Modeling Engineering Change Management Process in Virtual Collaborative Design Environments

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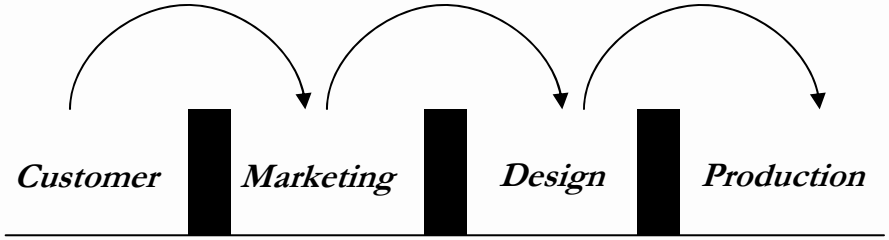
OUTLINE

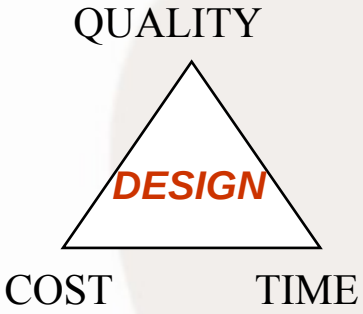
- Motivation behind the research
- Objective of our research
- Overview of ECM process
- Background and related research
- Proposed system: ADVICE
- Validating ADVICE: Experiments
- Contributions and future work

MOTIVATION

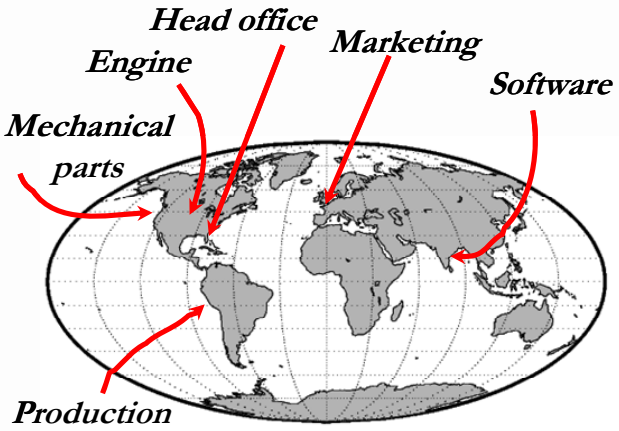
Improvement of design process

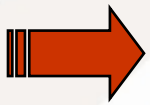


Throw-over-the-wall strategy



Early involvement of geographically dispersed parties in design

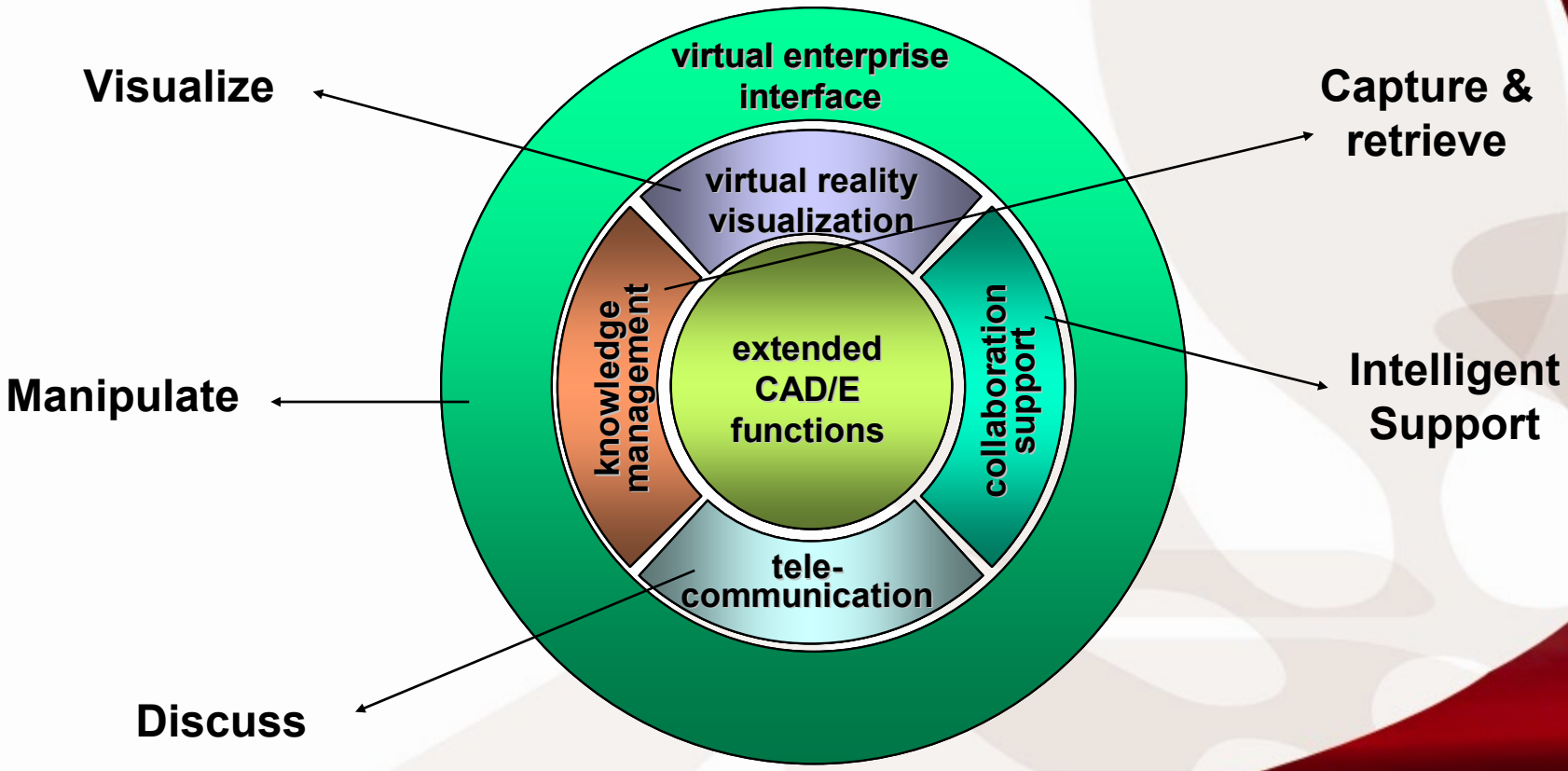




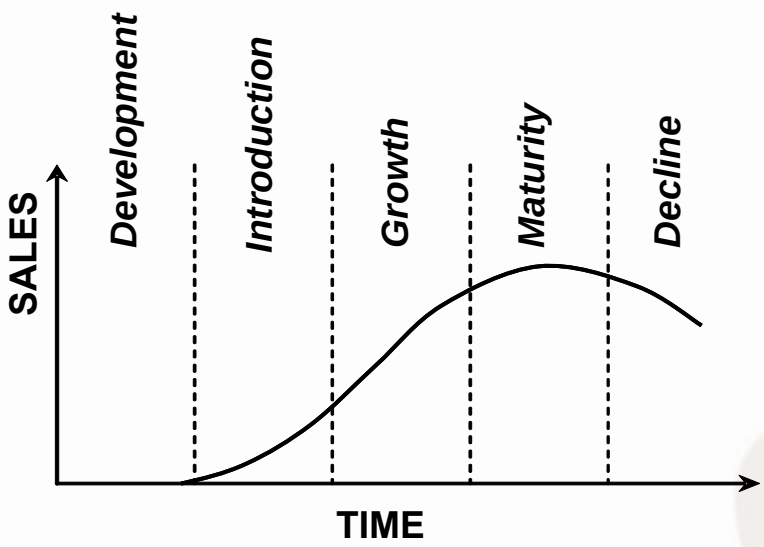
VCDE

Virtual Collaborative Design Environments

a shared real-time simulated 3D environment that facilitates creative collaboration of the design team



MOTIVATION



Engineering Changes:
Modifications in

- forms
- fits
- functions
- materials
- dimensions, etc.

