Freie Universität Berlin

Course "Empirical Evaluation in Informatics"

Case studies

Prof. Dr. Lutz Prechelt
Freie Universität Berlin, Institut für Informatik
http://www.inf.fu-berlin.de/inst/ag-se/

- Example 1: Ramp-up of new members of a SW team
- Characteristics of case studies
  - unit of analysis
  - many sources of evidence (triangulation)
  - validity dimensions
- Example 2: A non-traditional approach to requirements inspections

"Empirische Bewertung in der Informatik"

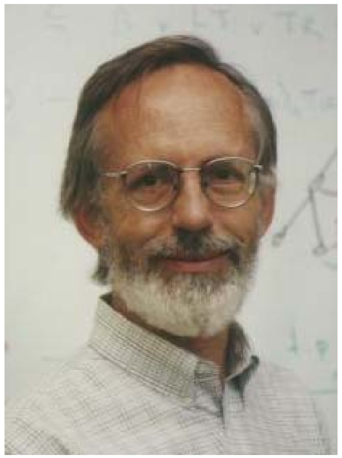
Fallstudien

Prof. Dr. Lutz Prechelt
Freie Universität Berlin, Institut für Informatik
http://www.inf.fu-berlin.de/inst/ag-se/

- Beispiel 1: Einarbeitung in ein Softwareteam
- Eigenarten von Fallstudien
  - Was ist der 'Fall'?
  - Nutzung vieler Datenarten, Triangulierung
  - Gültigkeitsdimensionen
- Beispiel 2: Ein unkonventioneller Ansatz für Anforderungs-Inspektionen

Example 1: Naturalization of SW immigrants

- Susan Sim, Richard Holt: *"The Ramp-Up Problem in Software Projects: A Case Study of How Software Immigrants Naturalize"*,
  20th Intl. Conf. on Software Engineering, pp.361-370, IEEE CS press, April 1998
- Topic: What happens during the time when an experienced newcomer acclimates to a software project?
- Approach: exploratory multi-case case study



Goals and basic method

- Goals:
  - describe naturalization process
  - identify shortcomings and successes
  - characterize adaptation strategies used by immigrants

- Basic method: multiple interviews with four "immigrants"
  - 2 cases with 6 interviews spaced over first 4 months
  - 2 cases with 1 interview after 7 (or 8) months on the team
  - all interviews performed by the same investigator

Interview questions

- There are questions on background and on the naturalization process

- Examples:
  - What is your current assignment?
  - How did you gather information about the problem?
  - What resources did you use? (documentation, people)
  - What new things did you learn over the last week?
  - What new tools did you use over the last week?
  - What have you done to become more familiar with the software system?
  - Draw a diagram of your current understanding of the system

- Interviewees would also elaborate on their anwers
  - How? Why? What else?

Analysis

- 17 variables of interest were determined from the material. Areas:
  - respondent characteristics,
  - orientation and training,
  - difficulties outside of learning about the system,
  - timing and type of tasks given, and
  - approaches used to understand the system

- The values were filled into a data matrix

- Pattern matching relates information from one or more cases to a theoretical proposition
  - Seven such propositions ("patterns") were found

Example answers

- "Most people operate under the assumption that
  - there are no documents, so you shouldn’t try asking for one."
- "I tried to [set up backups for my machine],
  - but I got stalled because I had to register my machine. So when that comes back, I’ll continue.. ."
- "The system was humongous and I didn’t know what comes first or anything.
  - So the only way to do it is to dump everything [execution traces]. I didn’t do that from the beginning, but I found it really frustrating because I wouldn’t know what was actually being done."
- "I had to modfify just four files at first.
  - It didn’t seem very challenging, but looking back, I appreciate the fact that they gave me something so isolated."

Patterns found

- Mentoring
  - Pattern 1: Mentoring is effective, though inefficient
  - Pattern 2: Lack of documentation forces immigrants to consult people
- Difficulties outside of the software system
  - Pattern 3: Administrative and environmental issues are a major source of frustration
- First assignments
  - Pattern 4: Initial tasks were simple or open-ended and began no earlier than after two weeks
  - Pattern 5: Mentors tend to pass on low-level information about the software system

Patterns found (2)

- Predictors of job fit
  - Pattern 6: Programmers who prefer to use bottom-up comprehension approaches have a smoother naturalization than those who don't
  - Pattern 7: There needs to be a minimal interest match between immigrants and the software system.

