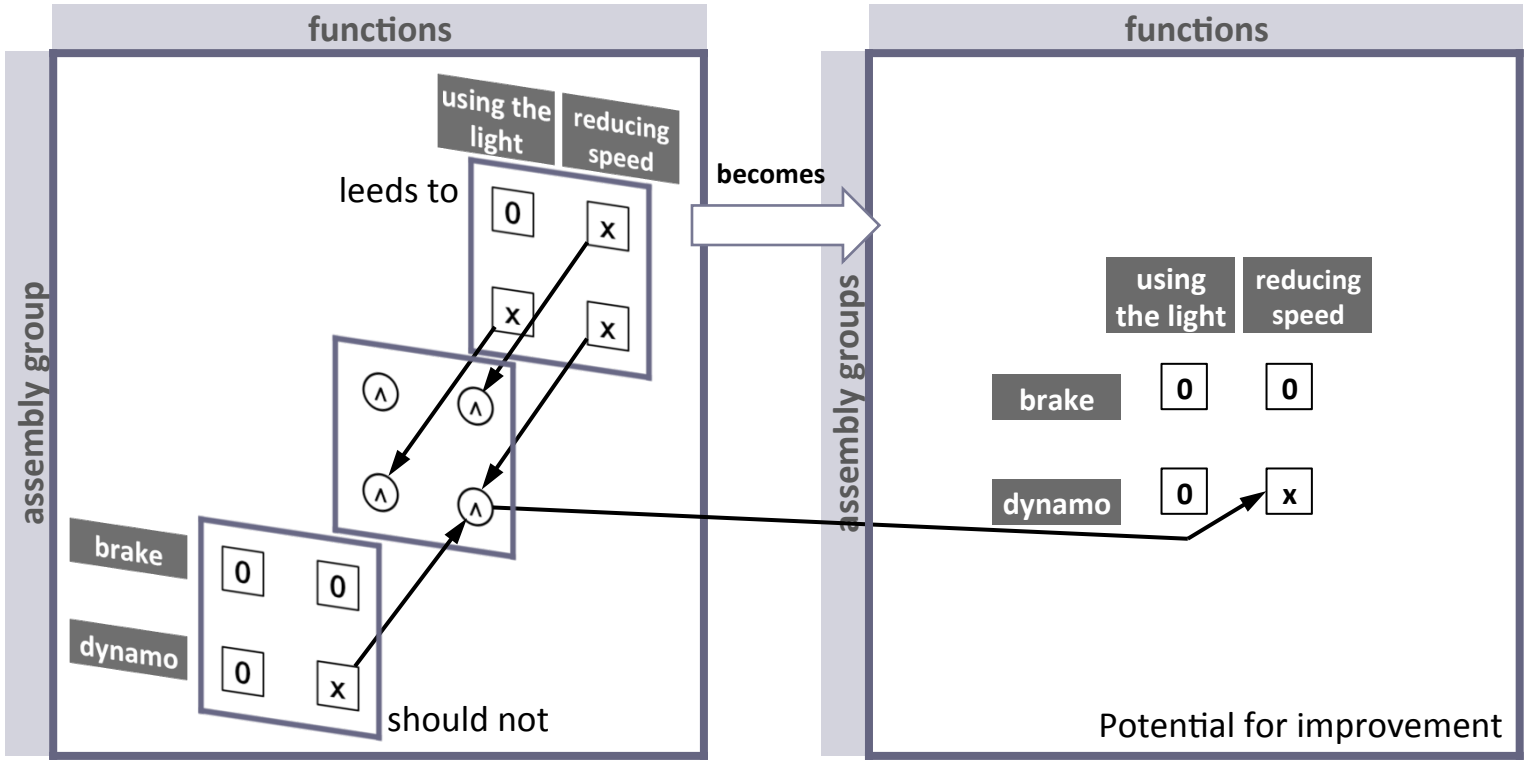


Dependencies between edges
in different subsets
(with one node in common)

