Validation Methodologies for Construction Engineering and Management Research

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Applied Science
in
Civil Engineering

Waterloo, Ontario, Canada, 2013

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Validation of results is an important phase in the organization of a researcher's work. Libraries and the internet offer a number of sources for guidance with respect to conducting validation in a variety of fields. However, construction engineering and management (CEM) is an area for which such information is unavailable. CEM is an interdisciplinary field, comprised of a variety of subjects: human resources management, project planning, social sciences, etc. This broad range means that the choice of appropriate validation methodologies is critical for ensuring a high level of confidence in research outcomes. In other words, the selection of appropriate validation methodologies represents a significant challenge for CEM researchers. To assist civil engineering researchers as well as students undertaking master's or doctoral CEM studies, this thesis therefore presents a comprehensive review of validation methodologies in this area. The validation methodologies commonly applied include experimental studies, observational studies, empirical studies, case studies, surveys, functional demonstration, and archival data analysis. The author randomly selected 365 papers based on three main perspectives: industry best practices in construction productivity, factors that affect labour productivity, and technologies for improving construction productivity. The validation methodologies that were applied in each category of studies were examined and recorded in analysis tables. Based on the analysis and discussion of the findings, the author summarized the final results, indicating such items as the highest percentage of a particular methodology employed in each category and the top categories in which that methodology was applied. The research also demonstrates a significant increasing trend in the use of functional demonstration over the past 34 years. As well, a comparison of the period from 1980 to 2009 with the period from 2010 to the present revealed a decrease in the number of papers that reported validation methodology that was unclear. These results were validated through analysis of variation (ANOVA) and least significant difference (LSD) analysis. Furthermore, the relationship between the degree of validation and the number of citations is explored. The study showed that the number of citations is positively related to the degree of validations in a specific category, based on the data acquired from the examination of articles in Constructability and Factors categories. However, based on the data acquired from the examination of articles in the year 2010, we failed to conclude that there existed significant difference between clear-validation group and unclear validation group at the 95 % confidence level.

Acknowledgements

I would like to express my sincerest appreciation and gratitude to my supervisor, Dr. Carl T. Haas, for his patient guidance, inspiring motivation, and generous and unconditional help and support. Without his assistance, this thesis could not have been completed.

I would like to thank the readers of my thesis, Dr. Tarek Hegazy and Dr. Giovanni Cascante, for their insightful comments and suggestions.

I would like to express special thanks to Ms. Barbara Trotter for her patient proofreading help. Her valuable advice contributed a great deal to this thesis.

I would also like to acknowledge and say how much I valued the helpful advice I received from my officemate Di Zhang as well as from A. J. Antony Chettupuzha, Shahin Karimidorabati, Hasaan Nasir, Mohammad Nahangi, Mahdi Safa, Arash Shahi, Samin Shokri, Maryam Shahtaheriand Yasaman Shahtaheri, etc.

I'm also grateful to the Constructional Industry Institute for providing support and the opportunity to attend meetings in the United States.

Last but not least, I would especially like to thank my parents for their unconditional love and support. They have always been there to encourage me.

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Chapter 1
Introduction

1.1 Background and Motivation

In performing a comprehensive study, researchers generally organize their work in three phases: develop a proposal for the research, conduct the research, and validate the results. All three phases are critical for the success of the research. For a variety of research fields, libraries and the internet offer numerous sources of detailed instructions for developing a project and for validating the results. However, construction is one area for which such information is not available. Although some studies have examined validation methodologies in general, only a few have discussed in detail the application of these methodologies to construction engineering and management research.

The importance of validation is universally acknowledged. According to *The Advanced Learner's Dictionary of Current English* (1963), the term is defined as the process of rendering an element legally valid and ratified or of making an entity logical or justifiable. The latter meaning is the one that applies to academic research. In the work conducted for this thesis, any techniques that include one of the following features are considered to be validation methodologies:

- Presentation of evidence to support observations or conclusions
- Demonstration of the accuracy of the research at a specific level

Applying appropriate methodologies for validating results, however, is a challenge to investigators working in construction engineering and management research, because this area is interdisciplinary, comprised of a variety of subjects: human resources management, project planning, social sciences, systems engineering, etc. This broad range means that appropriate validation methodologies must be selected in order to ensure a high level of confidence in the outcome of the research. Detailed investigation and analysis of the methodologies authors have used for validating their results are thus imperative. This thesis therefore presents a comprehensive review of validation methodologies for construction engineering and management (CEM) research.