- The study discusses specific evidence for and implications of each pattern

Conclusions drawn

- Immigrants could profit much from a high-level intro course about the system
  - focussing on architecture and design rationale
  - It cannot replace mentors, but would reduce their load
  - It would help in top-down understanding

- A recurring topic in the naturalization process is frustration
  - so avoiding frustration is a good improvement guideline

- Process improvements cannot be purely technical
  - they have to be organizational

Case studies: Main characteristics

- A case study is a prolonged observation of some phenomenon of interest in its natural setting

- Case studies are firmly bound to a certain **context**
  - The phenomenon of interest cannot be clearly separated from the context
- Case studies are **longitudinal**
  - They study a phenomenon over some time
- **Little control** is exerted
  - usually because more is impossible
- The **observations are broad** and multi-faceted
  - both qualitative and quantitative
  - sometimes additional observations are introduced during the study

Case study method

- Formulate research question
  - Types: How? Why?
- Find appropriate observation context
- Plan and implement data collection
  - and chose criteria for interpreting the data
- Collect data until satisfied
  - There may be no "natural" end of the observation period
- Analyze data
  - May be concurrent with data collection (to decide when to stop)
- Produce explanation (for why-questions)
  or description (for how-questions)
- Draw conclusions: Answer the question

Case study objectives

One of

- Exploration
  - Gain an overview of a hardly understood phenomenon
- Characterization
  - Describe in detail how something works
- Validation
  - Check whether a pre-formulated assumption is true
  - Typically these are existence proofs

- Case studies aim at deep understanding
- The target phenomena are
  - Existing situations (such as a project, team, system)
  - Interventions (such as a process, method, tool)

Examples of case study research questions

Why questions:

- Why does this organization follow this process model?
- Why do developers prefer this notation?
- Why do programmers fail to document their code?
- Why have formal methods not been adapted more widely for safety-critical systems?

How questions:

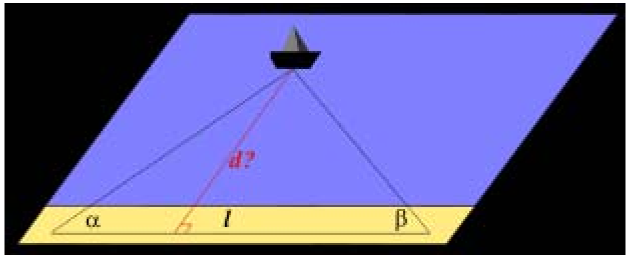
- How are inspections carried out in practice?
- How does agile development work in practice?
- How does software evolve over time?
- How does a company identify which project to start?

How questions tend to be wider than why questions.

Main case study problem

- In a single-case study, there is but a single object of interest
  - The "case"
  - We can take repeated measurements of that same case over time
  - We can measure many different aspects of the case
  - Note: There are multiple-case case studies as well
    - But the number of cases will rarely be more than a dozen
- Worse: We are often interested in multiple variables

- Solution approach
  - Rely on multiple sources of evidence
  - Bring them together to "**triangulate**" your variables



Case study design

- Like for an experiment, the measurements to be made during a case study must be designed in advance
  - so that the data can (presumably) answer the question
  - Additional data is also often found during the study
- The design is often influenced by prior knowledge (assumptions, called ***propositions***)
  - Propositions indicate where to look for evidence
- The central technical design decision concerns the ***unit of analysis***:
  - What exactly is the 'case' of the case study?
  - Sometimes we consider units and subunits

Case study design: elements

1. Research question(s)
2. Propositions (may be missing)
3. Unit(s) of analysis ←
4. Method of analysis ←

Unit of analysis

- Not always obvious
- Must be chosen to fit the research question

Examples:

- For a study of how software immigrants naturalize, it can be
  - individual immigrant; development team; organization
- For a study of pair programming, it can be
  - programming session; pair of programmers; development team; organization
- For a study of software evolution, it can be
  - modification request; file; system; system release etc.

Method of analysis

This consists of two parts

1. A mechanism or logic for how to link the observations to the propositions (if any)
2. Criteria for interpreting the observations in terms of the research question

- Both of these aspects are not very well understood
  - There is little theory for how to do this in general
  - We need to find plausible ways for each study seperately

Generalization from case studies

- In a well-designed survey or controlled experiment, we generalize quantitatively
  from a (random) sample to a whole population
  - *Statistical generalization* (level-1 inference)
  - There are well-defined procedures for this, using notions such as significance, confidence, effect size etc.

- Note: In practice, true random samples from a well-defined population are quite rare

- In a case study, statistical generalization is impossible
  - Even in multiple-case studies, as the cases cannot claim to form a random sample

Generalization from case studies (2)

- In case studies, we have to use *analytical generalization* instead:
  - Compare your results to previously existing theory
  - Replication: 2 or more cases all support the same theory
  - Best if multiple cases support one theory but do not support another (rival) theory

- Analytical generalization is level-2 inference
  - Can also be used for surveys, experiments etc. after statistical inference
  - Can be quantitative as well as qualitative

- Case study design goal:
  Make successful analytical generalization likely

How many cases do we need?

Case study types:

- Types 1 and 2 (single-case):
  - Type 1 (holistic): 1 context, 1 unit of analysis
  - Type 2 (embedded): 1 context, n units of analysis
- Types 3 and 4 (multiple-case):
  - Type 3 (holistic): k contexts, 1 unit of analysis in each
  - Type 4 (embedded): k contexts, n_i units of analysis each

- When are single-case studies sufficient?
  - it is a critical case (for testing some theory)
  - it is an extreme or unique case
  - it is the only case available at all
  - it is arguably a representative or typical case
- In most situations multiple-case studies are preferable

Multiple-case studies and replication

After investigating case 1, for case 2 we may expect

- either similar results
  - then it is like replicating an experiment
- or different results (because of differences in context)
  - then it is like doing a related experiment.