ECs are:

- unavoidable
- desirable
- problematic

MOTIVATION

- ECs consume 1/3 to 1/2 of the total engineering capacity.

- Value-added time in ECM process is only 8.5%.

- An EC spends most of its life-time waiting for further processing.

MOTIVATION

Problems:

- # of ECs processed
- variety of product families
- # revisions
- parametric vs. graphical data
- interaction with other elements
- # decision makers
- background of decision makers
- change propagation
- batching: determining priority

OBJECTIVE

- **Can we expedite and improve ECM process by employing VCDE for presenting information more effectively?**

- **Is it possible to predict effects of changes requested and prioritize change requests based on historical change-data?**

Propose a smart ECM system embedded in a distributed VCDE:

1. *A shared real-time simulated 3D representation of EC perceived rapidly and accurately by users*

2. *User support by capturing and retrieving change data for predicting change propagation and ordering change requests*

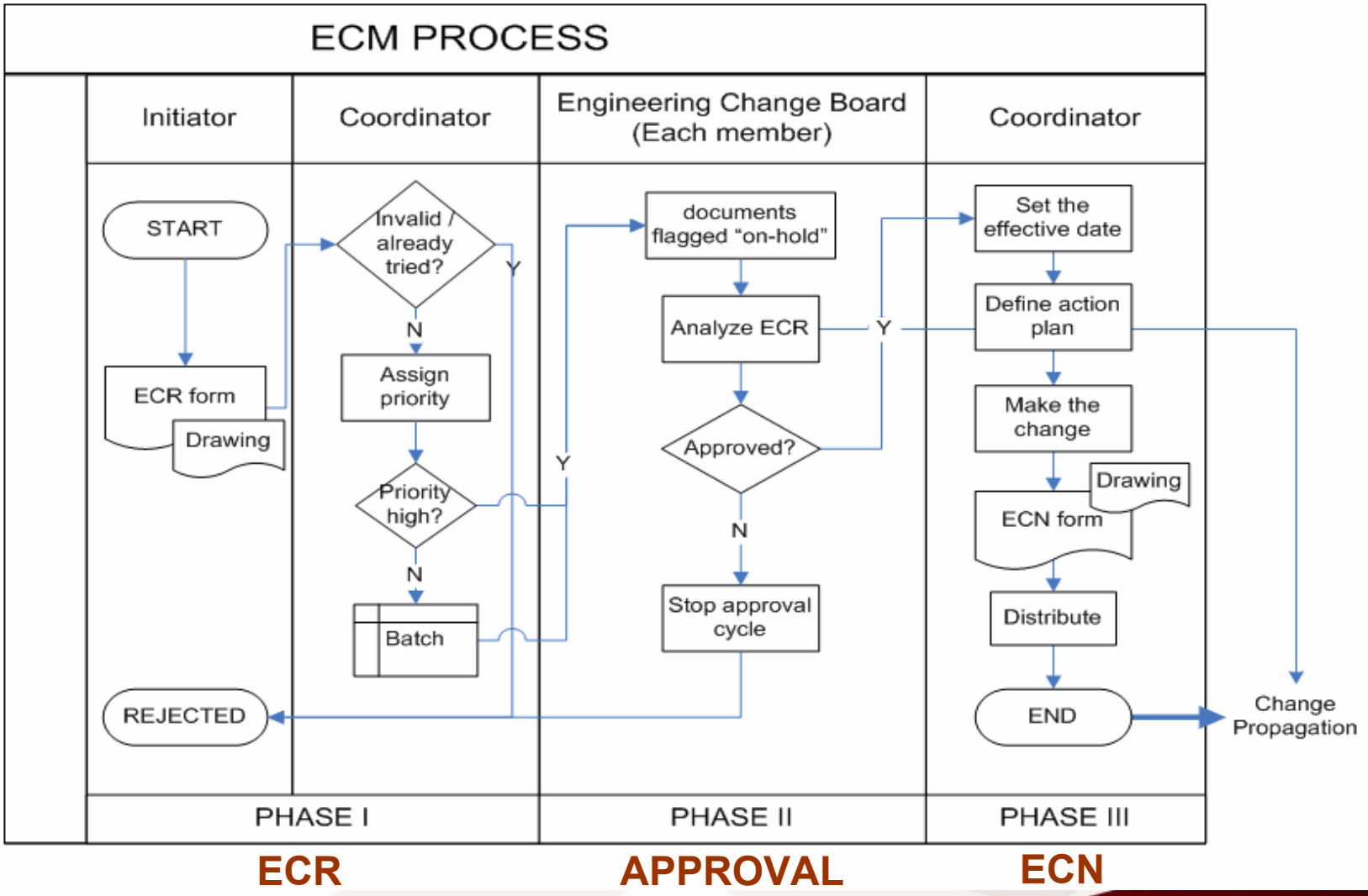
ADVICE

OBJECTIVE

Problems:

- # of ECs processed
- variety of product families
- # revisions
- ☑ parametric vs. graphical data
- ☑ interaction with other elements
- # decision makers
- ☑ background of decision makers
- ☑ change propagation
- ☑ batching: determining priority

ECM PROCESS


ECM PROCESS
Initiator
Coordinator
Engineering Change Board (Each member)
Coordinator
START
ECR form
Drawing
Invalid / already tried?
Y
N
Assign priority
Priority high?
Y
N
Batch
REJECTED
documents flagged "on-hold"
Analyze ECR
Approved?
Y
N
Stop approval cycle
Set the effective date
Define action plan
Make the change
Drawing
ECN form
Distribute
END
Change Propagation
PHASE I
PHASE II
PHASE III
ECR
APPROVAL
ECN