1.2 Objectives

This thesis focuses primarily on the investigation of CEM validation methodologies. The particular of goal of the research is to assist civil engineering researchers as well as students undertaking studies in this area for master’s or doctoral degrees so that they can select appropriate methodologies for validating their results. The main goal includes the following objectives:

- Understand the importance of choosing appropriate validation methodologies.
- Clarify the definition of each validation methodology.
- Identify the features of each validation methodology.
- Describe published articles about CEM research, and develop specific categories for their classification.
- Determine the percentage of each methodology in each category, and explore the principles underlying the application of each methodology in CEM research.
- Explore the trends in academic practice in construction engineering.
- Explore the question of whether degree of validation relates to the number of citations and validate the results.
- Attempt to gain insight into why specific validation approaches prevail in key areas of CEM research.

The achievement of these objectives will not only contribute to the overall goal but will also help researchers acquire a better understanding of this topic.

1.3 Scope

The papers selected for this research are related to construction engineering and management, with particular emphasis on the improvement of labour productivity. Labour productivity is defined as the number of labour hours per unit output in an industry. In 2007, the Construction Industry Institute (CII) developed a 5-phase program to help industries determine the amount of any improvement and assigned this program to Research Team 252 (RT 252) (CII: Research Team 252, 2009). RT 252 has thus been working on this program for about six years, and their efforts have resulted in breakthrough improvements in construction productivity.

The topics of the papers studied for this thesis were chosen primarily from *Best Practices* (CII: Research Team 252, 2011) and *The Productivity Handbook* (CII: Research Team 252, 2013). To enhance the accuracy of this research, articles have been randomly selected from a variety of databases, with publication dates ranging from the early 1980s to the present.

1.4 Research Methodology

To achieve the research objectives, the following steps were followed:

- Prior to a comprehensive literature review of CEM validation methodologies, conduct a review of the background and literature related to validation methodologies in general: those related to a variety of subjects, such as computer science, education, management science, chemical engineering, and medical science.
- Thoroughly review the literature related to CEM validation methodologies.
- Clarify the definition of each CEM validation methodology, and explore the features of individual methodologies so that they can be differentiated.
- Develop appropriate tables for collecting the data related to validation methodologies, as reported in selected publications, and carefully enter the data.
- Synthesize the data and literature reviews.
- Statistically analyze the data, and validate the results.
- Draw conclusions based on the research.

Figure 1-1 illustrates the research methodology, which includes the process of completing the thesis.

1.5 Thesis organization

Seven chapters address the process and achievements of the research, beginning with this introductory chapter.

Chapter 2 presents the background about and a literature review of validation methodologies. It includes 9 sections:

- The first three sections examine validation methodologies that are applied to a variety of areas, with the third section focusing on a comprehensive review of articles about CEM research methodologies.
- The fourth section compares scholarly validation and business case validation.
- The fifth section provides a comparison of engineering and management in the area of construction.

