Case Studies for Software Engineers

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Case Studies

“A technique for detailed exploratory investigations, both prospectively and retrospectively, that attempt to understand and explain phenomenon or test theories, using primarily qualitative analysis”

❖ good for
- Answering detailed how and why questions
- Gaining deep insights into chains of cause and effect
- Testing theories in complex settings where there is little control over the variables

❖ limitations
- Hard to find appropriate case studies
- Hard to quantify findings

See:
Flyvbjerg, B.; Five Misunderstandings about Case Study Research. Qualitative Inquiry 12 (2) 219-245, April 2006
Myths about Case Study Research

1. General, theoretical (context-independent) knowledge is more valuable than concrete, practical (context-dependent) knowledge.

2. One cannot generalize on the basis of an individual case; therefore, the case study cannot contribute to scientific development.

3. The case study is most useful for generating hypotheses; that is, in the first stage of a total research process, whereas other methods are more suitable for hypothesis testing and theory building.

4. The case study contains a bias toward verification, that is, a tendency to confirm the researcher’s preconceived notions.

5. It is often difficult to summarize and develop general propositions and theories on the basis of specific case studies.

[See: Flyvbjerg, B.; Five Misunderstandings about Case Study Research. Qualitative Inquiry 12 (2) 219-245, April 2006]

When should you use a case study?

❖ When you can’t control the variables
❖ When there are many more variables than data points
❖ When you cannot separate phenomena from context
   • Phenomena that don’t occur in a lab setting
   • E.g. large scale, complex software projects
   • Effects can be wide-ranging.
   • Effects can take a long time to appear (weeks, months, years!)
❖ When the context is important
   • E.g. When you need to know how context affects the phenomena
❖ When you need to know whether your theory applies to a specific real world setting
Why conduct a case study?

❖ To gain a deep understanding of a phenomenon
  ● Example: To understand the capability of a new tool
  ● Example: To identify factors affecting communication in code inspections
  ● Example: To characterize the process of coming up to speed on a project

❖ Objective of Investigation
  ● Exploration- To find what's out there
  ● Characterization- To more fully describe
  ● Validation- To find out whether a theory/hypothesis is true

❖ Subject of Investigation
  ● An intervention, e.g. tool, technique, method, approach to design, implementation, or organizational structure
  ● An existing thing or process, e.g. a team, releases, defects

Misuses of the term "Case Study"

❖ Not a case history
  ● In medicine and law, patients or clients are "cases".
  ● Hence sometimes they refer to a review of interesting instance(s) as a "case study".

❖ Not an exemplar
  ● Not a report of something interesting that was tried on a toy problem

❖ Not an experience report
  ● Retrospective report on an experience (typically, industrial) with lessons learned

❖ Not a quasi-experiment with small n
  ● Weaker form of experiment with a small sample size
  ● Uses a different logic for designing the study and for generalizing from results
How can I tell it's a case study?

- Has research questions set out from the beginning of the study
- Data is collected in a planned and consistent manner
- Inferences are made from the data to answer the research questions
- Produces an explanation, description, or causal analysis of a phenomenon
  - Can also be exploratory
- Threats to validity are addressed in a systematic way

Parts of a Case Study Research Design

- A research design is a "blueprint" for a study
  - Deals more with the logic of the study than the logistics
  - Plan for moving from questions to answers
  - Ensures data is collected and analyzed to produce an answer to the initial research question
  - (Analogy: research design is like a system design)
- Five parts of a case study research design
  1. Research questions
  2. Propositions (if any)
  3. Unit(s) of analysis
  4. Logic linking the data to the propositions
  5. Criteria for interpreting the findings
Part 1: Study Questions

❖ Study design always starts with research questions
  ● Clarify precisely the nature of the research question
  ● Ensure the questions can be answered with a case study
  ● Generally, should be "how" and "why" questions.
  ● Identify and interpret the relevant theoretical constructs

❖ Examples:
  ● "Why do two organizations have a collaborative relationship?"
  ● "Why do developers prefer this tool/model/notation?"
  ● "How are inspections carried out in practice?"
  ● "How does agile development work in practice?"
  ● "Why do programmers fail to document their code?"
  ● "How does software evolve over time?"
  ● "Why have formal methods not been adopted widely for safety-critical software?"
  ● "How does a company identify which software projects to start?"

4 Types of Case Studies

❖ Explanatory
  ● Adjudicates between competing explanations (theories)
  ● E.g. How important is implementation bias in requirements engineering?
    ● Rival theories: existing architectures are useful for anchoring, vs. existing architectures are over-constraining during RE

❖ Descriptive
  ● Describes sequence of events and underlying mechanisms
  ● E.g. How does pair programming actually work?
  ● E.g. How do software immigrants naturalize?