Boolean operators in Multiple Domain Matrix

Across superimposed subsets

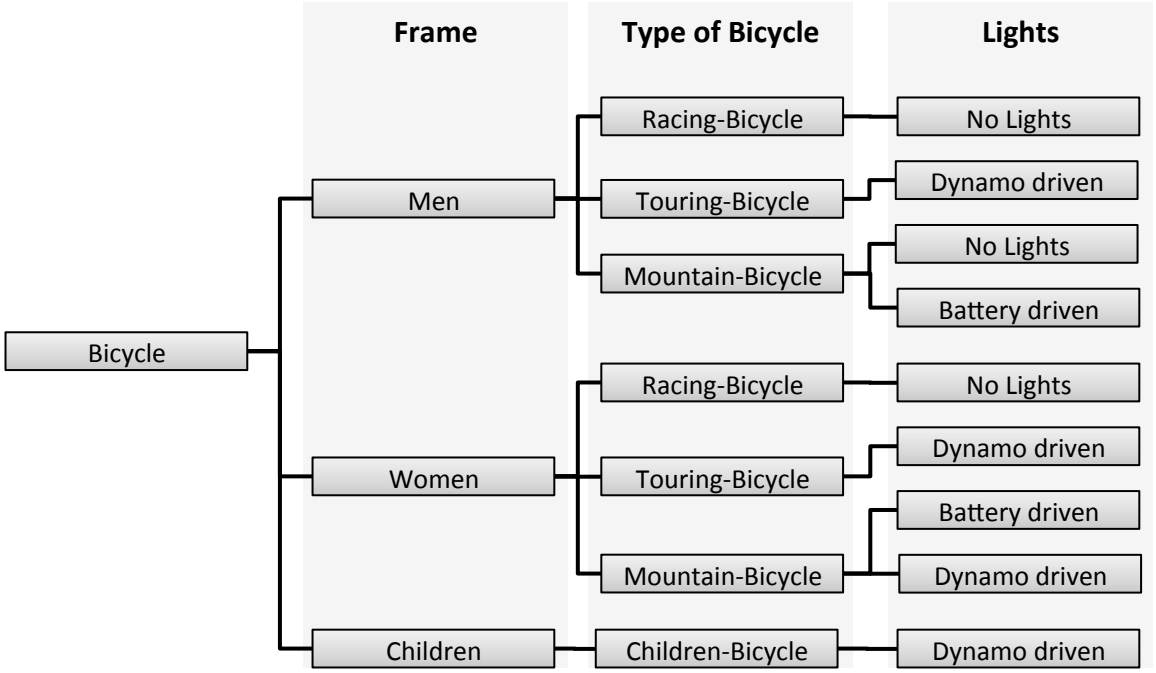
Dependencies between edges with different meaning
in superimposed subsets
(with two nodes in common)