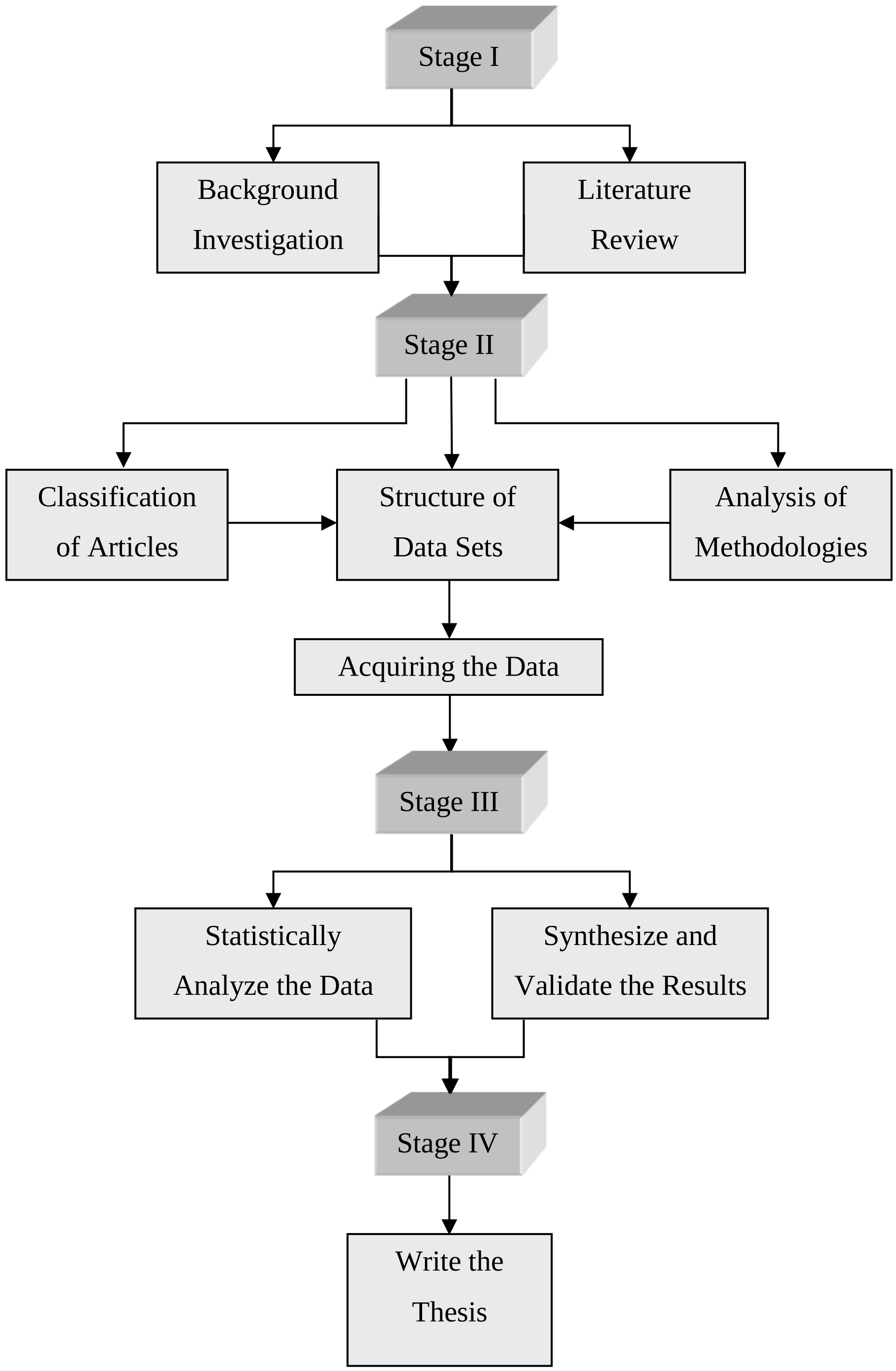

Figure 1-1 Research Methodology

- The sixth section outlines a major concern with respect to construction: labour productivity. Three classes of sources of influence on labour productivity are introduced in this section.
- The seventh section presents a relatively new validation methodology, called meta-analysis, which is not commonly used in the construction area but which has future potential because of its advantages.
- As a useful tip for readers, the second last section describes how to use search engines to find information about a specific subject efficiently.
- The last section summarizes Chapter 2.

Chapter 3 illustrates the process of designing the structure of the analysis tables used in this research and the principles underlying the classification of the articles. It explains how each article fits into each corresponding category, what differentiates each methodology, and which features apply to each methodology. All of the articles presented in this chapter focus on improving productivity from three main perspectives: industry best practices in construction productivity, factors that affect labour productivity, and technologies for improving construction productivity. The best practices category includes 10 subcategories, with the investigation covering an average of 30 papers for each subcategory, for a total of about 300 papers. The other two categories encompass a total of about 40 papers each.

Chapter 4 includes all the tables showing the data entered. A detailed example of the method of classifying papers in each category is also presented as clarification of the application of the classification principles.

Chapter 5 provides an explanation of the analysis and a discussion of the results. Also included is a summary of the final results, indicating such items as the highest percentage of a particular methodology in each category, the top categories that apply to that methodology, the trends in the usage of validation methodologies over the past 33 years and the relationship between the degree of validation and the number of citations.

Chapter 6 introduces the barriers to the application of meta-analysis in construction engineering and management.

Chapter 7 presents comprehensive conclusions and recommendations for further research as well as an overview of the entire study.

There are two appendices included in this thesis. Appendix A presents all the journals and sources that the examined articles come from. Appendix B presents the detailed bibliography information of each examined article.