This is valid only if our theory provides arguments

  - when to expect similar results and
  - when to expect different results
- If we have such expectations (derived from a theory), then
  - meeting these expectations lends high credibility to the case study
  - seeing them fail requires revising some propositions
    - but we do not necessarily know how

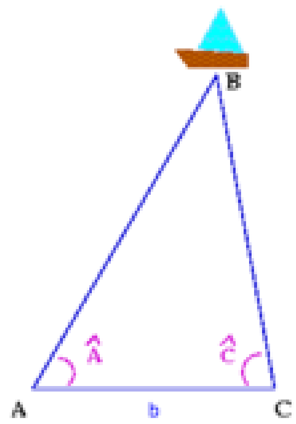
Use multiple sources of evidence

- The small number of cases must be compensated by the breadth of the observations

- We try to use all six possible sources of evidence:
  1. Documentation (unstructured, semi-structured)
     - email, agendas, minutes, reports, previous studies, etc.
  2. Archival records ((semi-)structured, quantitative)
     - service records, logs, budgets, survey data, etc.
  3. Interviews
     - open-ended, focused, or formal survey
  4. Direct observation
     - via presence-at-site or specialized automated measurement
  5. Participant-observation
     - observer participates in setting (intense, but danger of bias)
  6. Physical artifacts
     - e.g. hand-drawn multi-person design sketches

Triangulation

- For maximum breadth of observation we try to observe each single thing in more than one way
- This is called *triangulation* (approach target from different directions)



- Kinds:
  - **data triangulation**: different data sources
  - **investigator triangulation**: different observers or evaluators
  - **theory triangulation**: interpret observations from point of view of multiple competing theories
  - **methodological triangulation**: complement case study by surveys, experiments etc.

Case study database

- The large variety of data makes it hard to maintain proper overview
- Thus one should keep a formal case study database:
  - list all relevant materials
  - describe their structure
  - include all their content (or pointers)
- A well-formed database may be useful for later studies as well
  - to retrieve information that was not part of the results
- One should maintain an explicit chain of evidence
  - explicitly linking questions asked to data collected to conclusions drawn
  - Has much higher level of detail than result report

Data analysis in case studies

- The breadth of data makes it hard to combine it all.
  - There are few standard methods
  - Ad-hoc procedures need to be invented
- Goals for the procedures:
  - Present and consider all the evidence
  - Include prior knowledge or expert knowledge
  - Clearly separate evidence from interpretation
    - Much like in journalism: news versus commentary
  - Consider multiple hypotheses and explanations
- General strategies:
  - Rely on theoretical propositions (and focus accordingly)
  - Think about rival explanations (and focus on differences)
  - Develop a case description (otherwise)

Analytic techniques

- Pattern matching
  - Compare observations to predictions
- Explanation building
  - Incrementally account for more and more observations
- Time series analysis
  - Trace quantiative data over time; statistical analysis
- Cross-case synthesis
  - In multiple-case studies: Concentrate on evidence that is compatible and consistent across cases
- Details are beyond our scope

The validity universe

Mostly not specific to case studies

- Construct validity
  - Is our study design adequate for what we want to find out?
  - intentional v.; representational v.; observation v. (predictive v.; criterion v.; concurrent v.; convergent v.; discriminant v.)
- Internal validity
  - (For explanatory or causal studies:) Have confounding variables (and hence rival hypotheses) been eliminated?
  - Reliability: Would repeating the study on the same cases come to the same findings?
- External validity
  - Generalizability of findings to other situations
    - typically much stronger in multiple-case studies

The case study report

- Presenting a case study is particularly difficult
- Typical approaches:
  - Top-down case description, bottom-up analysis description
  - Multiple-case studies: One chapter per case or per case tuple comparison
  - Chronological
  - Theory-building: Each section adds one piece to a theoretical argument
  - Suspense: Reveal results first, then explain it step-by-step in an interesting way
  - Question and answer format
- One should decide on the format during study design!
  - Advice: Start writing early

"Case study": Notion and term

- In Informatics, case studies as defined here are often called "field studies" instead
  - (and are then often not done properly)

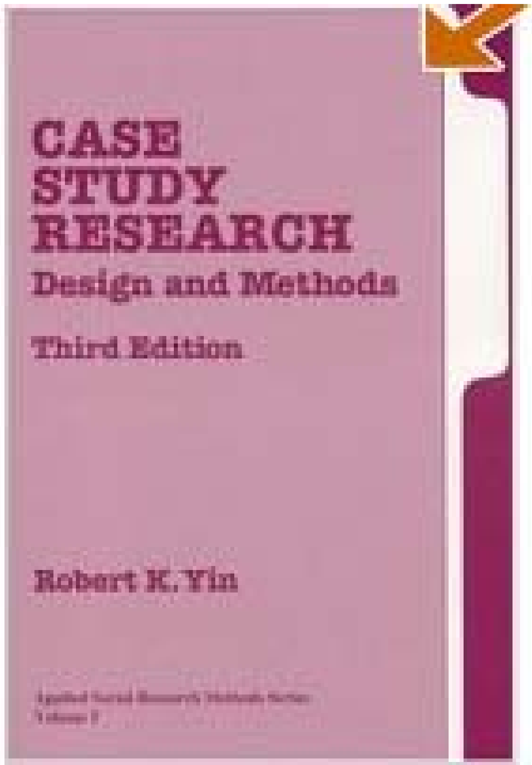
- In Informatics, the term "case study" is often used
  - for a trial of a technique in a non-realistic setting
    - even just an informal illustration of its use;
  - for what should be a controlled experiment, except it has n=1
  - for a controlled experiment where no findings are statistically significant

