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Root Cause Analysis at Four Software Companies

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Agenda

1. Introduction
2. Study 1: How to Conduct Root Cause Analysis?
3. Study 2: What Problem Causes Are Detected?
4. Conclusions

Introduction

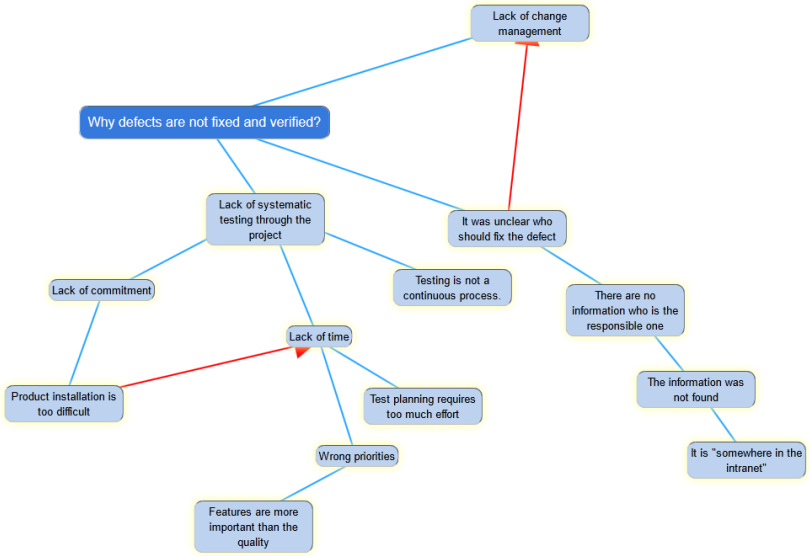
- The key for effective problem prevention is to know why the problem occurs [1]
  - You can't prevent the reoccurrence of a problem without elimination of the problem causes
- In the context of software process improvement, should we eliminate the symptoms (reactive) or the illness (proactive)?
  - Analyzing problem causes is considered in various software process improvement models, e.g., CMMI [2]

1. J.J. Rooney, L.N. Vanden Heuvel, Root cause analysis for beginners, Quality Progress 37 (7) (2004) 45–53

2. M. Kalinowski, G.H. Travassos, D.N. Card, Towards a defect prevention based process improvement approach, in: Proceedings of the 34th EUROMICRO Conference on Software Engineering and Advanced Applications, Parma, Italy, 2008, pp. 199–206.

Introduction

Root Cause Analysis is a structured investigation of a problem to detect the problem causes that need to be eliminated [3]



3. R.J. Latino, K.C. Latino (Eds.), Root Cause Analysis: Improving Performance for Bottom-Line Results. 6000 Broken Sound Parkway NW, Suite 300 Boca Raton, CRC Press, FL, 2006.

Study 1: How to Conduct RCA?

- *The goal was to develop a lightweight RCA method for medium-sized software companies and evaluate it at industrial cases.*

- **RQ1:** *Is the method efficient?*

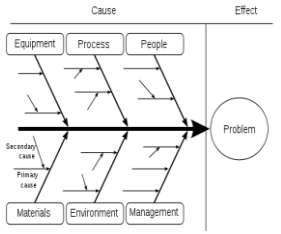
- **RQ2:** *Is the method easy to use?*

Methodology

- **Development of the RCA Method**
  - Elicitating the requirements of the method
  - Followed by a literature review
  - Finalized by a pilot case with students

- **Field studies at four software product companies**
  - Interview before each case
  - Observations combined with video recordings during the case
  - Inquiry forms after the main steps
  - Interview after each case
  - Measuring the used effort and the output of the cases

Literature review

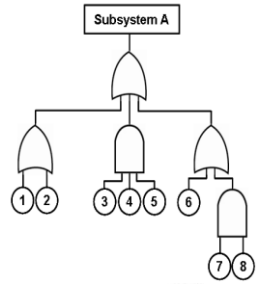


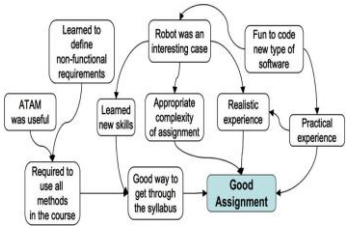
Many prior RCA methods available: Ammerman, Rooney, Card, Latino, Anderssen, Björnsson…

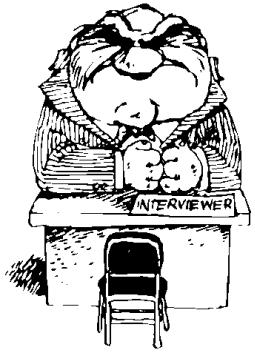
And just a few recommended tools for RCA…

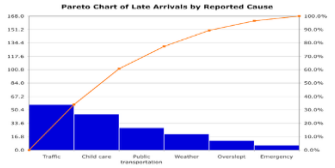
Flowcharts, spider charts, critical incidents, performance matrixes, brainstorming, brainwriting, is-is not matrixes, nominal group techniques, paired comparisons, samplings, surveys, check sheets, interviews , histograms, pareto charts, scatter charts, problem concentration diagrams, relations diagrams, Affinity diagram, cause-and-effect charts, matrix diagrams, five whys, fault tree analyses, six thinking hats, Systematic Inventive Thinking, The Theory of Inventive Problem Solving….