RELATED RESEARCH

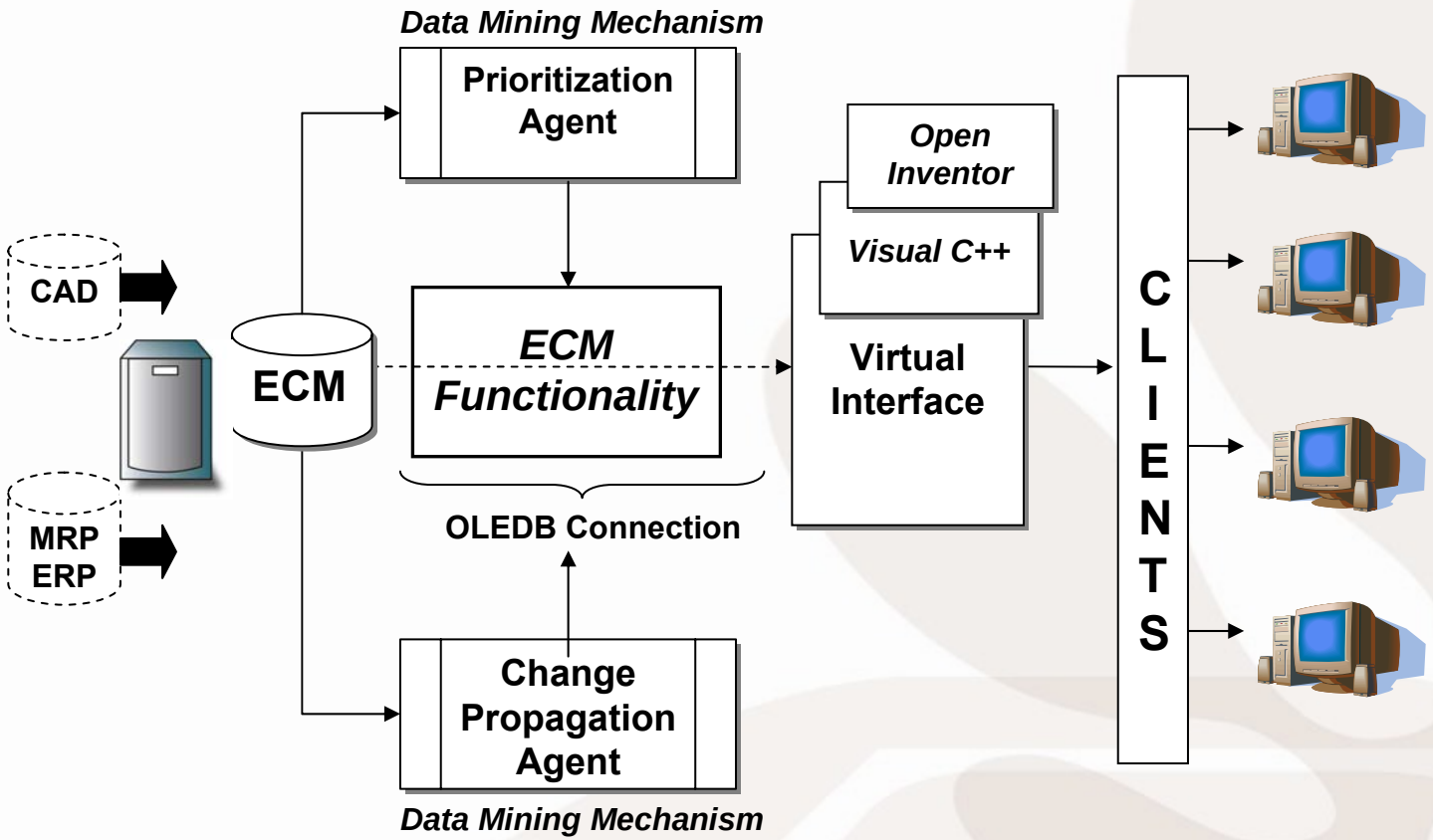
- **Engineering Change Management**
  - surveys and reviews
  - industrial case studies
  - tools & solutions (scarce)
  - change propagation (parameter, DSM, STEP- static & subjective)
- **Virtual Collaborative Design Environments**
  - immersive vs. non-immersive
  - conceptual & embodiment (preliminary design)
  - solutions specific to industries
- **Data Mining techniques for sequential data**
  - Fundamental and generic algorithms
  - AprioriAll
  - MINEPI (Minimal Episodes)

METHODOLOGY

- Establish the database structure (ECM database)
- Build a VCDE linked to ECM database assuring synchronisation of parametric and graphical data
- Develop a smart methodology to automatically analyze and retrieve change history stored in ECM database for supporting prioritization and change propagation
- Propose effective means of presenting this information to the users facilitating comprehension

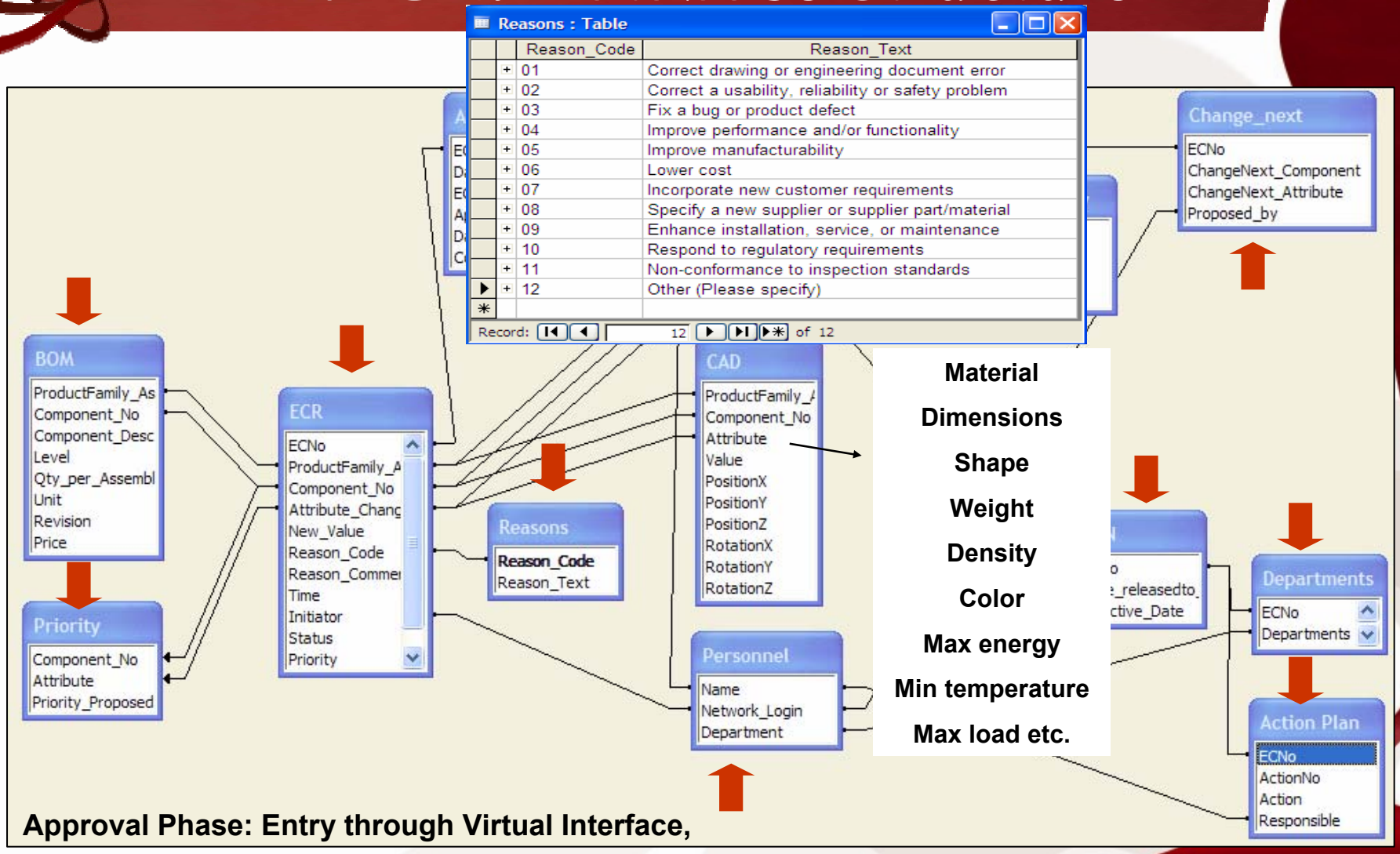
ADVICE: System Architecture

Impact of an EC -> Priority -> time to process



Components to be changed due to this change

ADVICE: Database Structure



Approval Phase: Entry through Virtual Interface,

ECN Phase: Entry through Virtual Interface, limited to triggered changes in our sample application

Supplementary Tables: Already available in data warehouse

Prioritization table fed by Data Mining Agent

ADVICE: Virtual Interface

- Linked to the database structure (in-out)
- 360° perspective
- Zoom-in/out
- Use of colors and highlighting