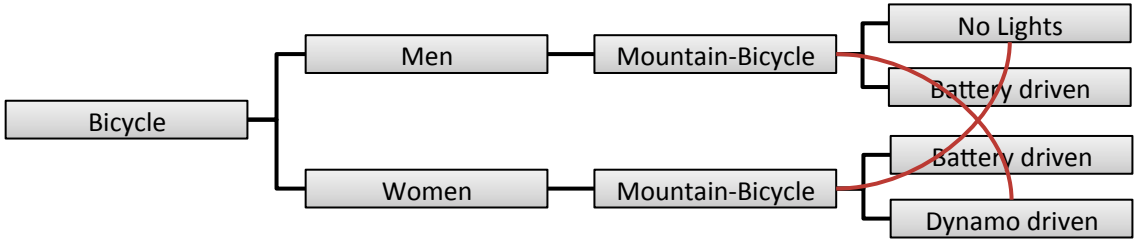
Individual pathes

Variant Tree

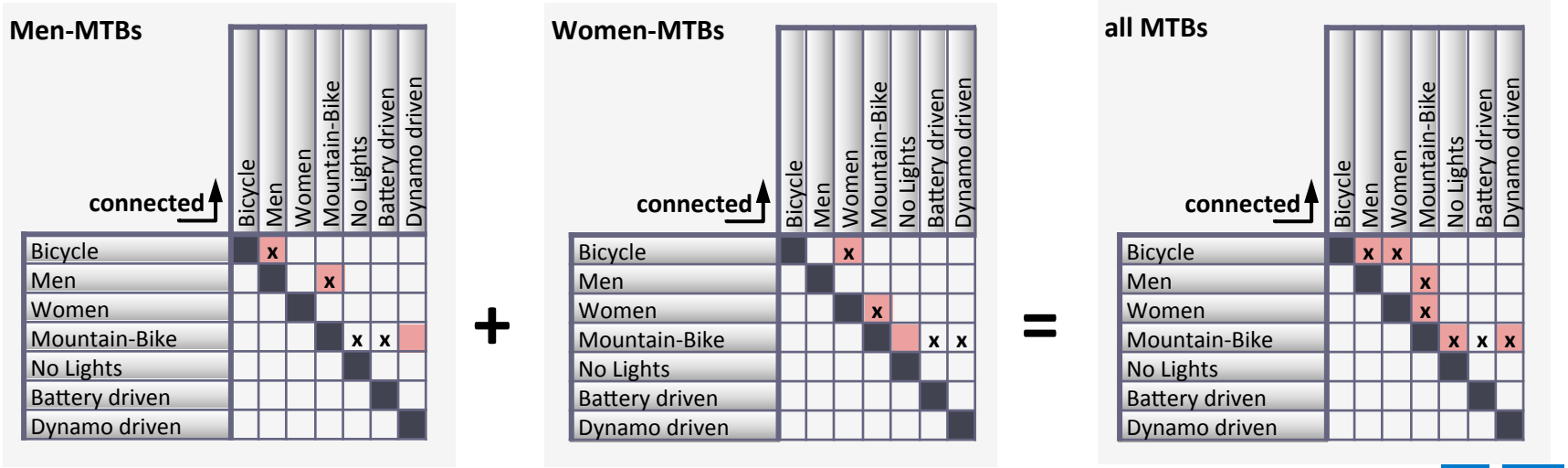
- Vertical OR-Splits;
- Horizontal AND-Join



Individual paths



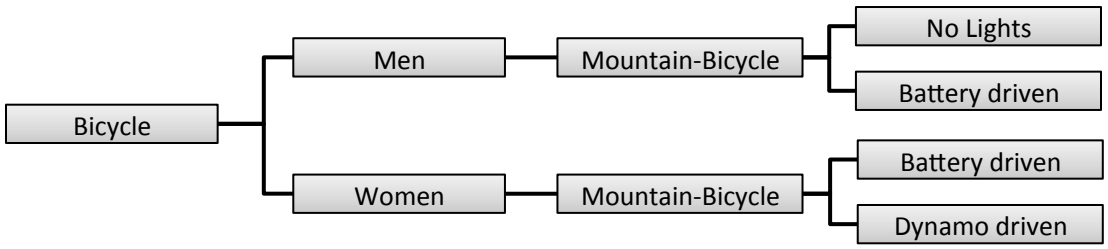
Adding different individual pathes in one matrix, leads to a possible notation of non existing paths.



Existing approaches | Individual paths

Adding domain „path“

- Each unique path becomes one node in the domain „path„
- This node is connected via edges with every node the path consists of.



becomes

Bicycle-Variants

connected

	Bicycle	Men	Women	Mountain-Bicycle	No Lights	Battery driven	Dynamo driven
Bicycle		x	x				
Men				x			
Women				x			
Mountain-Bicycle					x	x	x
No Lights							
Battery driven							
Dynamo driven							
Variant 1	x	x		x	x		
Variant 2	x	x		x		x	
Variant 3	x		x	x		x	
Variant 4	x		x	x			x

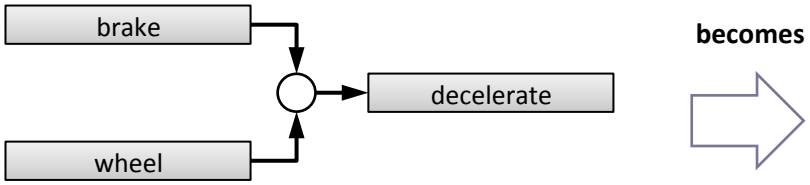
Shortcommings:

Paths can only be modeled by combining information of two different subsets.

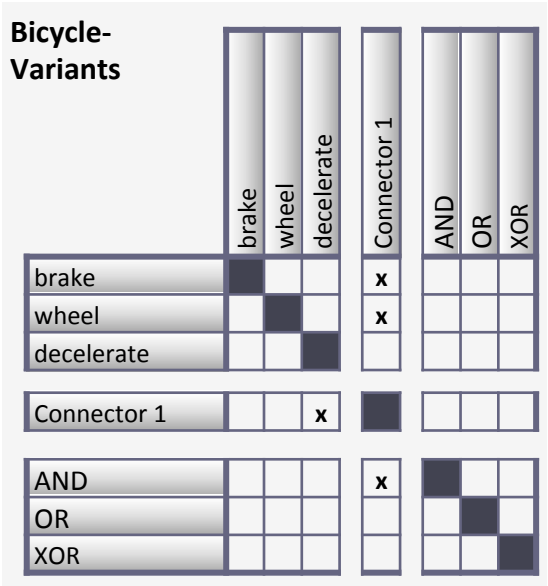
Existing approaches | Operators

Adding a connector-Domain and applying attributes to edges

- Connector is modeled by adding a domain „connector“
- The logical dependency of edges is modeled by applying an additional attribut in the domain „type of connector“
- Cascading of connectors is possible