AAAAAAARGG!!!!!





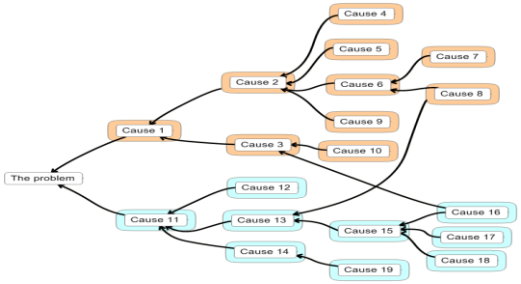


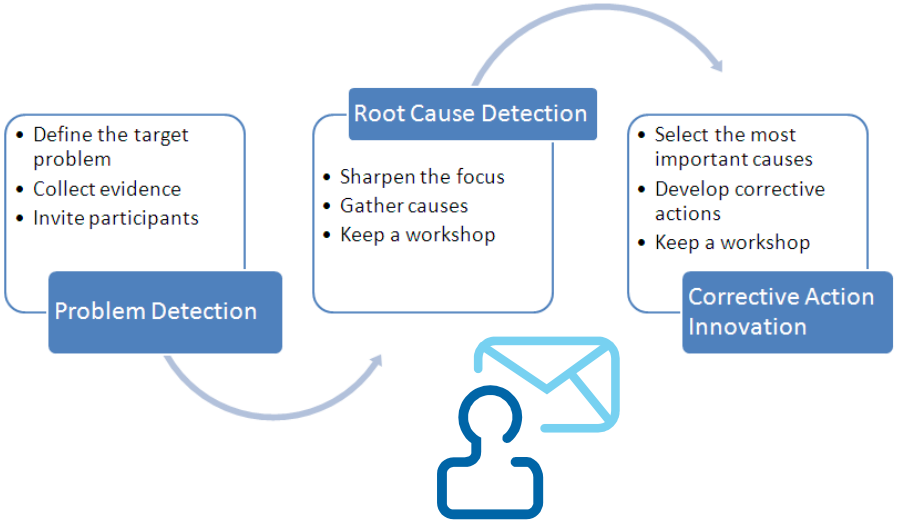


The ARCA method vs. Prior RCA Methods

RCA method	Approach	Problem Detection		Root Cause Detection		Corrective Action Innovation	
		Step	Practices	Step	Practices	Step	Practices
RCA by Rooney	Top-down	Data collection	Interviewing, inspections	Causal factor charting	Sequence diagrams	Recommendation generation	-
				Root cause identification	Decision diagram		
PIC by Ammerman	Top-down	Problem definition and data collection	-	Event and causal factor charting	Sequence diagrams	Corrective action development	Interviewing
		Task analysis	Paper-and-pencil, walk-through	Root cause determination	Interviewing, event and causal factor charts, lists, and worksheets		
		Change analysis	Flow charts				
		Control barrier analysis	Flow charts				
PROACT by Latino	Bottom-up	Opportunity analysis	Sequence diagrams, interviewing, brainstorming, Pareto Analysis	Data analysis	Flow chart, fault tree chart, meetings	Recommendations development	Writing individually, meetings
DCA by Card	Bottom-up	Defect sampling	Sampling, meetings	Determining principal cause	A fishbone diagram, cause categories, meetings	Action proposals development	Meetings
		Defect classification	Classification scheme, meetings				
		Identifying systematic errors	Pareto Analysis, meetings				
ARCA by Espa	Top-down	Problem Detection	Brainstorming in a meeting	Preliminary cause collection	Anonymous email inquiry, a directed graph	Root cause selection Corrective action workshop	Email inquiry Brainwriting combined with skeptical and optimistic perspectives in a meeting
				Causal analysis workshop	Brainwriting and Brainstorming in a meeting, a directed graph		

ARCA root cause analysis method





Field Studies of the ARCA Method

The ARCA root cause analysis method [4] has been utilized with our industrial partners..