ComponentName	ComponentShape	ComponentMaterial	Height	Depth	Width	Radius	PositionX	PositionY	PositionZ	RotationX	Rotation
top	cube	wood	0.2	2	3	1.8	0	0	0	0	
leg1	cylinder	metal	1	0.08	0.08	0.05	1.45	-0.5	0.95	0	
leg2	cylinder	metal	1	0.08	0.08	0.05	-1.45	-0.5	0.95	0	
leg3	cylinder	metal	1	0.08	0.08	0.05	1.45	-0.5	-0.95	0	
leg4	cylinder	metal	1	0.08	0.08	0.05	-1.45	-0.5	-0.95	0	
screw1	cylinder	metal	0.08	0.01	0.01	0.04	1.48	-0.05	0.95	0	
screw2	cylinder	metal	0.08	0.01	0.01	0.04	-1.48	-0.05	0.95	0	
screw3	cylinder	metal	0.08	0.01	0.01	0.04	1.48	-0.05	-0.95	0	
screw4	cylinder	metal	0.08	0.01	0.01	0.04	-1.48	-0.05	-0.95	0	
panel1	cube	metal	0.4	0.1	3	1	0	-0.2	-0.95	0	
panel2	cube	wood	0.8	2	0.1	1	-1.45	-0.4	0	0	
panel3	cube	wood	0.8	2	0.1	1	1.45	-0.4	0	0	
shelf1	cube	wood	0.05	0.5	0.8	0.45	-1	-0.4	0.7	0	
shelf2	cube	wood	0.05	0.5	0.8	0.45	-1	-0.8	0.7	0	
panel5	cube	metal	0.85	0.1	0.85	1	-0.98	-0.4	0.45	0	
panel6	cube	wood	0.85	0.5	0.1	1	-0.6	-0.4	0.7	0	
screw5	cylinder	metal	0.08	0.01	0.01	0.03	1.45	-0.05	-0.98	1	
screw6	cylinder	metal	0.08	0.01	0.01	0.03	-1.45	-0.05	-0.98	1	
screw7	cylinder	metal	0.06	0.01	0.01	0.03	-0.57	-0.4	0.7	0	
screw8	cylinder	metal	0.06	0.01	0.01	0.03	-0.57	-0.8	0.7	0	
screw9	cylinder	metal	0.06	0.01	0.01	0.03	-0.98	-0.4	0.42	1	

Record: 25 of 43

ADVICE: A sample application

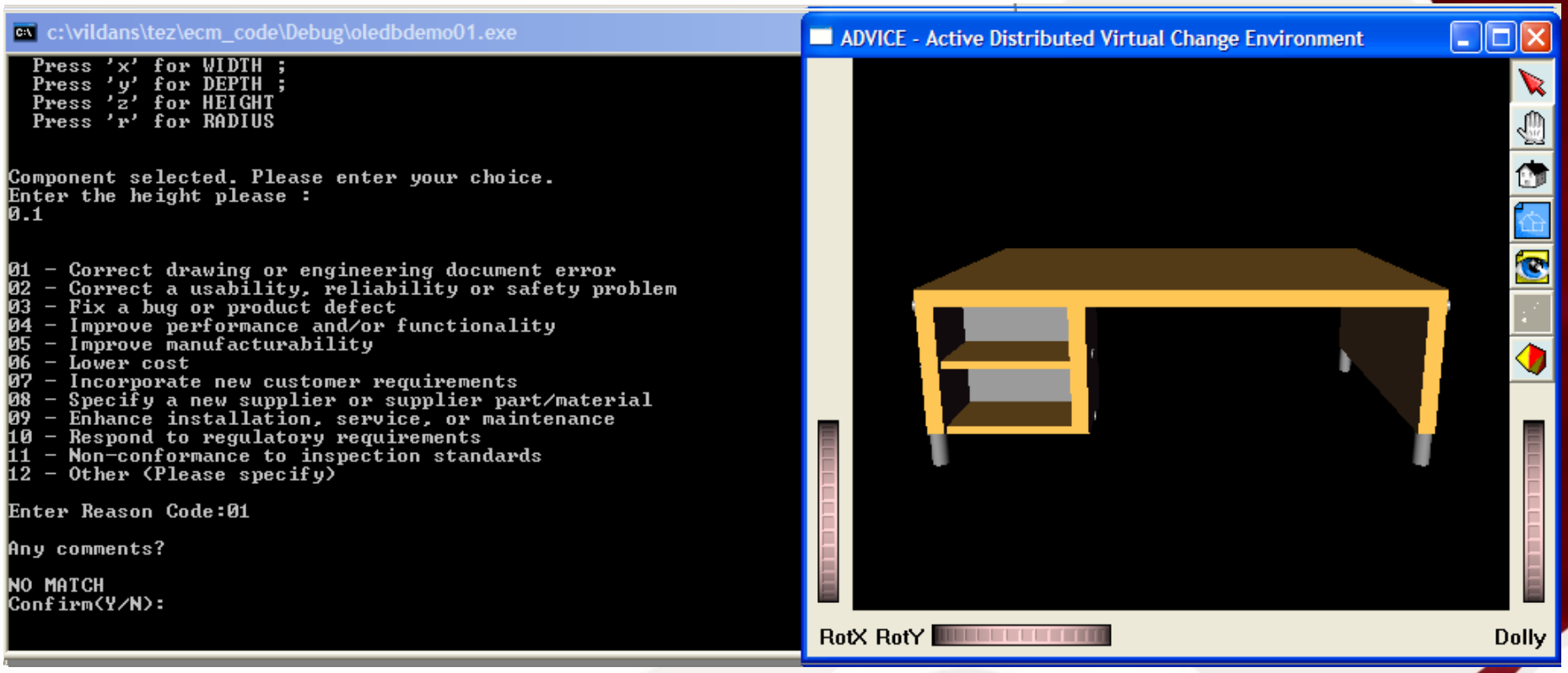
- Application is used for explaining ADVICE's characteristics and working principles

- BOM and CAD tables created for 4 different office table assemblies and 43 components

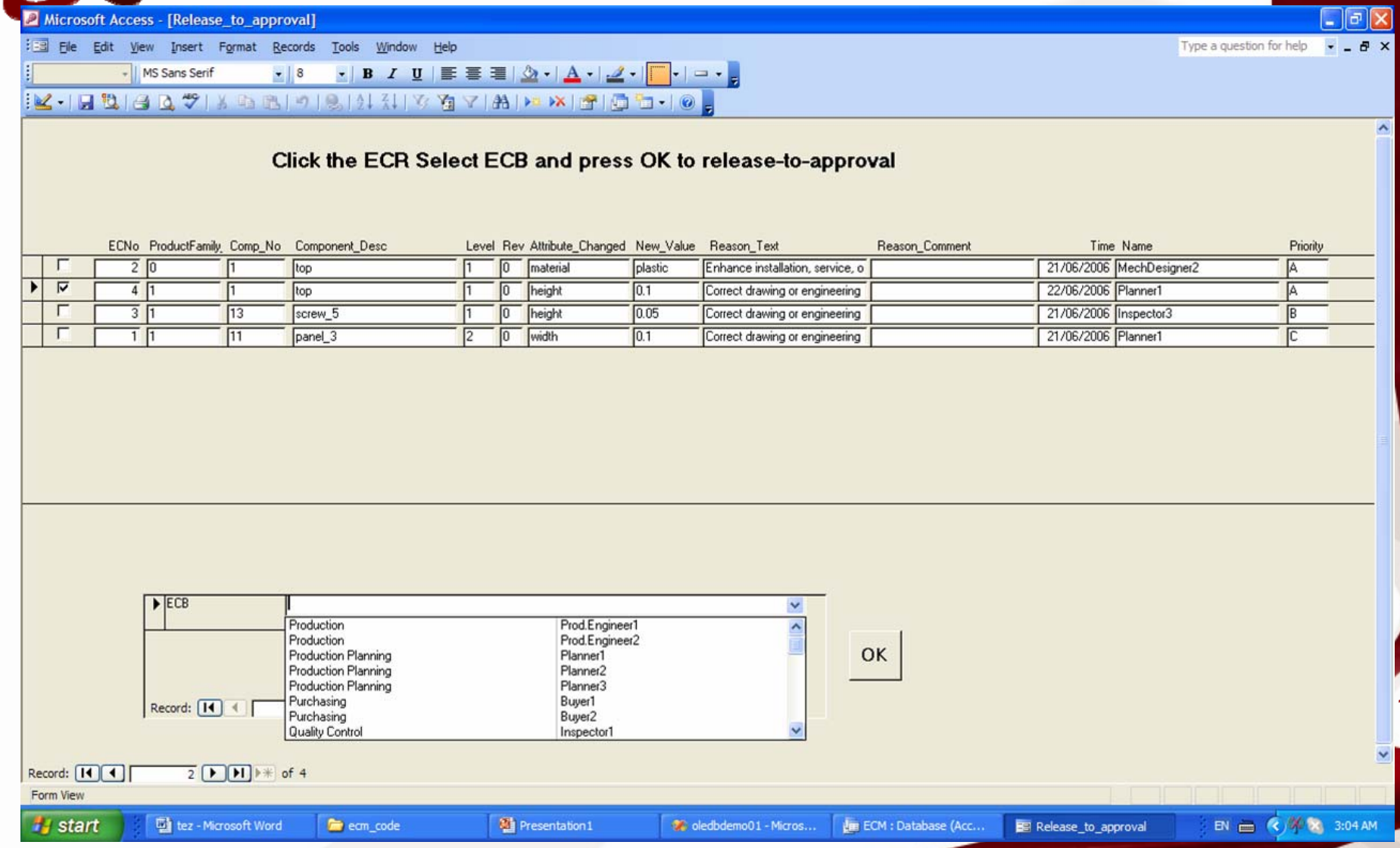
- Attributes limited to explicit attributes