Chapter 2
Background and Literature Review

2.1 Introduction to Validation

Validation refers to the process of making an entity legally valid and ratified or making an item logical or justifiable. Two main considerations associated with the validation process are internal and external validity (Leedy, 1980). Internal validity indicates the causality among multiple variables that interact with one another. External validity denotes the induction and generalizability of research results for the purpose of prediction (Leedy, 1980). CEM studies must be conducted in real-life settings, which entail numerous uncontrollable and unpredictable variables that affect the results (Lucko & Rojas, 2010). The consequent complicated interactions among such variables create challenges with respect to both internal and external validity, because the ability to generalize results requires that the study sample be representative, a requirement that is difficult to meet. Randomizing the sample is considered to be one option for overcoming this difficulty.

In addition to these two main types of validity, other components of validation include face validity, content validity, criterion validity, and construct validity (Lucko & Rojas, 2010). Briefly, face validity means that non-researchers consider the research results valid (Leedy, 1980). Content validity is related to the degree that the contents of the study, such as tasks, activities, and events, can represent actual real occurrences (Lucko & Rojas, 2010). Criterion validity refers to the correlation between one assessment instrument and another (Babbie, 1973). Construct validity is established based on a true match between the research measurement tools and the study objectives (Leedy, 1980).

"The objective of validation of an analytical procedure is to demonstrate that it is suitable for its intended purpose" (EMEA, 2006). In other words, performing the validation means ensuring that, considering the goal of the research, correct and appropriate action is taken. Validating the results is therefore one of the most crucial elements of an entire research project.

Completing the validation process and achieving its objectives require researchers to find appropriate methodologies. Validation methodologies refer to all scientific methods that can prove or support the research results and ensure their quality. Therefore, any research methodologies that can be employed to present evidence in support of observations/conclusions or that demonstrate the accuracy of the results can be applied in order to validate the study results and can thus be considered validation methodologies. The following background and literature review focuses on the topic of validation/research methodologies. The next section introduces the methodologies used by researchers in a number of fields.

2.2 Validation Methodologies for a Variety of Research Fields

This section is a general review of most of the common validation methodologies for a variety of research fields. For each subject area, a number of randomly selected papers were chosen as a means of investigating the kind of methodologies that researchers in that area have applied to their studies. Table 2-1 provides a brief summary of the results of the literature review presented in this section.

2.2.1 Biology Methodologies

Based on a review of biology articles, one of the most popular validation methodologies in that field is an experimental study, also known as biological assay. The purpose of the experimental study is to investigate the accuracy and specificity of and variations in assay performance. The critical parameters for experimental studies can be summarized as accuracy, precision, selectivity, sensitivity, reproducibility, and stability (Bansal & DeStefano, 2007). Other methodologies, such as surveys and case studies, are also used in biology.

2.2.2 Chemical Engineering Methodologies

A validation methodology frequently employed in chemical engineering is modeling and simulation through the implementation of appropriate algorithms. Modeling is the process of establishing a model that represents the construction and operation of systems related to the researcher's studies (Maria, 1997). Simulation indicates the operation of a model. Modeling and simulation are generally well-recognized methods in engineering and provide a useful tool that enables engineers to validate their research results. This methodology is explained in greater detail in a later section of this chapter. Another validation option for chemical engineers is empirical study: researchers often establish an empirical model in order to test the hypothesis. Experimental studies are also used as a validation methodology in chemical engineering.

2.2.3 Computer Science Methodologies

Due to the nature of computer science, the validation methodologies used in this field are slightly different from those employed in other areas. Conducting numerous types of testing available is one of the most popular validation methodologies that computer science researchers apply: unit testing, integration testing, volume testing, usability testing, etc. (Easterbrook, 2001). In addition to testing, another common method is modeling and simulation, examples of which are numerous: discrete event modeling, individual-based modeling, molecular modeling, Monte Carlo Simulation, etc.

2.2.4 Education Methodologies

The research methodologies associated with educational studies vary widely. Case studies are often used to validate results because this subject has a long history, with numerous studies by many researchers. Statistical analysis is also commonly employed, with researchers mining data; calculating the characteristics of data sets, such as the mean, median, and standard deviation; establishing a model; and testing the hypothesis. This kind of statistical analysis process is called empirical study. Observational study is another methodology quite useful for educational research, which is often combined with statistical analysis. Meta-analysis is an additional method very popular among educational researchers. It can be considered a type of statistical analysis but a special one that is often useful for systematic reviews. A detailed review of the literature related to this method is included later in this chapter.