- **Case 1**: Fixing and verifying defects took surprisingly long time.
  - 100 employees, 10 case participants, 122 causes
- **Case 2**: A release containing a high number of blocker type defects was released.
  - 450 employees, 10 case participants, 191 causes
- **Case 3**: New product installation and updating are highly challenging tasks.
  - 100 employees, 8 case participants, 166 causes
- **Case 4**: Some issues lead time was surprisingly long.
  - 110 employees, 7 case participants, 169 causes

A total of 648 target problem causes was detected!

4. T. O. A. Lehtinen, M. V. Mäntylä and J. Vanhanen, Development and evaluation of a lightweight root cause analysis method (ARCA method) – field studies at four software companies, Information and Software Technology 53 (10) (2011) 1045-1061.

Results

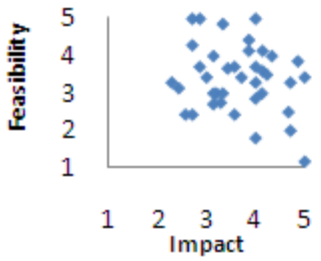
Output of the ARCA method

Results of the method

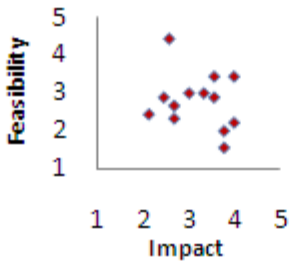
		Case 1	Case 2	Case 3	Case 4	Avg	Std
Step 2	Problem causes from the preliminary cause collection	93	108	66	52	80	25.4
	Problem causes from the causal analysis workshop	80	137	105	116	110	23.7
Step 3	The number of the selected root causes	6	2	5	6	5	1.9
	The number of the processed root causes including sub-root causes	41	24	77	42	46	22.3
	The number of the corrective actions	38	13	33	40	31	12.4

Corrective actions of the cases (scales: 1=low, 2, 3, 4, 5=high)

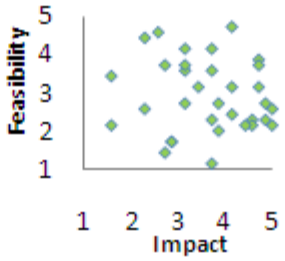
Case 1: 38 corrective actions



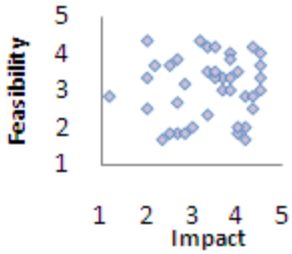
Case 2: 13 corrective actions



Case 3: 33 corrective actions



Case 4: 40 corrective actions



Results

The used effort in the cases

Used effort of the cases (h=hours) and the number of the case participants (n) (*= RCA facilitator only)

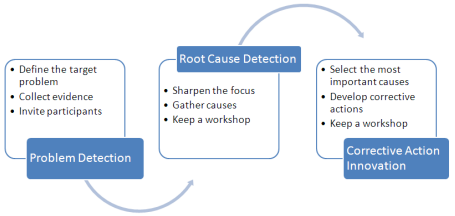
The step of the method		Case 1		Case 2		Case 3		Case 4		Avg		Std	
		h	n	h	n	h	n	h	n	h	n	h	n
Step 1	Problem Definition Meetings (start-up)	17	10	10	5	6	6	6	4	9.6	6.3	5.3	2.6
Step 2	Preliminary cause collection (email inquiry)	3	7	5	5	3	6	1	4	3.2	5.5	1.5	1.3
	Organizing the cause-effect diagram (*)	9	1	10	1	17	2	9	1	11.3	1.3	3.9	0.5
	Causal analysis workshop	21	10	20	10	22	8	14	7	19.3	8.8	3.6	1.5
	Smartening up the cause-effect diagram (*)	4	1	4	1	4	1	4	1	4.0	1.0	0	0
Step 3	Root cause selection	6	5	6	8	3	6	5	7	5.2	6.5	1.5	1.3
	Corrective action workshop	23	8	24	11	18	8	16	7	20.3	8.5	3.9	1.7
Step 4	Final report (*)	12	1	12	1	12	1	12	1	12.0	1.0	0	0
Total (h)		**98**		**96**		**90**		**73**		**89.3**		**11.4**	

Results

Feedback of the Case Attendees

Feedback of the case participants
(N=the number of respondents, Avg=average, Std=standard deviation, scale: 1=very low, 2, 3, 4=neutral, 5, 6, 7=very high)