becomes

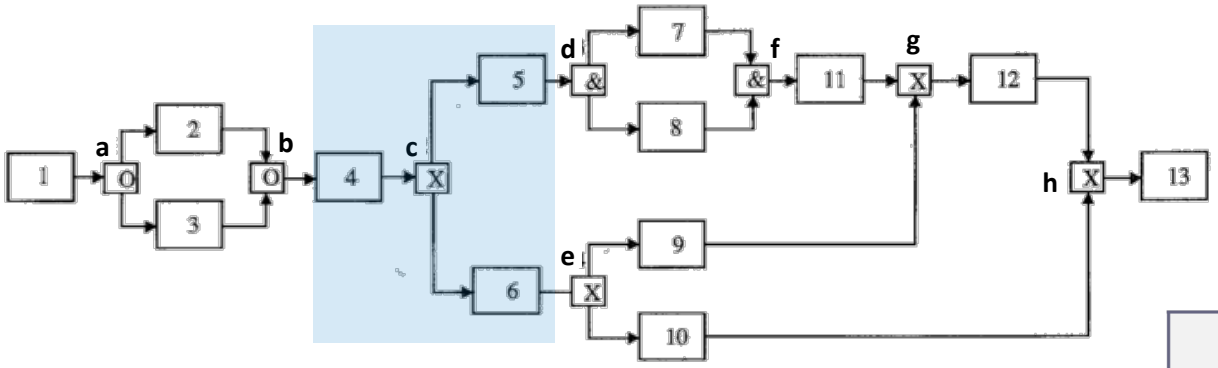


Shortcommings:

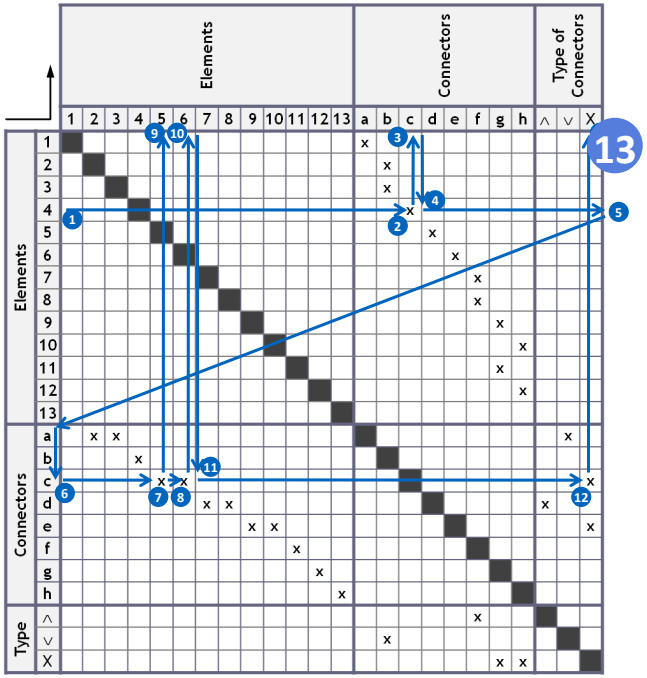
- Extensive naming of operators
- Complex modeling of even very simple dependencies
- Paths can only be modeled by combining information of three different subsets

Adapted from: Kreimeyer, M.; Braun, S.; Gürtler, M.; Lindemann, U.:
Extending multiple domain matricesto allow for the modelingof Boolean operators in process models