2.2.5 Human Resources Management Methodologies

Human resources management refers to the management of the workforce of a specific organization and involves the hiring, training, assessment, and rewarding of employees. Human resources management forms a major component of the social sciences since it relates to all areas of society, such as student associations, industrial corporations, and even government. Researchers usually validate their results by conducting surveys, which include both questionnaires and interviews. Other popular options are case studies, meta-analysis, and observational studies.

2.2.6 Medical Science Methodologies

Medical science is a precise science that supports the body of knowledge in medicine. It focuses on vital aspects of life, such as health, disease, and death (Indrayan, 2008). Two major categories of the methodologies in this field are quantitative research and qualitative research. Quantitative methodologies include experimental studies, empirical studies, meta-analysis, case studies, and statistical surveys. To validate their results, researchers normally combine two or more methodologies in order to strengthen the evidence that supports their conclusions. Qualitative methodologies include descriptive surveys and questionnaires, observational studies, and case studies. In addition to these two categories, Andrew and Halcomb (2009) also recommended that medical science employ mixed methods research, which combines qualitative methods with quantitative methods in a single study (Andrew & Halcomb, 2009).

2.2.7 Physics Methodologies

The field of physics is characterized by two types of research: fundamental, or basic, research and applied research (Rajasekar, Philominathan, & Chinnathambi, 2006). Either type can be quantitative, qualitative, or both. Quantitative research includes experimental studies, modeling and simulation, and meta-analysis. Qualitative research includes field observational studies, case studies, and ethnography and narrative reports (Thomas, Nelson, & Silverman, 2011).

2.2.8 Psychology Methodologies

Psychologists employ a variety of validation methodologies. Two main categories are quantitative and qualitative. Quantitative methodologies include experimental studies, case studies, statistical surveys, and computational modeling (Wikipedia, Psychology, 2012). Qualitative methodologies include interviews (descriptive surveys), observational studies in the case of physics, case studies, archival research, and grounded theory (Creswell, 2009). Grounded theory is a systematic methodology, which, unlike traditional social science research methodologies, requires researchers to start with data collection rather than with a hypothesis. Through analysis of the data, researchers develop theories that become the explanations of the research topics (Glaser, 1967). It should be mentioned that meta-analysis is also popular with psychology researchers.

2.2.9 Summary

This section has provided a basic review of the validation methodologies used in a number of fields. Researchers in the natural sciences such as biology and physics apply experimental studies and case studies in order to validate their results. In social and management sciences, such as education, human resources management, and psychology, the common methodologies are case studies, observational studies, and meta-analysis. In applied sciences, which include engineering and healthcare, in areas such as chemical engineering and medical science, experimental studies and empirical studies are widely used. In formal sciences such as computer science, the modeling and simulation method is considered a good choice for validation.

The review presented in this section helped the author conduct a further and deeper investigation of the validation methodologies related to CEM. Table 2-1 summarizes the validation methodologies in the fields mentioned in this section.

Table 2-1 Validation Methodologies Used in a Variety of Fields

Field	**Examples of Validation Methodologies**
Biology	Experimental Studies, Case Studies, Surveys
Chemical Engineering	Modeling and Simulation, Empirical Studies, Experimental Studies
Computer Science	Program Testing, Modeling and Simulation
Education	Empirical Studies, Observational Studies, Meta-Analysis
Human Resources Management	Surveys, Case Studies, Meta-Analysis, Observational Studies
Medical Science	Experimental Studies, Empirical Studies, Meta-Analysis, Case Studies, Surveys, Observational Studies, Mixed Methods Research
Physics	Experimental Studies, Modeling and Simulation, Meta-Analysis, Field Observational Studies, Case Studies, Ethnography and Narrative Reports
Psychology	Experimental Studies, Case Studies, Surveys, Computational Modeling, Observational Studies, Archival Researchers, Ground Theory, Meta-Analysis

2.3 Validation Methodologies in Construction Engineering and Management

Based on general knowledge about methodologies used in other fields, a more focused investigation of validation methodologies associated with CEM was conducted, as described in this section.

2.3.1 Introduction to Validation Methodologies in CEM

As with several other areas, validation methodologies used in CEM research can be divided into two categories: quantitative and qualitative. Quantitative approaches are believed to be scientific methods in which the initial study of the theory and literature has precise objectives with respect to hypotheses to be tested (Popper, 1965). Qualitative research, on the other hand, is an exploration of the subject conducted without prior formulations (Fellows & Liu, 2008). In other words, qualitative research can be regarded as a precursor to quantitative research. However, the objectivity of qualitative data is often questioned by people whose background is in the scientific and quantitative tradition, because the data collected for qualitative research are unstructured (Fellows & Liu, 2008).