❖ Causal
  ● Looks for causal relationship between concepts
  ● E.g. How do requirements errors and programming errors affect safety in real time control systems?
  ● See study by Robyn Lutz on the Voyager and Galileo spacecraft

❖ Exploratory
  ● Used to build new theories where we don't have any yet
  ● Choose cases that meet particular criteria or parameters
  ● E.g. Christopher Columbus' voyage to the new world
  ● E.g. What do CMM level 3 organizations have in common?
Part 2: Study Propositions

- Propositions are claims about the research question
  - State what you expect to show in the study
  - Direct attention to things that should be examined in the case study
  - E.g. "Organizations collaborate because they derive mutual benefits"

- Propositions will tell you where to look for relevant evidence
  - Example: Define and ascertain the specific benefits to each organization

- Note: exploratory studies might not have propositions
  - …but should lead to propositions for further study
  - …and should still have a clearly-stated purpose and clearly-stated criteria for success

- Analogy: hypotheses in controlled experiments

Part 3: Unit of Analysis

- Defines what a "case" is in the case study
  - Choice depends on the primary research questions
  - Choice affects decisions on data collection and analysis
  - Hard to change the unit of analysis once the study has started (but can be done if there are compelling reasons)
  - Note: good idea to use same unit of analysis as previous studies (why?)

- Often many choices:
  - E.g. for an exploratory study of extreme programming, Unit of Analysis could be…
    - individual developer (focuses on a person’s participation in the project)
    - a team (focuses on team activities)
    - a decision (focuses on activities around that decision)
    - a process (e.g. examines how user stories are collected and prioritized)
    - …
Examples of Units of Analysis

- For a study of how software immigrants naturalize
  - Individuals?
  - ... or the Development team?
  - ... or the Organization?

- For a study of pair programming
  - Programming episodes?
  - ... or Pairs of programmers?
  - ... or the Development team?
  - ... or the Organization?

- For a study of software evolution
  - A Modification report?
  - ... or a File?
  - ... or a System?
  - ... or a Release?
  - ... or a Stable release?

Why Defining your Unit of Analysis matters

- Clearly bounds the case study
  - ...and tells you which data to collect

- Makes it easier to compare case studies
  - ...incomparable unless you know the units of analysis are the same

- Avoid subjective judgment of scope:
  - e.g. disagreement about the beginning and end points of a process

- Avoids mistakes in inferences from the data
  - E.g. If your study proposition talks about team homogeneity...
  - ...Won't be able to say much if your units of analysis are individuals
Part 4: Linking Logic

- Logic or reasoning to link data to propositions
- One of the least well developed components in case studies
- Many ways to perform this
  - ...none as precisely defined as the treatment/subject approach used in controlled experiments
- One possibility is pattern matching
  - Describe several potential patterns, then compare the case study data to the patterns and see which one is closer

Part 5: Interpretation Criteria

- Criteria for interpreting a study's findings
  - I.e. before you start, know how you will interpret your findings
- Also a relatively undeveloped component in case studies
  - Currently there is no general consensus on criteria for interpreting case study findings
  - [Compare with standard statistical tests for controlled experiments]
- Statistical vs. Analytical Generalization
  - Quantitative methods tend to sample over a population
    - Statistical tests to generalize to the whole population
  - Qualitative methods cannot use statistical generalization
    - Hence use analytical generalization
Generalization

Statistical Generalization
- First level generalization:
  - From sample to population
- Well understood and widely used in empirical studies
- Can only be used for quantifiable variables
- Based on random sampling:
  - Standard statistical tests tell you if results on a sample apply to the whole population
- Not useful for case studies
  - No random sampling
  - Rarely enough data points

Analytical Generalization
- Second level generalization:
  - From findings to theory
- Compares qualitative findings with the theory:
  - Does the data support or refute the theory?
  - Or: do they support this theory better than rival theories?
- Supports empirical induction:
  - Evidence builds if subsequent case studies also support the theory (& fail to support rival theories)
- More powerful than statistical techniques
  - Doesn’t rely on correlations
  - Examines underlying mechanisms

Analytical and Statistical Generalization

LEVEL ONE
- sample

LEVEL TWO
- theory
  - policy implication
- rival theory
  - rival policy implication

SURVEY
- population characteristics

CASE STUDY
- case study findings

EXPERIMENT
- experimental findings
How can I evaluate a case study?

