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# AN UNDERSTANDING OF THE APPLICATION OF RESEARCH METHODS IN ENGINEERING MANAGEMENT

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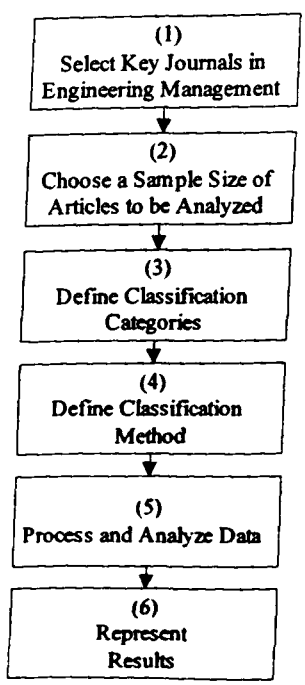
**Abstract**
In this article, the use of research methods in the field of Engineering Management is analyzed. For this study, a database was formed by using articles from three journals in the Engineering Management field: the Engineering Management Journal (EMJ), the IEEE Transactions on Engineering Management and the Journal of Engineering and Technology Management (JETM). Articles written between 1999 and 2003 were analyzed and an Engineering Management research position map was developed to describe holistically the research methods being used in Engineering Management. No judgment on the Engineering Management field per se was undertaken as a result of this study. Instead, its findings are presented as groundwork for future investigations on effective methods to execute Engineering Management research.

**Introduction**
The field of Engineering Management has been researched for many years, and the research methods used are themselves a topic of interest. Numerous articles and books have been written on research methods and how they should be implemented (Hill 1993; Baum 1995; Powell 1999; Green et al. 2002; Creswell 2003; Lee and Baskerville 2003). In these, many different approaches on the implementation, definition, and the link between the research question and the solution methodologies have been proposed. This fact is making difficult for researchers to find a common ground on which to base their research designs. Recently, Lewis and Spurlock (2003) carried out an analysis describing the purpose of the study, the research method and the topics of the study of articles written from 1993 to 2002 in three known journals of Engineering Management. Their focus was on articles studying "things other than people". Also, Lueck and Spurlock (2003) replicated the same study but their focus was on studying people, and they added the participants and their roles and the type of measures used. Finally, Cox and Spurlock (2003) reviewed the methods for data collection and the statiscal analysis used to carry out studies dealing with characteristics and behavior of people. These studies analyzed the existing research methods in Engineering Management, the tools used for these methods and the topics researched.

The following are the questions that guided our investigation: What research positions are used in the Engineering Management field? What research methods are used in the Engineering Management field? Under what paradigms do researchers and practitioners work in the Engineering Management field?

**Research plan**
A research plan was designed and implemented in order to answer our research questions. The research plan is shown in Exhibit 1.

**Exhibit 1.** Research Plan.



The database used in this analysis was formed by using articles from three journals, the Engineering Management Journal, Journal of Engineering and Technology Management and IEEE Transactions on Engineering Management. These three journals were chosen because of their comprehensive content on Engineering Management and related fields. Articles written between 1999 and 2003 were collected and analyzed. A 5 year time frame was chosen because it was believed to be sufficient to get valuable meaning through the analysis conducted. A total of 368 entries were processed. All the articles were analyzed, regardless of their context. Of the 368 articles, 52 were set aside because a specific methodology and a scholarly analysis approach could not be identified. Those articles were assumed to be "opinion" articles, and thus were not included in the subsequent analysis.

Each article was classified based on the following four main characteristics: Paradigm, Research Position, Methods. These characteristics are defined in the subsequent sections.

**Paradigm.** Paradigm defines the approach taken by the article's author to conduct the research. For the Paradigm classification, Creswell's definitions were used (Creswell 2003), which were Quantitative, Qualitative, Mixed, or Unclear. The Quantitative Approach represents: (a) post positivist knowledge claims, (b) surveys and experiments, (c) closed-ended questions, (d) predetermined methodologies, (e) numeric data, (f) theories testing or explanations, (g) identification of variables to study, (i) relationships between variables in questions or hypotheses, (j) mathematical, as well as, statistical procedures to analyze the observations.