(Material, Shape, Height, Width, Depth, Radius)

ADVICE: ECR Phase



ADVICE: ECR Phase



ADVICE: Prioritization Agent

- Impact: Total amount of work that needs to be re-done
- Use EC data history already stored through life-time
- Find patterns that are frequent among all models
- How: AprioriAll algorithm, 5 step approach to find patterns
- Input : Data sequences <M_i (C_{ij}..C_{ik}) t_i>
- Output: Patterns
- Convert patterns to priorities by following formulation

$$f_P(C_{ij}) = \sum_p \left[\mathrm{NTr}(C_{ij}, p) * \mathrm{supp}(p) \right]$$

Priority Index of C_{ij}

# of unique events triggered by C_{ij} in pattern p

Support of pattern

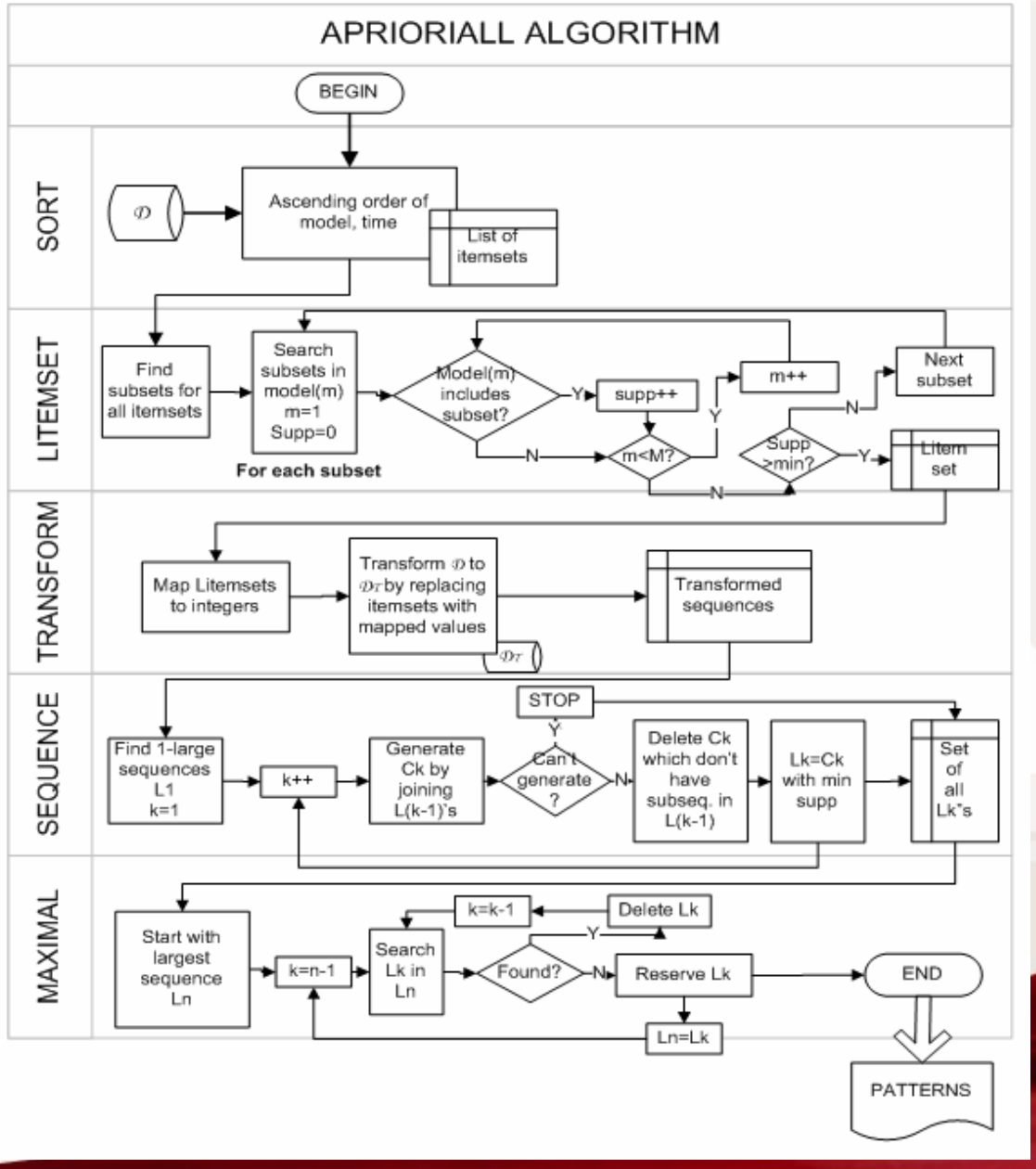
$$IF \quad f_P(C_{ij}) > Th_A \quad THEN \quad "A"$$