	Case 1			Case 2			Case 3			Case 4			All cases		
	N	Avg	Std	N	Avg	Std	N	Avg	Std	N	Avg	Std	N	Avg	Std
Root Cause Detection															
Easiness	9	4,3	0,8	7	4,9	1,2	6	5,1	1,2	6	4,8	0,4	28	4,7	1,0
Usefulness	9	5,4	0,8	8	5,6	0,7	6	5,7	0,8	6	5,1	1,1	29	5,5	0,9
Correctness of causes	8	6,0	0,5	8	5,8	0,7	6	6,2	0,8	6	5,5	0,8	28	5,9	0,7
Corrective Action Innovation															
Easiness	7	5,7	1,0	10	6,0	0,8	7	6,0	0,6	6	6,0	0,6	30	5,9	0,7
Usefulness	6	5,5	1,2	8	5,5	0,9	7	5,6	1,0	6	5,7	0,4	27	5,6	1,0
Impact of the CAs	7	5,6	0,5	9	5,4	0,7	7	5,9	0,7	6	5,3	0,8	29	5,6	0,7
Feasibility of the CAs	7	5,3	0,5	10	4,4	1,1	7	5,3	0,8	6	5,7	0,8	30	5,1	0,9



Interviews of the key representatives

Question	Case 1	Case 2	Case 3		Case 4
	Person 1	Person 2	Person 3a	Person 3b	Person 4
How easy and learnable is the method?	*Very easy to use and internalize.*	*Easy in contrast to required effort and the output of the method.*	*Very easy to use and learn.*	*It is fairly easy to use and learn. Organizing the causes was challenging.*	*It was easy with the assistance of the researchers.*
Was the detected root causes significant if compared to the target problem	*Most of the causes were significant.*	*As a general rule, yes. We have already butt in one of the causes!*	*Yes they were. They matched well with my conception.*	*Yes they were. I already knew some of those.*	*Yes they were. The causes were mainly issues, which lead the problem.*
Do the corrective actions prevent the target problem?	*Yes, I think they do, because they have a major impact on the processed root causes.*	*No, I think that the corrective actions don't prevent the problem, but they do help us to improve our processes.*	*Yes they do! We even wouldn't need to implement them all.*	*I think that the corrective actions won't remove the problem completely, but they do have a major impact on the problem's sub-fields.*	*Yes, the impact would be enormous.*
Would it have been possible to get the same results in lower costs by using some other method?	*No. We wouldn't be able to get this many relevant corrective actions.*	*The method didn't require much effort. However, there should be only one workshop session and I would drop the email inquiry.*	*I don't believe that. I don't know any such method.*	*I think that "better practice" would mean smaller group size and more talented experts in the second workshop.*	*Maybe some other brainwriting method, where ideas are developed in literal form, could work as well.*
Should your company adopt the method?	*Yes, we should. This works!*	*Maybe, because this is an easy method with much potential. Additionally, the costs are low.*	*I think that we should adopt this method.*	*I would gladly try this method again. Formal prioritization was nice!*	*We should use this method, or at least a very similar one.*

Conclusions

Is the ARCA method efficient and easy to use?
If compared to the prior RCA methods and the current process improvement practices of the case companies, we believe it is.

The method was experienced efficient and easy to use
→Correct and genuine target problem causes were detected in each case
→Many feasible corrective actions with high impact were developed in most of the cases
→The case attendees experienced it wouldn't have been possible to get the same results in lower costs by using some other method they knew
→The case participants experienced the method as highly useful and better than their currect process improvement practices are
→The case attendees experienced the method as easy to use and learn

Additionally, the ARCA method solves many difficulties of the prior methods

Study 2: What Problem Causes Are Detected?

- This study aims to analyze the output of the ARCA method:

  RQ1: What types of causes are related to the target problems of the cases?

  RQ2: In which process areas the causes of the cases can be mapped?

  RQ3: Are the causes interconnected?

"What are the causes and were they occur?"

Data Analysis

- We created a two dimensional classification system for target problem causes
  - Preliminary classification schemes for both the types and related process areas of causes [5, 6, 7] was first created
  - The preliminary classification schemes were combined using a grounded theory approach [8]
- We applied the classification system to all causes of the cases

5. D. N. Card, Learning from our mistakes with defect causal analysis, IEEE Software 15 (1) (1998) 56-63.
6) R. B. Grady, Software failure analysis for high-return process improvement decisions, Hewlett-Packard Journal 47 (4) (1996) 15 - 25.
7. P. Jalote and N. Agrawal, Using defect analysis feedback for improving quality and productivity in iterative software development, Proceedings of the Information Science and Communications Technology (ICICT 2005), 2005, pp. 701 - 714.
8. S. Salinger, L. Plonka and L. Prechelt, A coding scheme development methodology using grounded theory for qualitative analysis of pair programming, 19th Annual Psychology of Programming Workshop, Joensuu, 2007, pp. 144-157

Results

The Classification System

Note that the types and process areas are based on the causes detected in our cases only. Thus some types and process areas are likely to be missing..