Existing approaches | Boolean operators



becomes

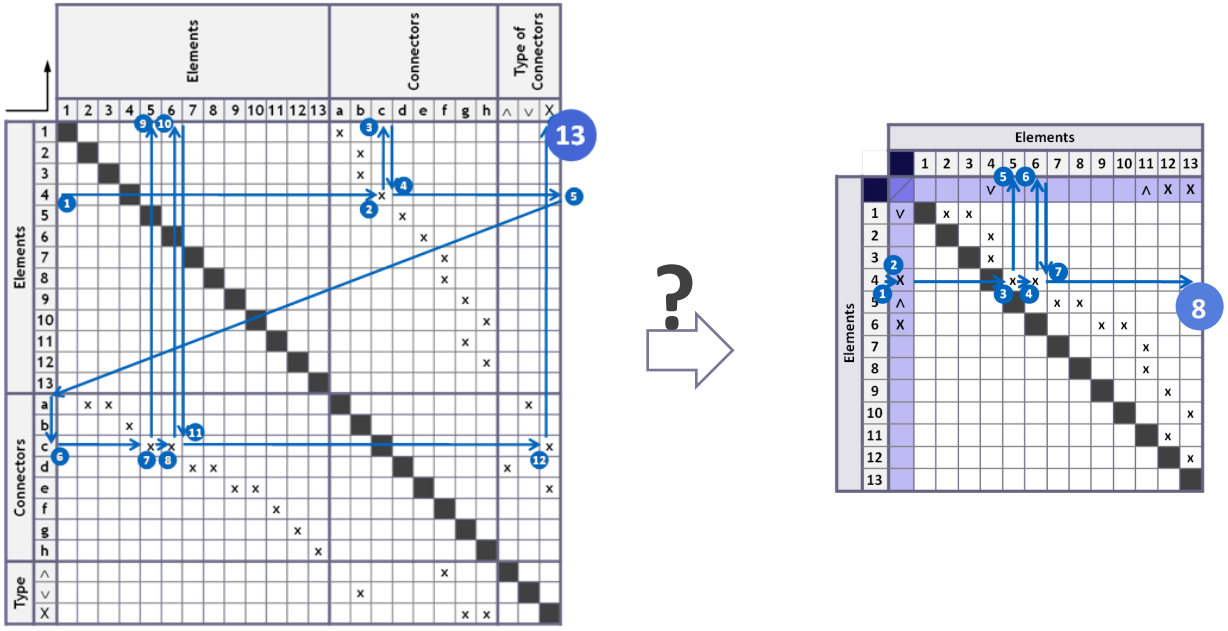


- 13 circles = 13 focus points the user has to remember and
- 13 arrows = 13 actions the user has to execute to
- identify the sub-process 4→5X6

Adapted from: Larson, N.; Kusiak, A.:
Managing Design Processes: A Risk Assessment Approach

New approach on matrix-based modeling of Boolean operators | Requirements

- The size of matrices should be as little as possible;
- Matrices should be manageable without requiring expert knowledge or extensive training;
- The transfer of system data between the new representation and conventional graphs, databases etc. should be possible without loss;
- Modeling cascades of operators and combinations of operators has to be possible.



Approach: Unique Combinations of Edges

Men-MTBs

connected	Bicycle	Men	Women	Mountain-Bicycle	No Lights	Battery driven	Dynamo driven
Bicycle		x					
Men				x			
Women							
Mountain-Bicycle					x	x	
No Lights							
Battery driven							
Dynamo driven							

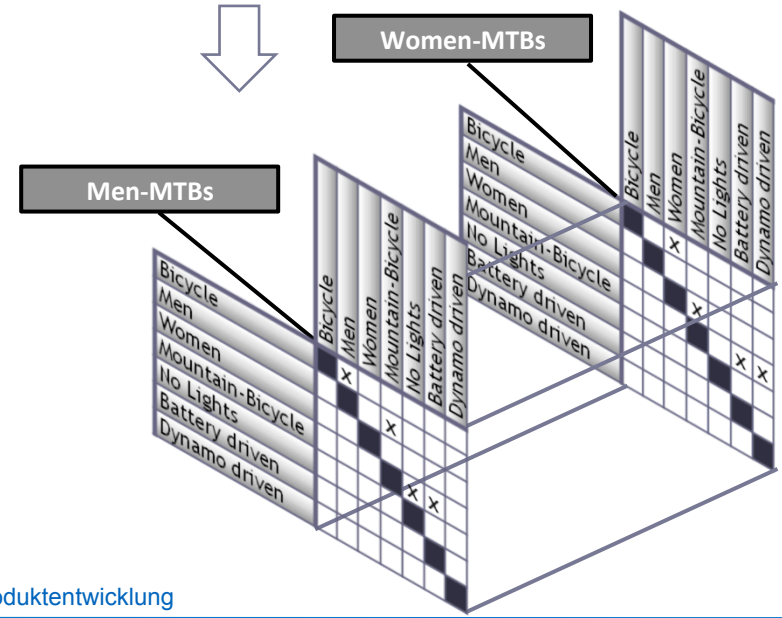
+

Women-MTBs

connected	Bicycle	Men	Women	Mountain-Bicycle	No Lights	Battery driven	Dynamo driven
Bicycle			x				
Men							
Women				x			
Mountain-Bicycle						x	x
No Lights							
Battery driven							
Dynamo driven							