Same criteria as for other empirical research:

- **Construct Validity**
  - Concepts being studied are operationalized and measured correctly

- **Internal Validity**
  - Establish a causal relationship and distinguish spurious relationships

- **External Validity**
  - Establish the domain to which a study's findings can be generalized

- **Empirical Reliability**
  - Demonstrate that the study can be repeated with the same results

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**Case Study Designs**

- **4 types of designs** (based on a 2x2 matrix)
  - Single-case vs. Multiple-case design
  - Holistic vs. Embedded design

Basic Types of Designs for Case Studies (Yin, page 40)
Holistic vs. Embedded Case Studies

- **Holistic case study**: Examines only the global nature of one unit of analysis (not any subunits)
  - E.g.: a case study about an organization

- **Embedded case study**: Involves more than one unit of analysis by paying attention to subunit(s) within the case
  - E.g.: a case study about a single organization may have conclusions about the people (subunits) within the organization

### Holistic Designs

- **Strengths**
  - Convenient when no logical subunits can be defined
  - Good when the relevant theory underlying the case study is holistic in nature

- **Weaknesses**
  - Can lead to abstract studies with no clear measures or data
  - Harder to detect when the case study is shifting focus away from initial research questions
Embedded Designs

- **Strengths**
  - Introduces higher sensitivity to "slippage" from the original research questions

- **Weaknesses**
  - Can lead to focusing only on the subunit (i.e. a multiple-case study of the subunits) and failure to return to the larger unit of analysis

Rationale for Single-Case Designs

- As you might guess, a single-case design uses a single case study to address the research questions

- 5 reasons to use a single-case design
  - It represents the critical case in testing a well-formulated theory
    - The case meets all of the conditions for testing the theory thoroughly
  - It represents an extreme or unique case
    - Example: a case with a rare disorder
  - It is the representative or typical case, i.e. informs about common situations/experiences
    - Gain insights on commonplace situations
  - The case is revelatory – a unique opportunity to study something previously inaccessible to observation
    - Opens a new topic for exploration
  - The case is longitudinal – it studies the same case at several points in time
    - The corresponding theory should deal with the change of conditions over time
Multiple-Case Designs

- Useful when literal or theoretical replications provide valuable information

- Advantages
  - Evidence is considered more compelling
  - Overall study is therefore regarded as more robust

- Disadvantages
  - Difficulty to find an appropriate number of relevant cases
  - Can require extensive resources and time

Replication in Multiple-Case Studies

- Select each case so that it either:
  - Predicts similar results (*literal replication*)
  - Predicts contrasting results but for predictable reasons (*theoretical replication*)

- If all cases turn out as predicted, there is compelling support for the initial propositions
  - Otherwise the propositions must be revised and retested with another set of cases

- The theoretical framework of the study should guide the choices of replication cases
How Many Cases?

- How many literal replications?
  - It depends on the certainty you want to have about your results
  - Greater certainty with a larger number of cases
    - Just as with statistical significance measures
    - 2 or 3 may be sufficient if they address very different rival theories and the degree of certainty required is not high
    - 5, 6, or more may be needed for higher degree of certainty

- How many theoretical replications?
  - Consider the complexity of the domain under study
    - If you are uncertain whether external conditions will produce different results, you may want to include more cases that cover those conditions
    - Otherwise, a smaller number of theoretical replications may be used

Replication Logic vs. Sampling Logic

- Multiple-cases analogous to multiple experiments
  - Not analogous to multiple subjects in a single experiment!

- Replication logic (in case studies) is different from sampling logic (in surveys)
  - Sampling logic requires defining a pool of potential respondents, then selecting a subset using a statistical procedure
  - Responses from the subset are supposed to accurately reflect the responses of the entire pool

- Sampling logic does not fit with case studies
  - Case studies are not the best method for assessing the prevalence of phenomenon in a population
  - Case studies would have to cover both the phenomenon of interest and its context
    - Too many variables, which leads to way too many cases!
Multiple-Case Designs: Holistic or Embedded

- A multiple-case study can consist of multiple holistic or multiple embedded cases
  - But there is no mixing of embedded and holistic cases in the same study

- Note that for embedded studies, subunit data are not pooled across subunits
  - Used to draw conclusions only for the subunit's case
Selecting Case Study Designs – Single or Multiple?

- If you have a choice and enough resources, multiple-case designs are preferred
  - Conclusions independently arising from several cases are more powerful
  - Differences in context of multiple cases with common conclusions improve the generalization of their findings
  - Capability to apply theoretical replications

- Single-case studies are often criticized due to fears about uniqueness surrounding the case
  - Criticisms may turn to skepticism about your ability to do empirical work beyond a single-case study
  - If you choose single-case design, be prepared to make an extremely strong argument justifying your choice for the case

- In some situations, single-case designs are the best (or only!) choice

Purposive Sampling of Cases

- Extreme or Deviant Case
  - E.g. outstanding success/notable failures, exotic events, crises.