On the other hand, Qualitative Approaches demonstrates: (a)constructivist/participatory knowledge claims, (b) methods such as phenomenology, grounded theory, case study, ethnography, and open-ended questions, (c) the use of personal values into the study, (d) studies of the context or setting of participants, and (e) interpretations of the data.

**Research Position.** The Research Position describes the research methodology the articles have taken in contributing to the Body of Knowledge. These approaches are: Pure Research, Engineering/Design, or Applied. Pure Research refers to the highest level of approaches taken. Research lies in the philosophical/theoretical domain, which are at the heart and core of the arguments and problems. The questions that drive this research position focus mainly on the advancement of knowledge (Boyer, 1992), not taking the applicability of its results into account extensively (Beer, 1992, 2001). Its intent is to fill gaps in the body of knowledge; to better comprehend an area(s) of research.

The direct usefulness and usability of the knowledge advanced by pure research is usually limited, however, these findings are commonly used as a foundation to advance practice in a field. For example, advances in the study of complexity establish the foundations that help understand complex engineering situations.

Engineering/Design refers to a narrower aspect of research. This research covers very specific and constrained portion of the body of knowledge. It deals with the development of a processes and tools to provide solutions for clearly defined problems (Cross, 1984; Hubka and Eder, 1987). Therefore, Engineering/Design research has well defined research questions that intent to frame problematic situations (Alexander, 1964; Gregory, 1966).

Problems may range from the generic to the highly specific. This position of research generates findings that are usable and useful due to its applicable nature (Beer, 1992, 2001). Engineering/Design research use the results of Pure Research as a foundation to develop methods that will lead to solve a problematic situation (Cross 1984). An example of this research position is the development of an optimization heuristic (generic) or the development of a decision support system for a given organization (specific).

Applied Research refers to a broader research approach. The approaches used and solutions developed are for a specific practical situation. Therefore approaches for executing applied research can vary. The common applied research approach involves seeking understanding of a given situation by using proven and valid theories and methods, as the ones that result from Pure Research and Engineering Design. Due to the lack of understanding of the phenomenon under study, a research question may or may not be present in the beginning of the research, as it is the case with hypotheses. A research question and hypotheses can be develop after having a better understanding of the phenomenon under observation (Dyer, et al, 1991).

In applied research, hypotheses can be refined depending on new insights collected from the field. The research process is over when enough understanding has been collected from the phenomenon as to enable the researcher to have well defined and operationally valid hypotheses that can lead to pure research or engineering/design research approaches (Eisenhardt, 1989). An example of this research position can be a large management change effort which requires an understanding of the organization and its current situation before a change strategy is designed. During this effort more knowledge is acquired that might affect

the researchers perceptions of the critical variables of the change process.

**Methods.** The methods describe the research methodologies that were used in the articles in order to collect and analyze data. These methods are (Gay and Airasian 2000): (a) Casual Comparative, (b) Correlational, (c) Descriptive, (d) Experimental, (e) Historical, (f) Literature, (g) Ethnography, (h) Phenomenology, (k) Case Study, and (l) Grounded Theory. These methods are briefly described in the Exhibit 2.

**Exhibit 2.** Research Methods.

| Method | Description |
|---|---|
| Casual Comparative | Cause-effect relationship |
| Correlational | Relationship between variables |
| Descriptive | Describes a behavior or condition |
| Experimental | Studies conducted have a control and an experimental group with manipulated and responding variable |
| Historical | Explain or predict a phenomenon, no measuring instruments, analyzing previously produced documents |
| Literature | Reviewing literature on given subject, summary of current thinking, developing new idea |
| Ethnography | Immersed in culture, active participant |
| Phenomenology | People's subjective experiences |
| Case Study | Specific case, contextual analysis |
| Grounded Theory | Questions, gather data, categorize |

Based on these characteristics (i.e., Paradigm, Research Position, and Methods) each article was classified. The results of the classification process and further analysis are explained in the following sections.

## Results

The first set of results show the outputs of the classification of articles based on their characteristics. Following, results from a cross tabulation analysis of the characteristics are represented. At last, further results are provided in the form of a research position map for Engineering Management.