- "Case study" as defined here is a term from social science methodology
  - it describes a middle ground between quantitative and qualitative research

- Robert K. Yin:

  "Case Study Research: Design and Methods",

  Sage Publications, 2002



Example 2: A specific form of inspections

- O. Laitenberger, T. Beil, T. Schwinn: *"An Industrial Case Study to Examine a Non-Traditional Inspection Implementation for Requirements Specifications"*, Empirical Software Engineering 7(4):345-374, Dec 2002

- Characterizes the specific approach to inspections as chosen due to the particular conditions in one organization

- Study type: Case study



Inspections

* A number of reviewers analyze a document (requirements, design, code, test plan, etc.) to identify defects
* The defects are collected and validated, then repaired

* Advantages of inspections:
  * Defects are found earlier (reducing rework cost)
  * More defects may be found (improving final quality)
  * Defects may be found with less effort
  * Reviewers learn information from the document
  * Reviewers learn about style and techniques

* Disadvantages of inspections:
  * Inspections consume resources and produce waiting time
  * If badly done, inspections can reduce motivation

Inspection parameters

Where inspections can vary:

- Sizing parameters
  - Number of reviewers; preparation time; meeting time; re-reviews; etc.
- Types or roles of reviewers
- Defect detection procedures
  - e.g. ad-hoc, checklists, perspectives, scenarios, question-answering, walkthrough in meeting, etc.
- Defect collection procedures
  - e.g. meeting (different kinds); electronic meeting; asynchronous electronic meeting; one-to-one meetings; no meetings
- Defect repair and re-review procedures
- ...and more

The context: DaimlerChrysler

- Introduced inspections during the 1990s
  - good track record
  - have established process descriptions, tutorials, internal coaching/consulting, inspection experience base
  - constant improvement of the inspection process

- Our case: A set of embedded systems responsible for driver and passenger comfort
  - 50 requirements documents
  - each was typically 20-50 pages and
  - typically contained about 10-16 functional requirements
  - 70% of requirements are considered fairly stable
  - Goals of inspection:
    - improve quality of requirement specifications;
    - enhance common understanding;
    - eliminate open points, mistakes, and ambiguities.

Inspection design

- 2000 pages of requirements:
  A parsimonious inspection process is required
- 19 inspections (for the 50 documents)
  - focus on quality attributes: correctness, consistency, testability, maintainability
- 2 inspectors each (one acting as moderator)
- Detection: Active involvement of inspector required
  - has to build a model (UML or SDL) of the artifact
- Collection: Present models in meeting,
  - focussing on requirements defects found

Propositions: Claimed advantages

- Ensures each inspector is well prepared for meeting
  - half-hearted preparation is less likely
- Technical justification if available for every defect proposed
  - as it is explained in the context of the model
- Discussion between inspector and author is based on technical content
  - personal conflicts are avoided
- Presentations make meetings more interesting

Analysis approach

- The study analyzed this inspection method as follows:

- How does this method differ from a traditional method with respect to
  - effort (for preparation, for meeting)
  - number of defects found (as accepted in meeting)
  - size of documents?

- Data collected for each inspection:
  - document size (in pages and other metrics)
  - preparation effort (in person minutes)
  - meeting effort (in person minutes)
  - number of non-trivial defects accepted in meeting