$$IF \quad Th_B \le f_P(C_{ij}) < Th_A \quad THEN \quad "B"$$

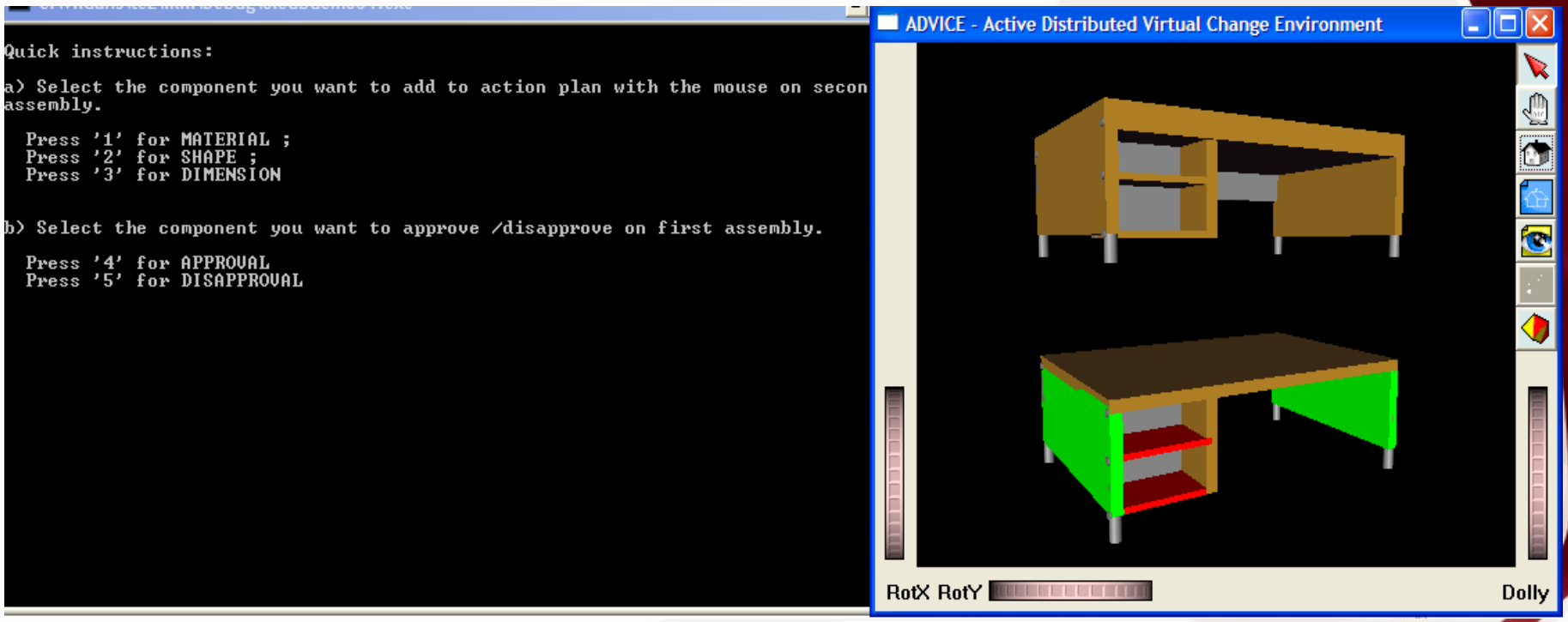
$$IF \quad f_P(C_{ij}) \le Th_B \quad THEN \quad "C"$$

ADVICE: Prioritization Agent

Apriori property

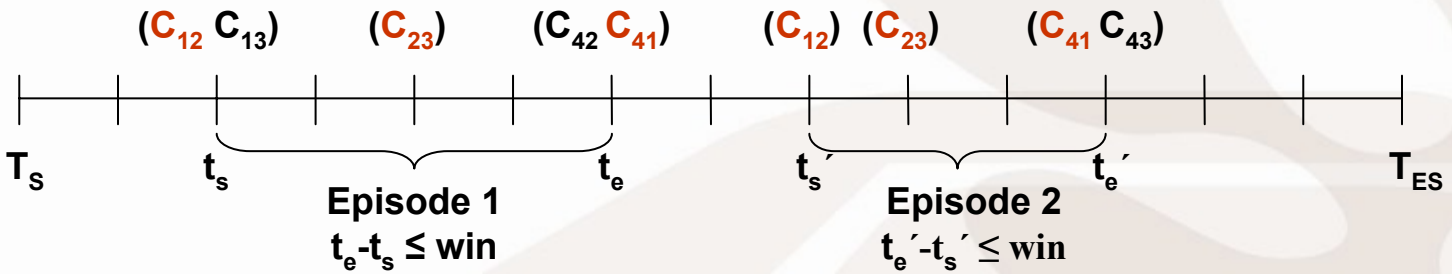


ADVICE: Approval Phase

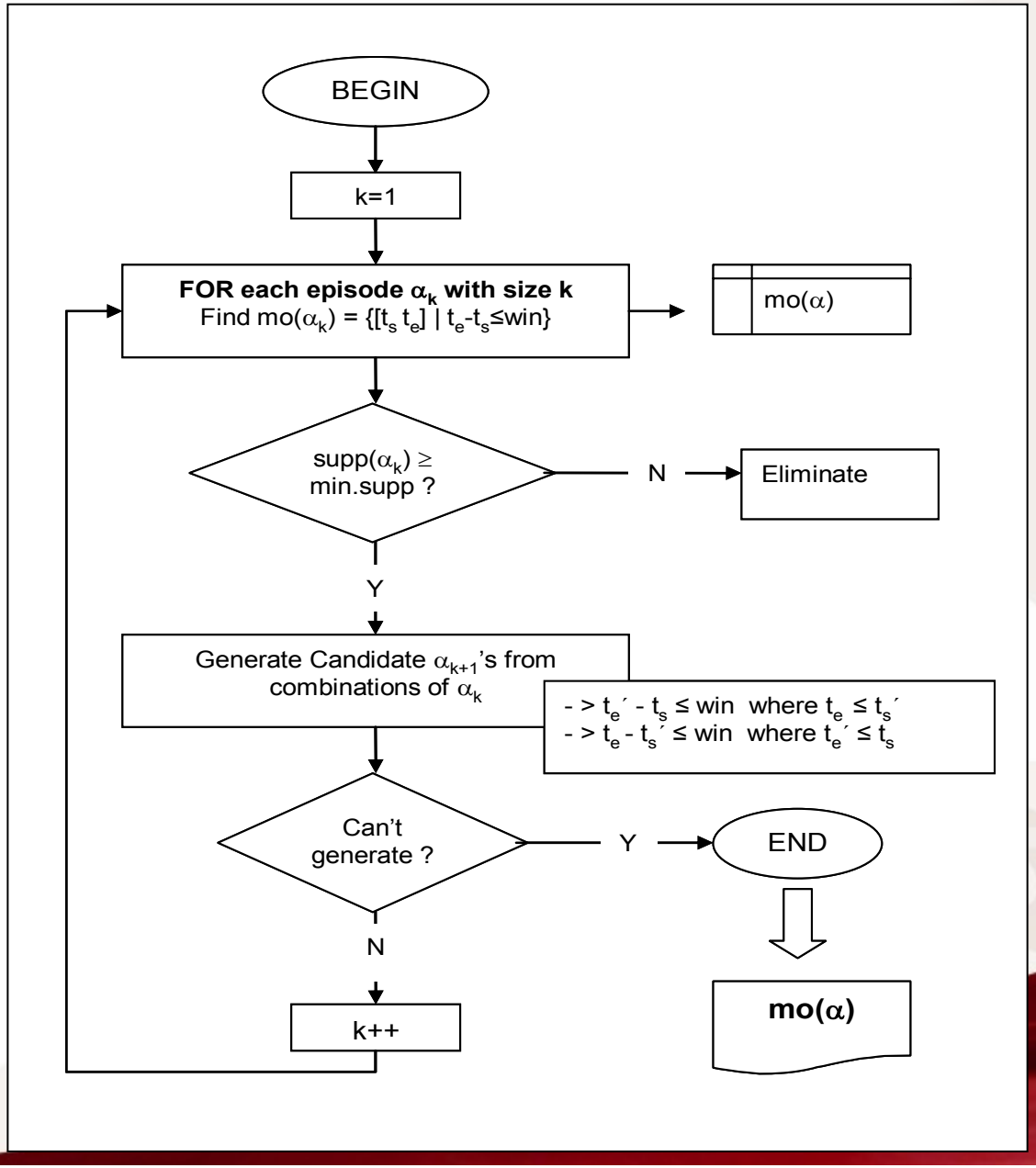


ADVICE: Change Propagation Agent

- Use EC data history already stored through life-time
- Find frequent patterns within each model
- Non-consecutive changes
- Parallel (concurrent) changes possible
- Episode-based approach
- How: MINEPI algorithm
- Probabilities of each 2-size pattern is converted to color codes (Red Yellow Green)