TABLE 1: THE CAUSE CLASSES AND RELATED TYPES OF CAUSES

Class	Type
People, P	Instructions and Experiences Values and responsibilities Co-operation Policies
Tasks, T	Task Priority Task Output Task Difficulty
Methods, M	Work Practices Process Monitoring
Environment, E	Existing Product Resources and Schedules Tools Customers

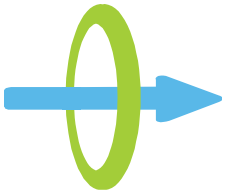


TABLE 2: THE PROCESS AREAS OF CAUSES

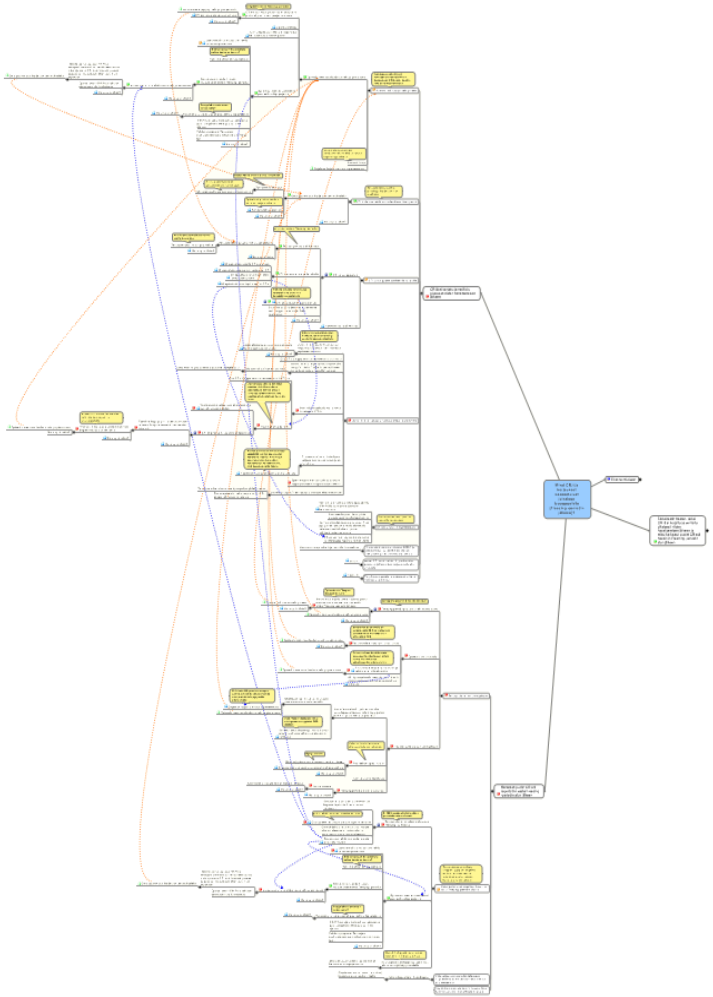
Process area
Management Work, MA
Sales & Requirements, S&R
Implementation Work, IM
Software Testing, ST
Product Release and Deployment, PD
Unknown, Un

What is the cause..

And where it occurs.

Distribution of target problem causes at Case 1

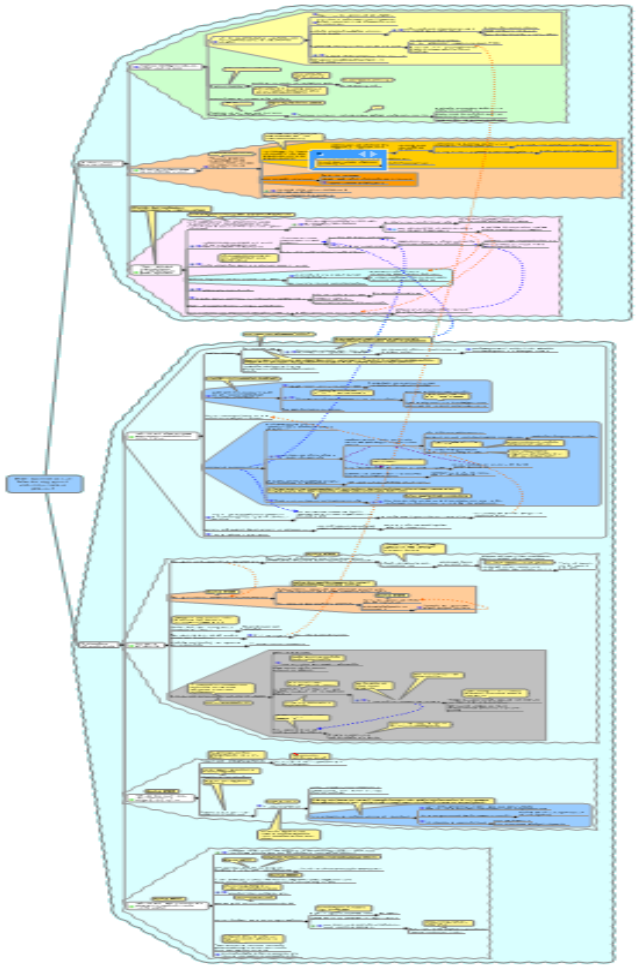
Why Fixing and verifying defects took surprisingly long time?