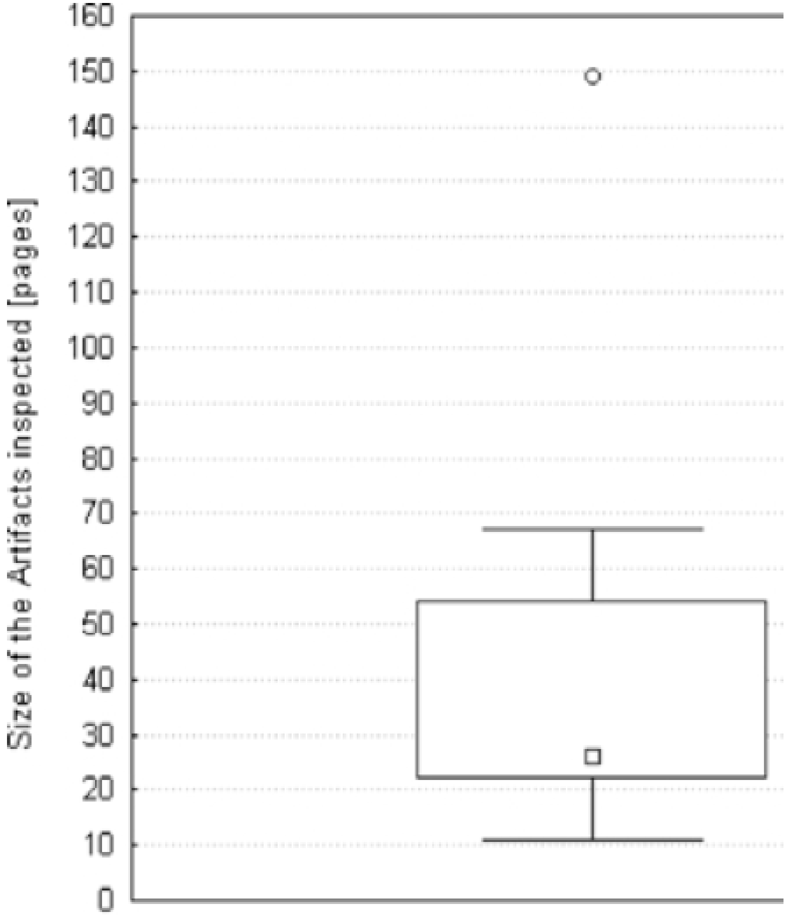
Hypotheses

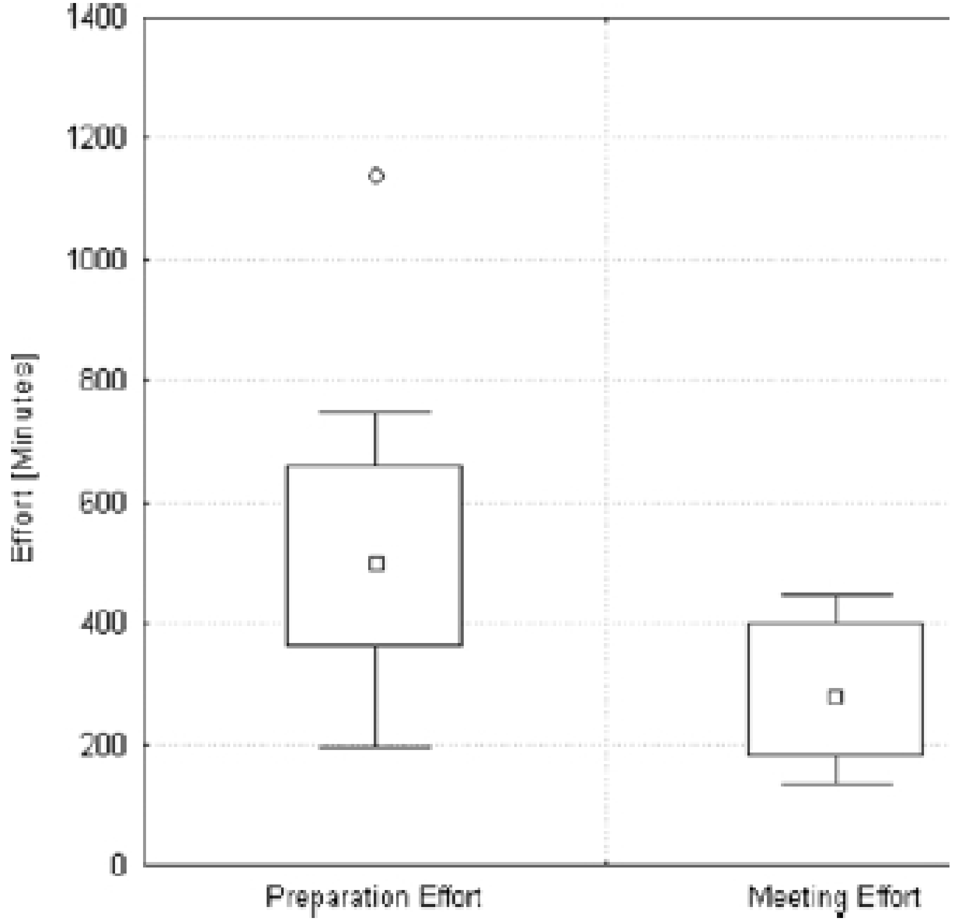
The analysis proceeds by checking the following hypotheses (about which something is known for conventional inspections):

- H1: The larger the inspection effort, the more defects are found
- H2: The larger the document size, the more defects are found
- H3: The larger the document size, the more effort is spent
- H4: Different inspectors will find similar numbers of defects
- H5: The meeting results outperform each individual inspector