### Classification's Results

**For the Paradigm characteristic.** There is no prevailing paradigm; 76.58% of the articles (242 articles) used either a Quantitative or Qualitative approach. However, a significant 21.84% used a mixed method. Exhibit 3 represents these results. Although this does not necessarily reflect well on the paradigm as a taxonomy, it may be viewed as a promising result since it may form the first step towards the development of a hybrid approach to do research in the Engineering Management field.

**For the Research Position characteristic.** Based on these results (87.66% of the articles were focus on either Engineering/Design or applied research and just 12.34% was oriented to Pure Research), it is possible to state that there is a potential requirement for the development of new theories or the enhancement of existing ones (both oriented to enrich the body of knowledge) in Engineering Management. Exhibit 4 represents these results.

**Exhibit 3.** Pie chart for the Paradigm characteristic.

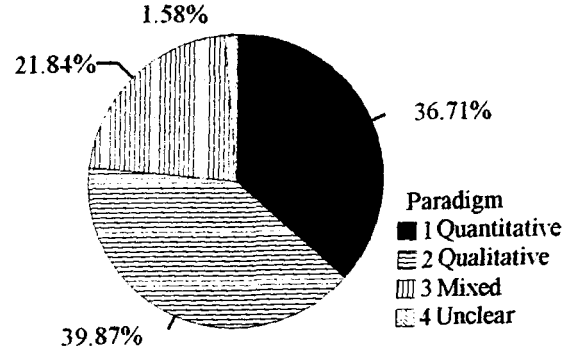
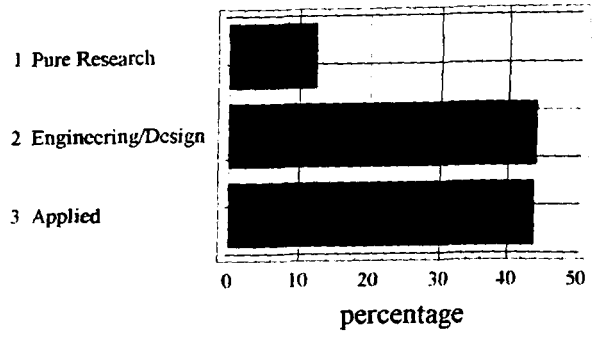


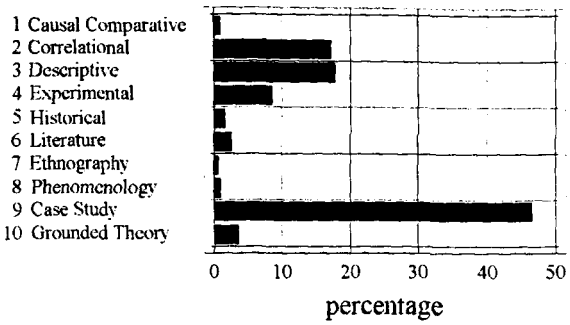

**Exhibit 4.** Research Position distribution throughout the articles




**For the Methods characteristic.** Exhibit 5 shows that the publications analyzed cover all of the ten research methods, although they are not equally distributed. The dominant category is Case Studies, with 147 articles (46.52%) using this method. The Descriptive method was the second most used method (17.72%), followed closely by the Correlational method (17.09%) and Experimental method (8.54%). The percentage of use

of the remaining categories (Causal Comparative, Historical, Literature, Ethnography, Phenomenology and Grounded theory) varied within a range of 0.63% to 3.48%. It is interesting to note that the spread of Engineering Management methods was fairly narrow with 89.87% of the publications being classified into 4 of the 10 categories.

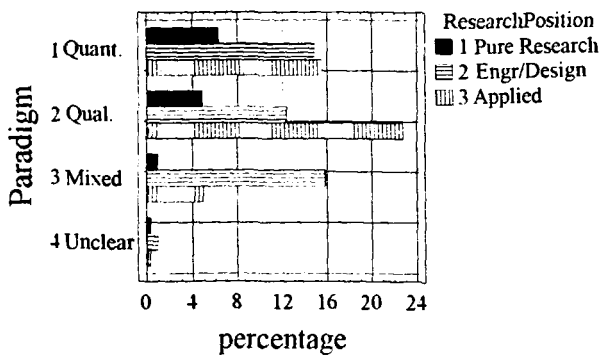
**Exhibit 5.** Method distribution throughout the articles.