C1	MA	S&R	IM	ST	PD	UN	Tot
	C%	C%	C%	C%	C%	C%	C%
Instructions & Exp. (P)	5.4	3.1	2.3	4.6	0.8	1.5	**17.7**
Work Practices (M)	3.1	1.5	2.3	4.6			11.5
Task Output (T)	**7.7**	1.5	2.3	3.1			14.6
Task Difficulty (T)	0.8	0.8		3.8	0.8		6.2
Existing Product (E)		0.8		2.3			3.1
Resources & Sch. (E)		0.8	3.0	6.2			10.0
Values and &Resp. (P)	6.2	0.8	2.3	5.4			14.6
Process (M)			1.6	3.1			4.6
Company Policies (P)		1.5	0.8	1.5			3.8
Co-operation (P)			1.5				1.5
Customers & Users (E)		0.8					0.8
Tools (E)	0.8						0.8
Task Priority (T)			5.4	1.5		0.8	7.7
Monitoring (M)			1.5	1.5			3.1
Tot	23.8	11.5	23.0	**37.7**	1.5	2.3	100

Distribution of target problem causes at Case 2

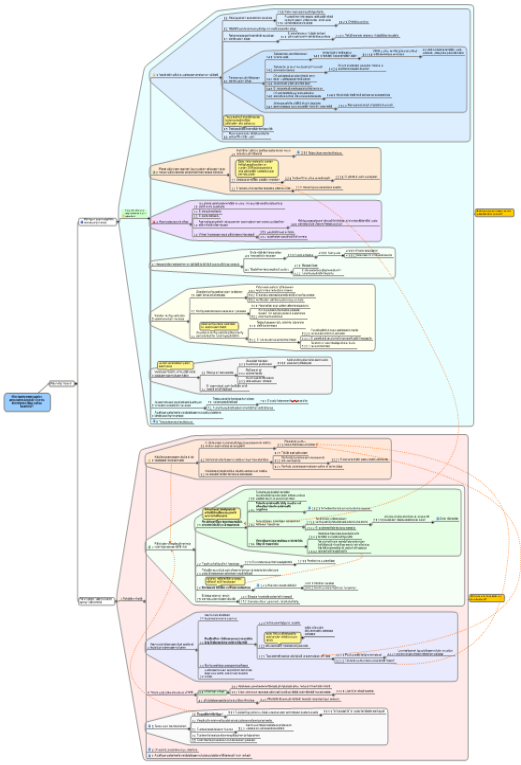
Why blocker types defects are done and not detected?



C2	MA	S&R	IM	ST	PD	UN	Tot
	C%	C%	C%	C%	C%	C%	C%
Instructions & Exp. (P)		2.7	4.9	3.8			11.4
Work Practices (M)		1.1	3.2	**8.1**	0.5		13.0
Task Output (T)	1.6	4.3	4.9	6.5	0.5		**17.8**
Task Difficulty (T)		1.6	1.6	6.5			9.7
Existing Product (E)		1.1	4.3	4.3	0.5		10.3
Resources & Sch. (E)			3.2	2.2	1.6		7.0
Values and &Resp. (P)	1.1	2.2	3.2	2.2		1.0	9.6
Process (M)			2.7	2.2	1.1		5.9
Company Policies (P)		0.5	1.6	0.5	0.5		3.2
Co-operation (P)		1.1	2.2				3.2
Customers & Users (E)		3.8	1.0				4.9
Tools (E)		1.1		1.1			2.2
Task Priority (T)			1.0				1.1
Monitoring (M)				1.1			1.1
Tot	2.7	19.5	34.0	**38.4**	4.9	1.0	100

Distribution of target problem causes at Case 3

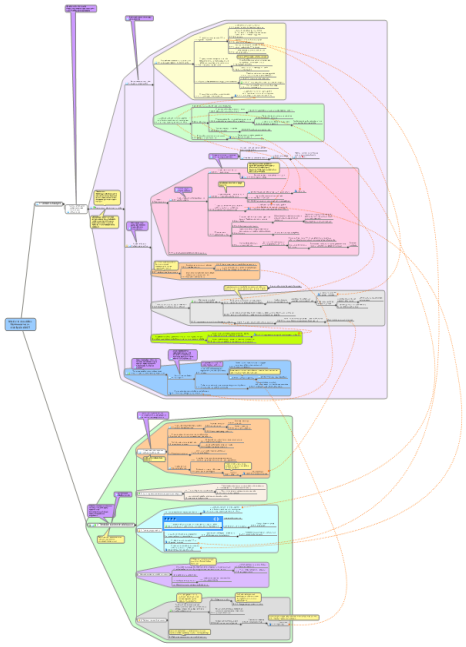
Why new product installation and updating are highly challenging tasks?