- Intensity
  - Information-rich cases that clearly show the phenomenon (but not extreme)

- Maximum Variation
  - Choose a wide range of variation on dimensions of interest

- Homogeneous
  - Case with little internal variability - simplifies analysis

- Typical Case
  - Identify typical, normal, average case

- Stratified Purposeful
  - Identify subgroups and select candidates within each group

- Critical Case
  - If it's true of this one case it's likely to be true of all other cases.

- Snowball or Chain
  - Select cases that should lead to identification of further good cases

- Criterion
  - All cases that meet some criterion,

- Theory-Based
  - Manifestations of a theoretical construct

- Confirming or Disconfirming
  - Seek exceptions, variations on initial cases

- Opportunistic
  - Rare opportunity where access is normally hard/impossible

- Politically Important Cases
  - Attracts attention to the study

- Convenience
  - Cases that are easy/cheap to study (but means low credibility!)

- Or a combination of the above
Collecting the Evidence

» Six Sources of Evidence
  ● Documentation
  ● Archival Records
  ● Interviews
  ● Direct Observation
  ● Participant-observation
  ● Physical Artifacts

» Three Principles of Data Collection
  ● Use Multiple Sources of Evidence
  ● Create a Case Study Database
  ● Maintain a Chain of Evidence

Documentation

» Letters, memos, and other written communication
» Agendas, announcements, meeting minutes, reports of events
» Administrative documents
  ● Proposals, progress reports, summaries and records
» Formal studies or evaluations of the same site
» Newspaper clippings, articles in media or newsletters
» Example: Classifying modification reports as adaptive, perfective or corrective based on documentation
  ● Audris Mockus, Lawrence G. Votta: Identifying Reasons for Software Changes using Historic Databases. ICSM2000; pp. 120-130
Archival Records

- **Service records**
  - Clients served over a period of time

- **Organizational records**
  - Organizational charts and budgets

- **Layouts**
  - Maps and charts

- **Lists of names and relevant articles**

- **Survey data**
  - Census records

- **Personal records**
  - Diaries, calendars, telephone lists

- **Example:** Study of parallel changes to source code was based on revision control logs

Interviews

- **Open-ended interviews**
  - Address facts and opinions about an event
  - Flexible structure of interview (or no structure at all!)

- **Focused interviews**
  - Short period of time (about an hour)
  - Similar approach as open-ended.

- **Formal surveys**
  - Produce quantifiable data

- **Example:** Used semi-structured interviews to understand the effect of distance on coordination in teams
Direct Observation

- Field visits - creates opportunity for direct observation
- Photographs of site
  - Need permission in order to proceed!
- Can be used to calibrate self-reports
  - Example: Informal, impromptu interactions
- Example: Followed software developers around to characterize how they spend their time

Participant-observation

- Not a passive observer, but actually participate in setting
  - Employee of the company under study
- Provides an opportunity to understand the rationale and behavior of people and organization being studied
- Example: Seaman participated in 23 code inspections over period of five months at NASA/Goddard Space Flight Center's Flight Dynamics Division
Physical Artifacts

- Technological tool, instrument, or device
- Artifacts can be collected or observed as part of a field visit
- Works of art or types of physical evidence
- Example: Diachronic study of art records to determine whether right-handedness was a recent or old trait
  - Two rival hypotheses: Physiological predisposition vs Social/environmental pressure
  - Tested by counting unimanual tool usage in art representations
  - 1200 examples from 1500 BC to 1950, world sources
  - 92.6% used right hand
  - Geo/historical distribution uniformly high
  - Seems to support physiological interpretation that right-handedness is an age-old trait

Principles of Data Collection

- Use Multiple Sources of Evidence
- Create a Case Study Database
- Maintain a Chain of Evidence

These principles can be applied to all six data collection methods
Multiple Sources of Evidence

- Triangulation of data sources

- Basic idea: Collect evidence from more than one source pointing towards the same facts
  - Warning: Collecting data from several sources does not guarantee data triangulation!

- Example: Different approaches were used collect data about how developers spend their time.
    - Collected cross-sectional and direct observation data
    - Collected longitudinal data

Multiple Sources of Evidence

Convergence of Evidence (Figure 4.2)

- Documents
- Archival Records
- Observations (direct and participant)
- Structured Interviews and Surveys
- Open-ended Interviews
- Focus Interviews

FACT