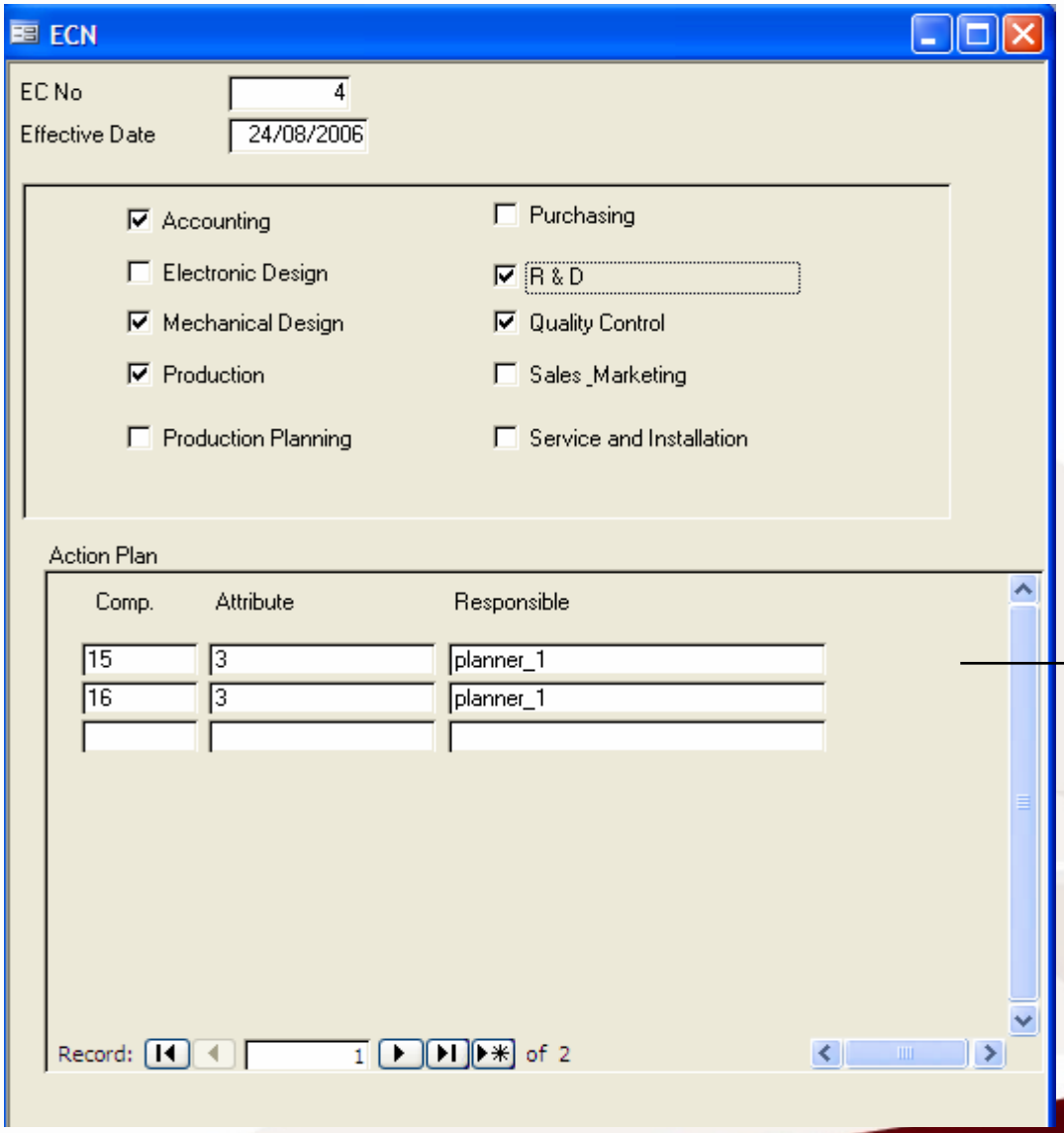
ADVICE: Change Propagation Agent



ADVICE: Approval Phase

```
Quick instructions:

a) Select the component you want to add to action plan with the mouse on secon
assembly.

  Press '1' for MATERIAL ;
  Press '2' for SHAPE ;
  Press '3' for DIMENSION


b) Select the component you want to approve /disapprove on first assembly.

  Press '4' for APPROVAL
  Press '5' for DISAPPROVAL
15 selected
3
15 deselected
16 selected
3
16 deselected
Original assembly selected
4
Approved
```

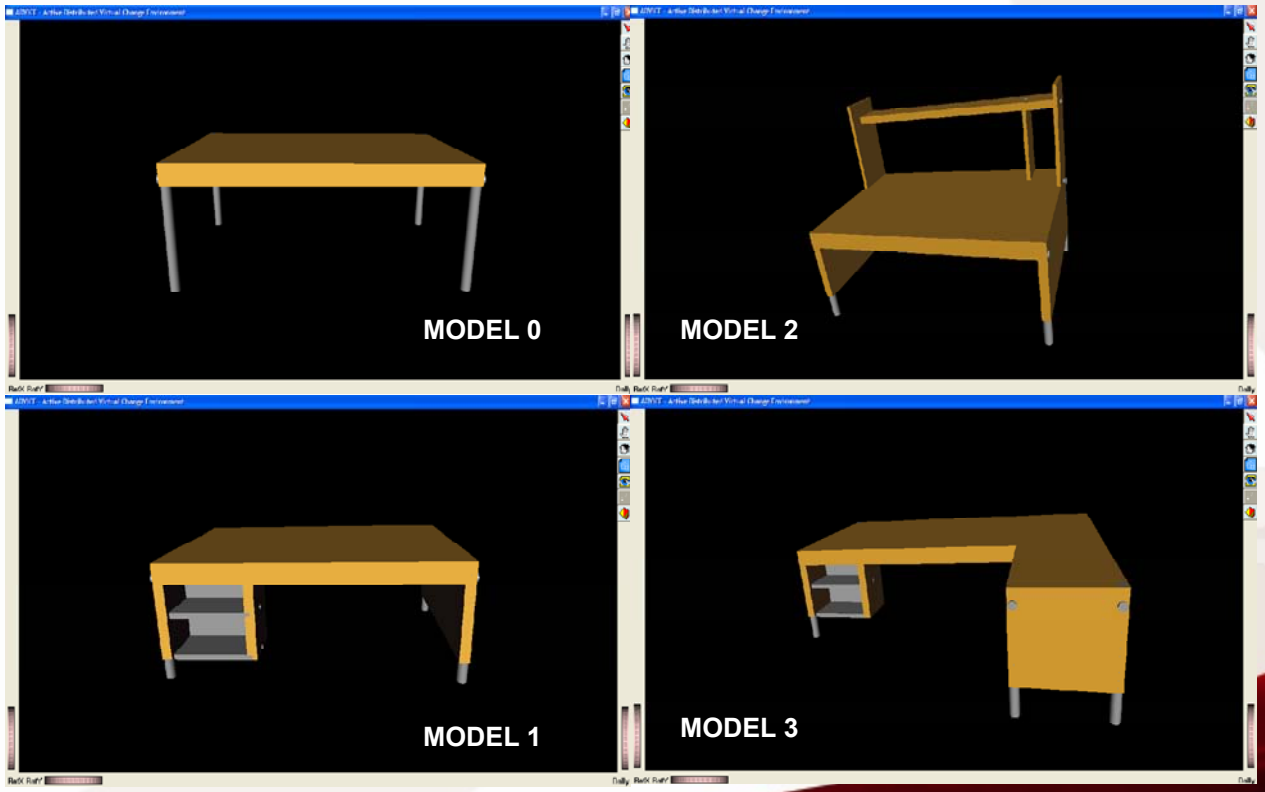
ADVICE: ECN Phase



Limited to changes to be triggered

Validation: Experiments

- Synthetic Data
- 4 models 43 components
- Prioritization: 5 experiments with 100 transactions
- Change Propagation: 4 experiments with 250 transactions