C3	MA	S&R	IM	ST	PD	UN	Tot
	C%	C%	C%	C%	C%	C%	C%
Instructions & Exp. (P)	0.7		2.8	3.5	**14.7**		21.7
Work Practices (M)	0.7		4.9	2.1	10.5		18.2
Task Output (T)	4.2		5.6	3.5	4.2		17.5
Task Difficulty (T)	0.7			2.8	6.3		9.8
Existing Product (E)			2.1	0.7	9.1		11.9
Resources & Sch. (E)	0.7			1.4	2.1		4.2
Values and &Resp. (P)							
Process (M)			1.4	1.4	0.7		3.5
Company Policies (P)	0.7		0.7				1.4
Co-operation (P)							
Customers & Users (E)	0.7		2.1	2.1	4.2		9.1
Tools (E)			0.7	0.7			1.4
Task Priority (T)			0.7				0.7
Monitoring (M)					0.7		0.7
Tot	8.4		21.0	18.2	52.4		100

Distribution of target problem causes at Case 4

Why some issues lead time was surprisingly long?



C4	MA	S&R	IM	ST	PD	UN	Tot
	C%	C%	C%	C%	C%	C%	C%
Instructions & Exp. (P)	2.9	7.6	3.5	0.6			14.5
Work Practices (M)	6.4	5.2	7.6		1.2		20.3
Task Output (T)	5.2	3.5	3.5	1.2	0.6		14.0
Task Difficulty (T)	0.6	1.2	1.2	0.6		1.2	4.7
Existing Product (E)	1.2	1.7					2.9
Resources & Sch. (E)	1.7	5.2	5.2	1.2	0.6		14.0
Values and &Resp. (P)	1.7	5.2	3.5				10.5
Process (M)			4.0				4.1
Company Policies (P)		2.9	0.6				3.5
Co-operation (P)		1.2	1.7				2.9
Customers & Users (E)	0.6	2.3	1.2				4.1
Tools (E)	0.6		0.6				1.2
Task Priority (T)			2.9				2.9
Monitoring (M)			0.6				0.6
Tot	20.9	36.0	36.1	3.5	2.3	1.2	100.0

Interconnections of the causes

Interconnections of detected causes between the process areas of causes

	Causes of the process area were caused by (%)									Causes of the process area were caused by (%)							
C1	MA	S&R	IM	ST	PD	UN	Causes	Tot %	**C2**	MA	S&R	IM	ST	PD	UN	Causes	Tot %
MA	**41.2**	**2.9**	**38.2**	**14.7**		2.9	100%	23.8%	MA		50.0		50.0			100%	2.7%
S&R	**9.5**	**42.9**	**19.0**	**28.6**			100%	11.5%	S&R	3.0	**66.7**	**21.2**		6.1	3.0	100%	19.5%
IM	**33.3**	**8.3**	**25.0**	**25.0**		8.3	100%	23.0%	IM	1.5	**10.8**	**72.3**	**12.3**	3.1		100%	34.0%
ST	**13.4**	**11.9**	**13.4**	**56.7**	3.0	1.5	100%	37.7%	ST	4.1	8.2	**5.5**	**80.8**	1.4		100%	38.4%
PD							0 %	1.5%	PD			45.5	18.2	**36.4**		100%	4.9%
C3	MA	S&R	IM	ST	PD	UN	Causes	Tot %	**C4**	MA	S&R	IM	ST	PD	UN	Causes	Tot %
MA	**100.0**						100%	8.4%	MA	**40.5**	**23.8**	**33.3**	2.4			100%	20.9%
S&R							0%	0%	S&R	**5.5**	**68.5**	**24.7**	1.4			100%	36.0%
IM	16.7		**50.0**	**12.5**	**20.8**		100%	21.0%	IM	**21.5**	**20.3**	**49.4**	3.8	3.8	1.3	100%	36.1%
ST	8.3		**8.3**	**75.0**	**8.3**		100%	18.2%	ST	50.0		37.5		12.5		100%	3.5%
PD	3.3		**17.8**	**5.6**	**73.3**		100%	52.4%	PD	50.0		25.0	25.0			100%	2.3%