**Cross tabulation's results**

**Paradigm crossed by Research Position.** The results depicted in Exhibit 6 show that for the quantitative approach, the studies are done primarily for Engineering/Design (14.87% of the cases) and for Applications (15.51%). Pure research is done in 6.33% of the quantitative articles. For the qualitative paradigm, the difference between the research position is more pronounced than for the quantitative paradigm. Here, 22.78% of the cases fell into the applications group, 12.34% were categorized as Engineering/Design, and just 4.75% were classified as pure research. Finally, researches are mixing paradigms mainly for Engineering/Design efforts (15.82% of the cases).

**Exhibit 6.** Cross tabulation between Paradigm and Research Position.




**Paradigm crossed by Methods.** The results show that for the quantitative approach, there are two leading methods used by researches: Correlational and Descriptive (15.51% and 13.92% respectively). For the qualitative paradigm, there is a leading method, the Case Study, which was used in 30.38% of the cases. This method was also preferred by the researchers using a mixed approach (quantitative and qualitative).

**Research Position crossed by Methods.** It is interesting to note that when doing Applied research in Engineering Management, researchers are using Case Studies as their primary research position (25.32% of the works). Correlational and Descriptive methods are used in a significantly smaller proportion (6.65% and 7.28% of the cases. For Engineering/Design, the use of methods is fairly spread although the Case Study plays a significant role with 17.72% of the cases. Finally, even though Applied research is a position not common for researchers in the Engineering Management field, it is important to note that it mainly uses Case Study and Descriptive as research methods.

**Further Results**

**Mapping of Research Methods.** Based on the results presented, the research methods, positions, and paradigms can be identified in an Engineering Management research position map.

According to the data, applied research and engineering design, representing 88% of the research position, follow an inductive approach. On the other hand, pure research represents a 12% of the total and it follows a deductive approach. Exhibit 10 shows these results. Additionally, the data represents that when the paradigm followed for researching in Engineering Management is a deductive one, the methods used are primarily quantitative. On the contrary, when an inductive approach is followed not only quantitative but also qualitative methods are used.

These results represents that both inductive and deductive approaches can be used in order to do research in Engineering Management. On the inductive approach, supported by either qualitative or quantitative research as shown in Exhibit 7, the environment allows the researchers to ask themselves the research question as well as to collect a set of data for validating their hypothesis. In order to do that, modeling, experimentation and validation processes must be used. Therefore some concepts and theories can be created. The right loop of Exhibit 7 depicts this process.

On the other hand, the deductive approach is mainly supported by quantitative research. It begins with a set of theories and concepts to be validated by following the modeling, experimentation and validation process.

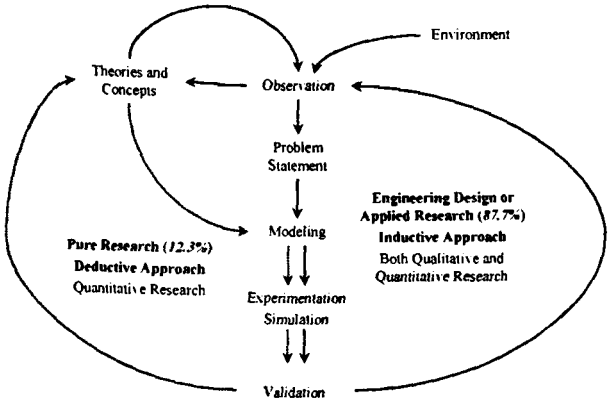
Here, the data collection, based on the problem statement are frequently of a quantitative nature. The left loop at Exhibit 7 depicts this process.

As pointed out by Axelrod (1997), a hybrid third approach mixing inductive and deductive approach has arisen to study complex social systems. In this approach, simulation is used to test theories and concepts as in the deductive approach but results are treated as in the inductive approach.

Additionally, by following an inductive approach supported with qualitative research, theories and concepts can be developed by observation to the environment as in grounded theory (Corbin and Strauss 1990).

Exhibit 7 shows the relationship among the steps involved in the research process as different methodological approaches are used allowing researchers to look for the most suitable based on their purpose.