Validation: Prioritization

EXPERIMENT 1		
A threshold	2.17188	
B threshold	1.08594	
Component - Attribute	Priority Index	Priority assigned
031	6	A
032	6	A
062	4	A
161	3.5	A
112	3	A
033	3	A
052	3	A
111	3	A
243	3	A
113	3	A
241	3	A
222	2.5	A
181	2.5	A
202	2	B
082	2	B
021	1.5	B
023	1.5	B
042	1.5	B
201	1.5	B
121	1.5	B
122	1.5	B
123	1.5	B
053	1.5	B
071	1	C
072	1	C
043	1	C
163	1	C
041	1	C
162	1	C
223	1	C
131	0.5	C
012	0.5	C

EXPERIMENT 2		
A th		
B th		
Com - A		
011		
031		
222		
051		
032		
[illegible]		
[illegible]		
191		
012		
063		
062		
142		
022		
083		
103		
052		
121		
033		
131		
182		

EXPERIMENT 3		
031	0.5	C
033	0.5	C

EXPERIMENT 4		
hold	2.958333	
hold	1.479167	
nent - bute	Priority Index	Priority assigned
	7.5	A
	6.5	A
	6.5	A
	6	A
	4.5	A
	3.5	A
	3.5	A
	3.5	A
	3.5	A
	3.5	A
	3.5	A
	2.5	B
	2.5	B
	2.5	B
	2	B
	1.5	B
	1.5	B
	1.5	B
	1	C
	1	C
	1	C
	1	C
172	0.5	C
022	0.5	C

EXPERIMENT 5		
A threshold	2.357143	
B threshold	1.178571	
Component - Attribute	Priority Index	Priority assigned
091	7.5	A
093	5	A
053	5	A
132	4.5	A
022	2.5	A
241	2.5	A
223	2.5	A
243	2.5	A
113	2	B
112	2	B
111	2	B
051	2	B
063	2	B
023	1.5	B
101	1.5	B
061	1	C
052	1	C
242	1	C
011	0.5	C
103	0.5	C
102	0.5	C

EXPERIMENT 1

A threshold	2.17188
B threshold	1.08594

Component - Attribute	Priority Index	Priority assigned
031	6	A
032	6	A
062	4	A
161	3.5	A
112	3	A

Validation: Change Propagation

Model 3; Minimum occurrence threshold =2; Time Window=4

EXPERIMENT 1		EXPERIMENT 2		EXPERIMENT 3		EXPERIMENT 4	
81 transactions; 133 changes		77 transactions; 130 changes		86 transactions; 140 changes		76 transactions; 118 changes	
Patterns	Probability	Patterns	Probability	Patterns	Probability	Patterns	Probability
021 >> 062	1.00	021 >> 062	1.00	021 >> 062	1.00	011 >> 352	0.40
041 >> 343	1.00	041 >> 343	1.00	041 >> 343	1.00	013 >> 201	0.50
162 >> 191	0.67	162 >> 191	0.67	162 >> 191	0.67	013 >> 202	0.50
181 >> 011	0.67	181 >> 011	0.67	181 >> 011	0.67	041 >> 011	0.67
183 >> 011	0.50	183 >> 011	0.50	183 >> 011	0.50	041 >> 341	0.67
193 >> 431	0.50	193 >> 431	0.50	193 >> 431	0.50	152 >> 421	1.00
202 >> 401	1.00	202 >> 401	1.00	202 >> 401	1.00	153 >> 421	1.00
202 >> 402	1.00	202 >> 402	1.00	202 >> 402	1.00	172 >> 202	0.67
221 >> 181	1.00	221 >> 181	1.00	221 >> 181	1.00	172 >> 233	0.67
221 >> 183	1.00	221 >> 183	1.00	221 >> 183	1.00	173 >> 202	1.00
231 >> 041	0.40	231 >> 041	0.40	231 >> 041	0.40	181 >> 152	1.00
231 >> 191	0.40	231 >> 191	0.40	231 >> 191	0.40	181 >> 153	1.00
231 >> 221	0.40	231 >> 221	0.40	231 >> 221	0.40	181 >> 421	1.00
231 >> 343	0.40	231 >> 343	0.40	231 >> 343	0.40	183 >> 152	0.50
231 >> 402	0.40	412 >> 241	0.33	231 >> 402	0.40	183 >> 153	0.75
232 >> 041	0.40	412 >> 243	0.33	232 >> 041	0.40	183 >> 421	0.75
232 >> 343	0.40	412 >> 353	0.33	232 >> 343	0.40	202 >> 182	0.50
233 >> 193	0.40	413 >> 041	0.67	233 >> 193	0.40	203 >> 161	1.00
233 >> 221	0.40			233 >> 221	0.40	203 >> 162	1.00
233 >> 402	0.40			233 >> 402	0.40	233 >> 041	0.67
243 >> 162	1.00			243 >> 162	1.00	352 >> 041	1.00
361 >> 231	1.00			361 >> 231	1.00	362 >> 203	0.40
361 >> 233	1.00			361 >> 233	1.00	362 >> 212	0.40
363 >> 231	0.67			363 >> 231	0.67	362 >> 213	0.40
363 >> 232	0.67			363 >> 232	0.67	382 >> 362	0.67
363 >> 233	0.67			363 >> 233	0.67	383 >> 362	0.67
363 >> 402	0.67			363 >> 402	0.67	393 >> 013	1.00
372 >> 183	1.00			372 >> 183	1.00	421 >> 362	0.67
411 >> 051	1.00			411 >> 051	1.00		
431 >> 232	0.50			431 >> 232	0.50		
431 >> 233	0.50			431 >> 233	0.50		

Patterns	Probability
021 >> 062	1.00
041 >> 343	1.00
162 >> 191	0.67
181 >> 011	0.67
183 >> 011	0.50
193 >> 431	0.50
202 >> 401	1.00
202 >> 402	1.00
221 >> 181	1.00
221 >> 183	1.00
231 >> 041	0.40
231 >> 191	0.40
231 >> 221	0.40
231 >> 343	0.40

RESULTS

The experiments demonstrated the capability of Proposed Agents to facilitate two important processes :

1. prioritization
2. change propagation

- depend on history (objective)
- no time required for preparing dependency data
- no need for update for new assemblies and components
- parameters for mining data can be changed when running

CONTRIBUTIONS

Novel approach to ECM by incorporating VCDE and Sequential Data mining to improve the process

By proposing ADVICE, we offer:

- **A compact solution combining parametric and graphical data into a Virtual object in ADVICE**
- **A shared environment connecting dispersed users**
- **Real-time manipulation of the shared model**
- **Effective means of presenting change data**
- **"Advice" on important decision parameters**
- **A superior approach to solutions in literature reducing cycle time and complexity**

FUTURE ENHANCEMENTS

- Inclusion of an industrial partner
- Integration of interactions with processes, machinery, fixtures, equipment, etc.
- ODBC-compliant data container
- Incorporation of ECs such as Adding / removing components
- Inclusion of other factors for prioritization of ECRs
- Automatically calculating cost of making a change based on triggered changes to provide smart support to users

Modeling Engineering Change Management Process in Virtual Collaborative Design Environments

Thanks for listening...

Questions?