Interconnections of the causes

Interconnections of detected causes between the classes of cause types

	Were caused by..							Were caused by..					
C1	People	Methods	Tasks	Env.	Causes	Total %	**C2**	People	Methods	Tasks	Env.	Causes	Total %
People	**51.4**	13.5	27.0	8.1	100%	28.5%	People	**31.6**	17.5	21.1	29.8	100%	29.2%
Methods	27.6	**37.9**	17.2	17.2	100%	22.3%	Methods	17.6	**41.2**	17.6	23.5	100%	17.4%
Tasks	**36.2**	17.0	29.8	17.0	100%	36.2%	Tasks	**31.7**	15.9	**31.7**	20.6	100%	32.3%
Environment	11.8	5.9	**52.9**	29.4	100%	13.1%	Environment	24.4	19.5	**31.7**	24.4	100%	21.0%
C3	People	Methods	Tasks	Env.	Causes	Total %	**C4**	People	Methods	Tasks	Env.	Causes	Total %
People	**54.5**	13.6	9.1	22.7	100%	15.3%	People	**37.7**	29.5	14.8	18	100%	33.0%
Methods	20.0	25.0	10.0	**45.0**	100%	13.9%	Methods	25.0	**28.8**	**28.8**	17.3	100%	28.1%
Tasks	22.1	26.0	**31.2**	20.8	100%	53.5%	Tasks	**29.8**	23.4	23.4	23.4	100%	25.4%
Environment	4.0	20.0	**44.0**	32.0	100%	17.4%	Environment	24.0	12.0	24.0	**40.0**	100%	13.5%

Conclusions

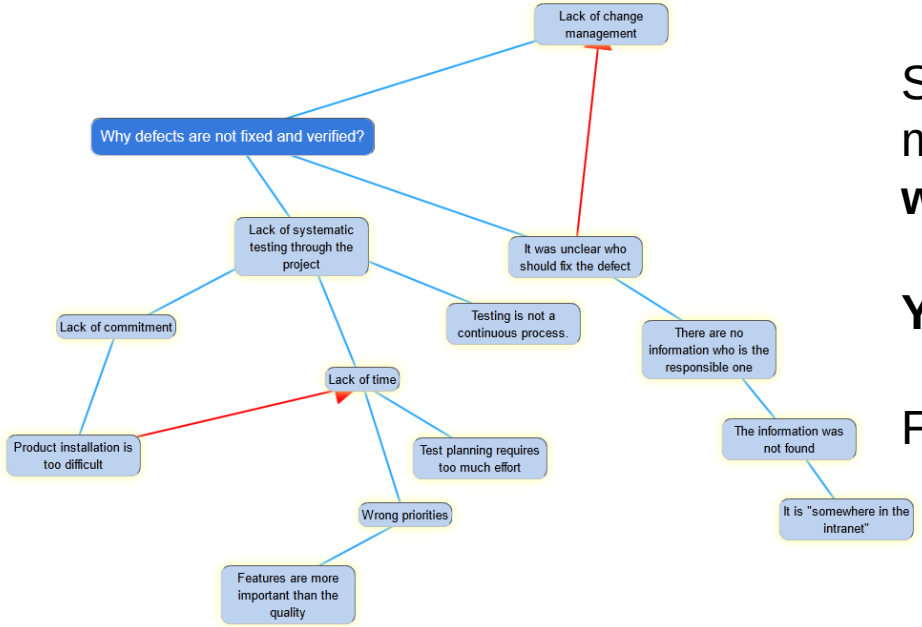
- Study 2 shows what causes the ARCA method revealed at those four companies..
  - Type perspective: lack of instructions & experiences, work practices, and task output were the most usual type of causes
  - Process perspective: management, sales & requirements, implementation work, software testing, product release & deployment
  - **Problems are caused by many effects simultaneously!**
    - Wrong work practices in software testing and implementation work, lack of instructions and experiences in implementation work, low quality task output in sales & requirements engineering, management work..
- Study 2 reveals the problem causes are detected in crosscutting discussions
  - New problem causes are detected by discussing problem causes of various process areas and with different type
    - e.g. causes of implementation work are revealed by the causes of software testing and vice versa

Limitations

- Our studies are based on assumptions of people
- Risk of researcher bias (reliability)
  - The classification of the causes was done only by the first author
    - Inter-rater agreement: Kappa_type=0.55, Kappa_process=0.65
- Case dependency (external validity)
  - The deviations between cases are higher in the process areas than it is in the types of causes → the problems are case specific?
  - As the total number of cases was only four, the results need to be validated by further studies.

Thank you ☺

- What quality problems you have faced?
  - Do you know what caused them?



Software (beta) for the ARCA method is freely available (MIT): **wirca.soberit.hut.fi**

You can try and download it ☺

Final release date: **1.3.2012!**