**Exhibit** 7. Research Position Map




## Discussion

As pointed out by Axelrod (1997), there is a continuous debate about methods to better study complex social systems (e.g., Engineering Management settings) and the role of human behavior inside them. In this sense, simulation, and more specifically agent-based modeling, has been used to understand properties of complex social systems. As Axelrod said: "this method can be compared with the two standard methods of induction and deduction. Agent-based modeling becomes a third way. Similar to deduction it starts with a set of explicit assumptions, and unlike typical induction, the simulated data comes from a specified set of rules rather than direct measurement of the real world. Whereas the purpose of induction is to find patterns in data and that of deduction is to find consequences of assumptions, the purpose of agent-based modeling is to help modelers to understand complex systems" (Axelrod 1997, pp.4).

This hybrid approach is not new, economists have been using laboratory experiments as a tool in a quasi-empirical economic analysis (Smith 1962; Smith 1976; Smith 1985). They have used this approach for development and verification of economic theories. Models and results found are the starting point for a more comprehensive understanding of such theories. Chamberlin (1948) pioneered these kind of approach by studying organizations and their behavior in open markets. He pointed out the difficulty faced by social scientist when they try to study the real world.

On the other hand, there has been a controversy between qualitative and quantitative approaches to study social sciences. In social sciences, qualitative approaches can be useful to describe personal experience and meaning, cultural diversity, contextual factors, theory and hypothesis generation and elaboration (Kidd 2002). Kidd revealed the importance of the qualitative research in psychology and how this kind of research has been increasingly appearing in psychology journals.

Corbin and Strauss (1990) and Munck (1998) give a complete set of procedures, canons, and evaluative criteria to research design with qualitative approaches. In particular, Corbin and Strauss (1990) attempt to answer the epistemological, ontological and methodological question of a well known qualitative research method, grounded theory. Additionally, Munck (1998) depicted a research cycle and a methodological set of rules to undertake qualitative research defined by King, Keohane and Verba in their work dated in 1994.

In order to describe the structure and dynamics of complex social systems new approaches and research methods are required. In this sense, a wider and more appropriate set of methods must include quantitative as well as qualitative approaches. Also, a hybrid method mixing inductive and deductive approaches may result in a more effective way for understanding, modeling, and intervening in complex social systems, as the ones commonly found in Engineering Management.

## Conclusions

The first "finding" that bears mentioning is the number of articles that failed to be classified using the categories used in this article (52 of 368 are opinion articles), although we do concede that some of these articles may follow very rigorous argument structures. The second finding is that mixed methods were used in 21.84% of the articles. Combining these two findings, we can conclude that a large portion of published research in Engineering Management fails to follow well defined research paradigms. Another finding is

that Case Study is the most used research method (46.52%), which is also supported by Lewis and Spurlock (2003). Although the time range is different, we can conclude that Case Study is the most used method in Engineering Management field.

The addition of a Mixed category by many researchers of research methods and the fact that so many articles fall into this category have some major implications. First, it may reflect the need for the development of well documented hybrid research approaches to address what are obviously problems that cannot easily be answered using either the quantitative or qualitative paradigms. A second implication is that these paradigms do not represent an effective classification system for research methods since it lacks the capability of uniquely defining research approaches. This must raise some concerns given the extensive use of these paradigms in education, research and practice.

The low percentage of (12.34%) pure research being undertaken is also an interesting result. This would appear to support the idea that both Engineering and Management are "applied" fields. However, the caution that must be presented is that this also indicates that a vast portion of Engineering Management research is being undertaken based on the fundamental research in other fields.

It must be noted that there are no definite categorizations for Research Methods, both Lewis and Spurlock (2003) and Lueck and Spurlock (2003) have used different categories for Research Methods. We have used a research position map to represent findings from the analysis. In developing the research position map, we have used the paradigms and approaches in Engineering Management.

This may be used by researchers to increase and seek understanding on research methods in Engineering Management.

As part of our continued research in this area we feel that an analysis should be conducted over an extended time frame. The results of such an analysis would be more precise in determining trends in research methods being used. Further classification structures should also be added to establish their usefulness in helping academics, practitioners and students to better understand the overarching concept of research in Engineering Management. Finally further development on either the proposed research framework or other frameworks of this kind should be undertaken.

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