Results:
size, preparation time, meeting time

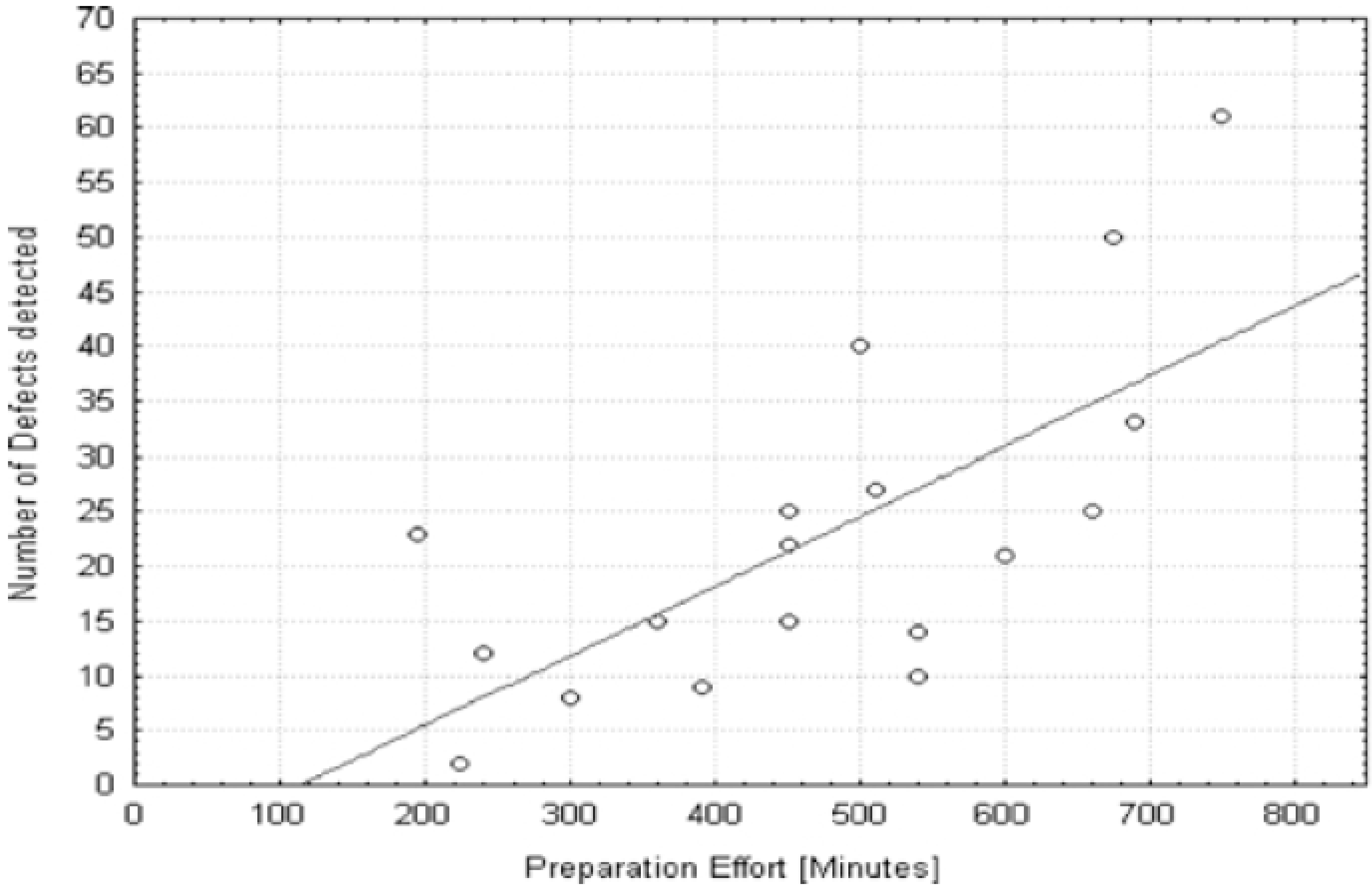
- Size has one outlier; preparation time dominates effort
- Number of defects: about one per two pages