Splitting similar nodes

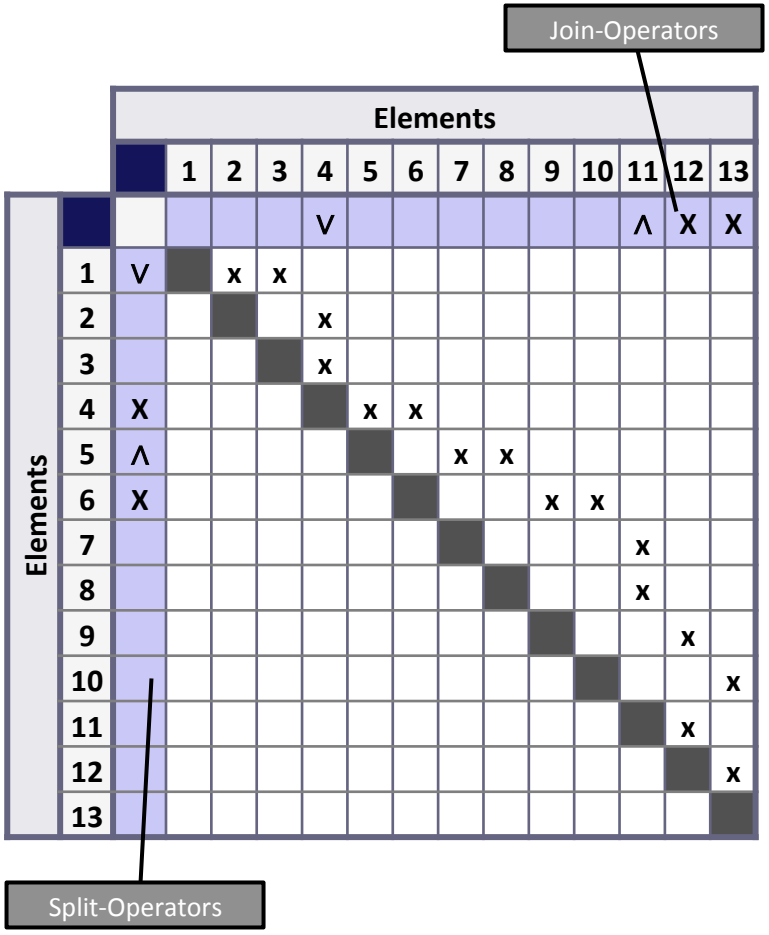
Nodes that are part of different edge combinations are splitted



Bicycle-Variants

connected	Bicycle	Men	Women	Mountain-Bicycle.1	Mountain-Bicycle.2	No Lights	Battery driven	Dynamo driven
Bicycle		x	x					
Men				x				
Women					x			
Mountain-Bicycle.1						x	x	
Mountain-Bicycle.2							x	x
No Lights								
Battery driven								
Dynamo driven								

The new representation



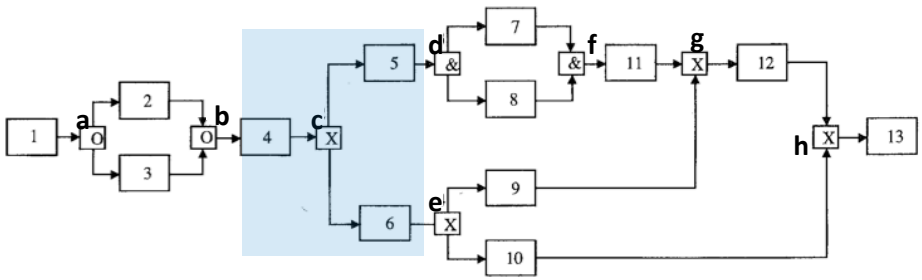
Split-Operators

- All edges of one row are downstream edges of the combined operator element
- Easy to learn and read because of the intuitive representation of information in reading direction