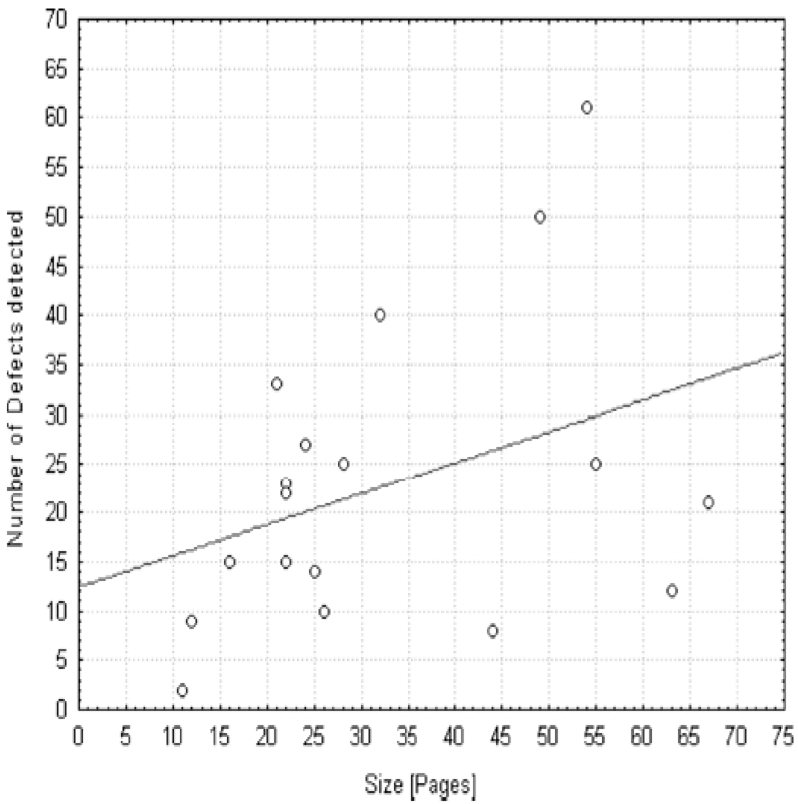
Results: Effort and defects

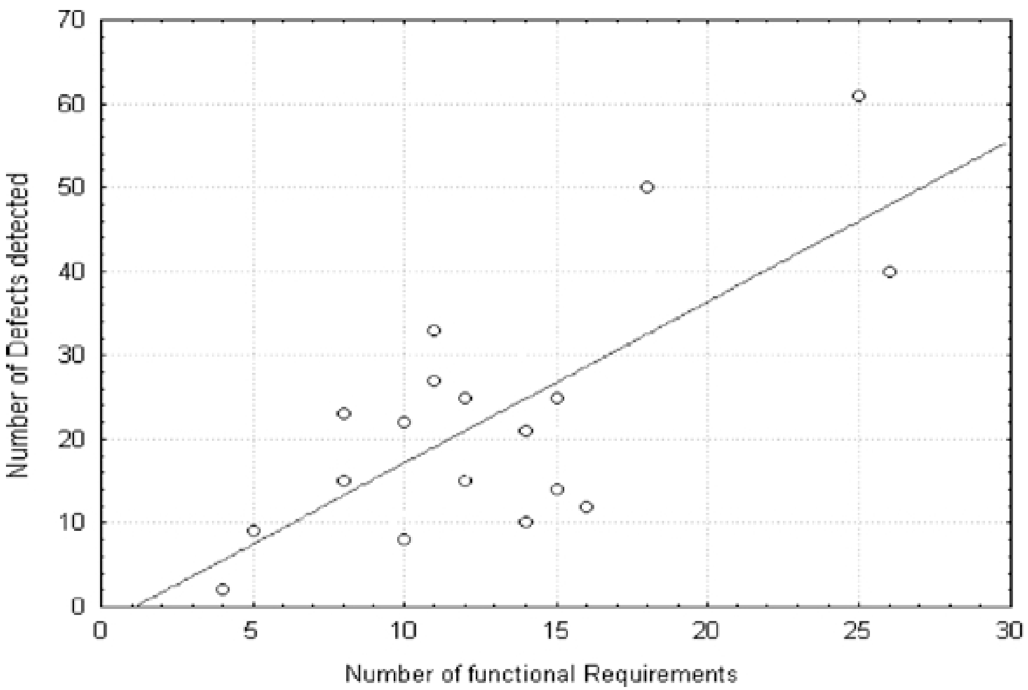
- Preparation time correlates strongly (0.7) with defects found, while meeting time and document pages do not



Results: Size and defects

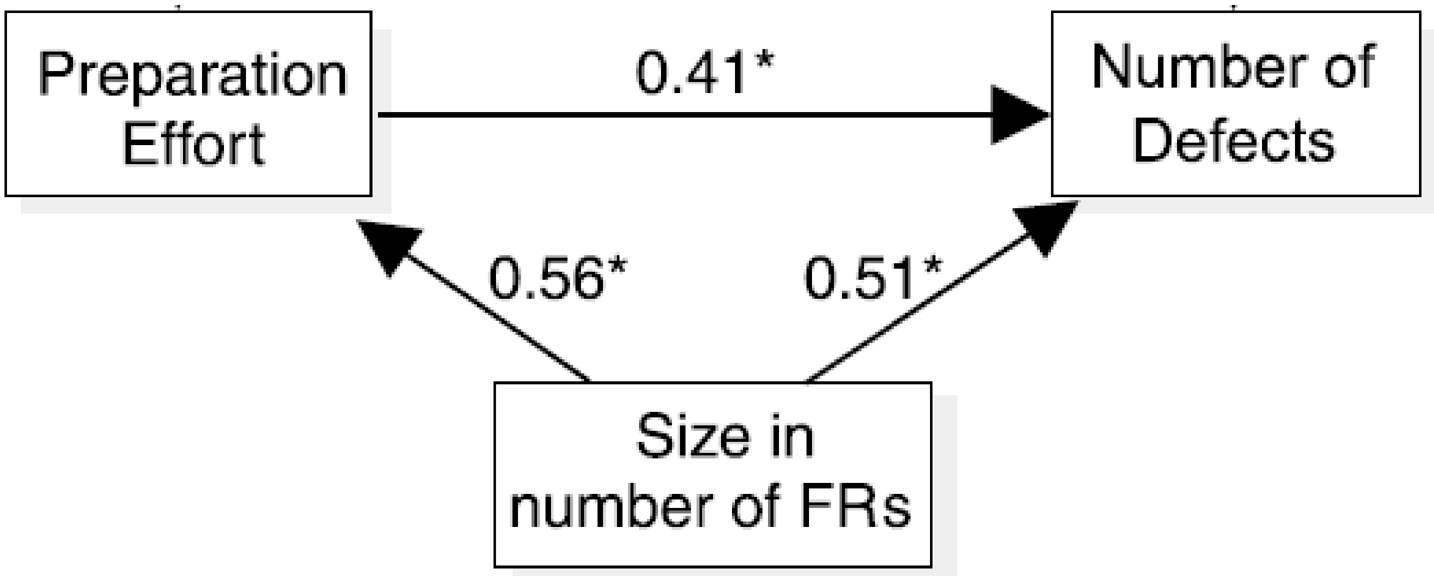
- Number of scenarios and number of requirements correlate strongly (0.69, 0.74) with defects found, while number of document pages does not