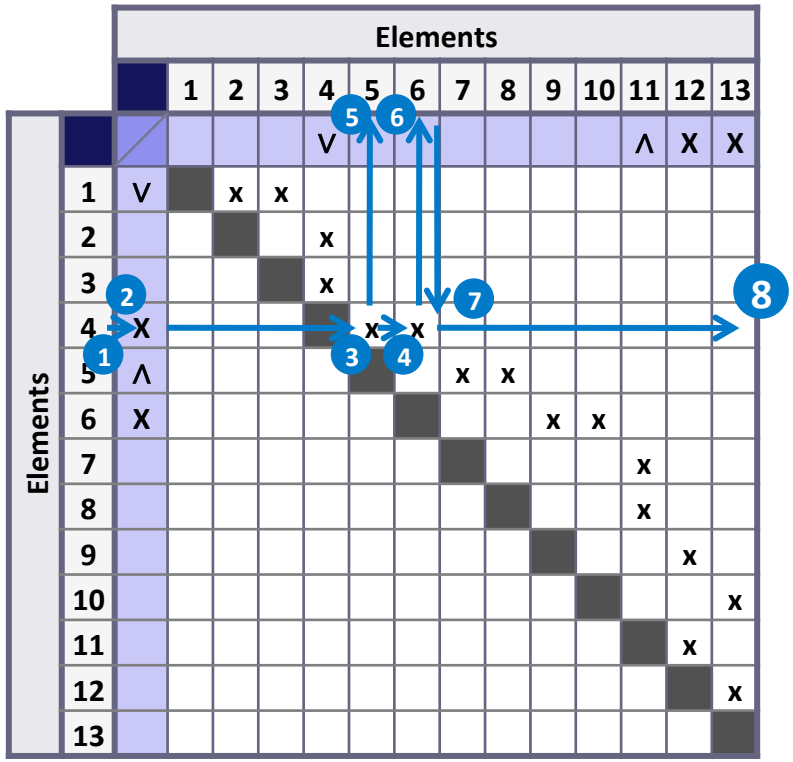
Join-Operators

- All edges of one column are upstream edges of the combined operator element
- Easy to learn and read because of the intuitive representation of information in reading direction

Comparison to the existing approach boolean Operators



becomes



- 8 circles = 8 focus points the user has to remember (before 13) and
- 7 arrows = 7 actions the user has to execute (before 13) to
- identify the sub-process 4→5x6

➔System is a lot easier to read and understand

➔Reading flow not interrupted

➔No searching for information about the connector and its characteristic in different parts of the matrix

The principles of the new representation

- **Principle 1:**
  Edges must not be removed or added to rows or columns, if Split-Operators exist in the rows or Join-Operators exist in the columns. This is necessary, because removal or addition would cause changes to the logic of the present edge combination, and therefore to paths, conditions or variants.
- **Principle 2:**
  Edges can be added and removed when previously acquired connections have to be adjusted (failure correction). However, edges may not be adapted if the state before and the state after the change are true. In such a case both states describe different valid situations and the node has to be split up.
- **Principle 3:**
  The representation of different combinations of outgoing or incoming edges (different paths) requires the division of affected nodes into similar nodes. These nodes then exist in different paths of the system, with different combinations of nodes and/or edges and the boolean logic between them.
- **Principle 4:**
  Every edge can be influenced by one Split-Operator and/or one Join-Operator only. This also applies for operators connecting multiple subsets.

Splitting of nodes

- Adding the edge **β→5** in the matrix
- **β** needs to be splitted, for not adding the edge **β→5** to the path **β→(2V4)**

Domain B	Domain A	1	2	3	4	5	6	7
α	Λ	x				x		
β	V		x		x			
γ					x			
δ							x	
ε				x		x		

+ β→5

Domain B	Domain A	1	2	3	4	5	6	7
α	Λ	x				x		
β	V		x		x	x		
γ					x			
δ							x	
ε				x		x		

new edge combination

Domain B	Domain A	1	2	3	4	5	6	7
α	Λ	x				x		
β.1	V		x		x			
β.2						x		
γ					x			
δ							x	
ε				x		x		

Conclusion

- The introduced representation offers an intuitive and easy to understand possibility for dealing with boolean operators in matrices.
- The representation of boolean operators and paths is similar to the common representation of edges and nodes in matrices.
- The transfer of system data between the new representation, graphs, databases etc. is guaranteed without the loss of any information.