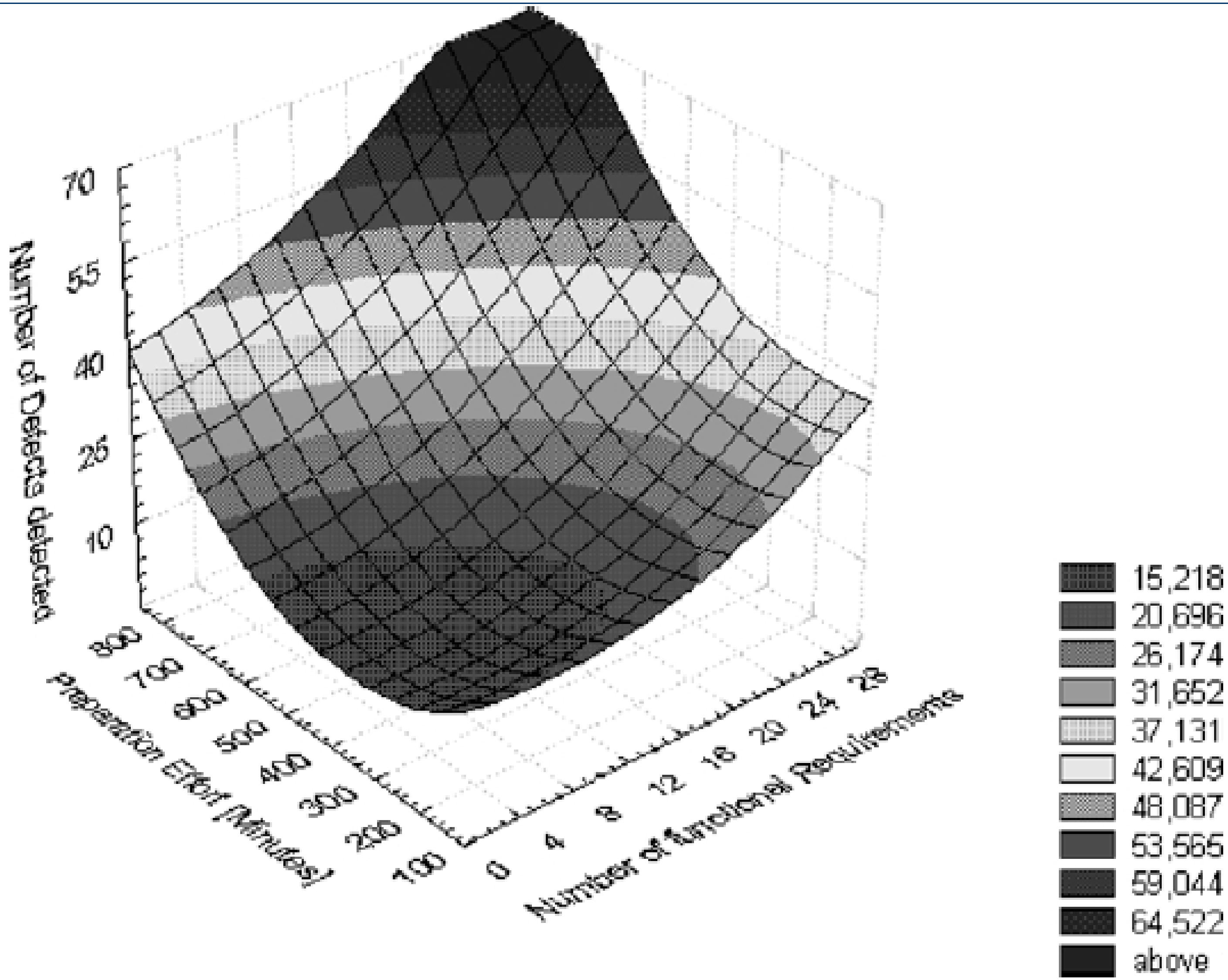


Results:
Size, effort, and defects found

- ...and so on
- leading (somehow) to the following path diagram for explaining number of defects found:



Results: Relationships



- Helpful?

Note on the case-studyness

- This is a borderline case study:
  - It is hardly longitudinal
  - The analysis is rather quantitative
  - There is little focus on the procedural HOWs or WHYs
- On the other hand
  - context *is* important
  - no control is exerted (retrospective study)
- Note that the unit of analysis is the whole set of inspections

- Another note:
  - The article is fairly precise when talking technically about statistics, but sometimes sloppy when talking about causality (which is sometimes implied where it is in fact unknown)

Summary

- A case study investigates a small number of cases in depth
  - describes and takes into account the context
  - uses a broad spectrum of observations (many sources of evidence)
  - uses observations over time (longitudinal study)
- It involves little or no control
- It unifies qualitative and quantitative observations
  - Both analysis and conclusions tend to be argumentative rather than numerical
- The goal is an understanding that is specific, but deep

Thank you!