Quantitative methodologies include experimental studies, modeling and simulation, empirical studies, surveys, quantitative case studies, and archival data analysis (Taylor & Jaselskis, 2010). Qualitative methods include observational studies, qualitative case studies, and the Delphi method. Taylor & Jaselskis (2010) stated that, according to the examination of 1102 manuscripts published from 1993 to 2007 in the *Journal of Construction Engineering and Management*, experimental research and survey research were the methodologies most frequently used in CEM. However, the trend of CEM validation methodologies may vary due to differing classifications of the articles and variations in the specific definitions of the methodologies.

2.3.2 Literature Review of Methodologies

2.3.2.1 Experimental Studies

An experiment is a carefully designed, methodical procedure employed for the purpose of testing the validity of a hypothesis. Experimental research is appropriate for “bounded” problems or issues (Fellows & Liu, 2008). Bounded problems refer to instances in which the variables related to the subject are known or hypothesised with a specific level of confidence. There are three types of experimental studies: controlled experiments, natural experiments, and field experiments. Controlled experiments are often conducted in laboratories, where the results from experimental groups are compared to those obtained with control groups, so this method is widely used in areas such as medical science, chemistry, and psychology. Where controlled experiments are difficult to conduct, such as for problems in epidemiology and economics, natural experiments are considered (DiNardo, 2008). Field experiments are conducted as a means of evaluating the results in the real world rather than in a laboratory. This type of experiment is appropriate for engineering. In addition to these three types of experiments, Bernold and Lee (2010) listed a few more, one of which is called a pilot test of devices and methods. In construction, a pilot test is used to ensure the quality of materials, the precision of building structures, or the validity of technological innovations (Bernold & Lee, 2010). Another method, called four-group design, is not easily found in journal articles since the large samples required in this type of research represent an extra burden for researchers.

While experimental studies may be the most scientific and useful method of supporting a hypothesis or theory, the problem of “bias” is inherent in every experiment. As well, in CEM, conducting experimental studies is not easy, and it is rare that a contractor is willing to participate in experiments due to the cost, safety, and scheduling concerns associated with construction projects (Bernold & Lee, 2010).

2.3.2.2 Observational Studies

Observational studies provide insight about the possible effect on specific subjects or the phenomena associated with a treatment or an action and why they occur (Leicht, Hunter, Saluja, & Messner, 2010). With the development of computing and audio-visual technology that can capture activities, such as cameras, microphones, and computer software, observational studies can generate qualitative information as well as quantitative data. As early as the 1880s, observational studies were used for examining the working class but not in the area of construction (Denzin & Lincoln, 1944). The use of observational methods is often identified as either structured observation or unstructured observation (Yin, Case Study Research: Design and Methods, 1989). Structured observation relies on pre-set frameworks of action and content so that the activity fits within the variables and scope of the research question (Leicht, Hunter, Saluja, & Messner, 2010). Unstructured observation represents the opposite conditions. In contrast with experimental studies, observational studies are conducted based on the limitation that researchers are unable to assign subjects to a treated group versus a control group (Wikipedia). Observational studies lack the statistical properties of experimental studies because the groups in observational studies are not randomly assigned as in experimental methods. In randomized experiments, the mean of each group is expected to be the same because of the central limit theorem, while groups in observational studies who receive different treatment may differ greatly due to their covariates. This feature of observational studies is the key to differentiating observational studies from experimental studies. As well, with respect to CEM, observational studies are often conducted with the assistance of tools or advanced techniques such as cameras and videos.

If combined with quantitative data analysis, observational studies can provide a context for a better understanding of the actual performance and properties of a workforce or of other specific research subjects. However, the process of generating the data and the methodology itself is time-consuming, and the personal bias and subjectivity of the researchers have a detrimental effect on the final outcome (Hammersly & Gromm, 1997). To minimize the disadvantages of observational studies, researchers must obtain a larger sample size and choose a sample that is representative of the population (Leicht, Hunter, Saluja, & Messner, 2010).

2.3.2.3 Empirical Studies

In CEM, empirical studies have a significant potential for research applications. In empirical studies, also known as empirical modeling, researchers develop a theory or a set of principles for a system on the basis of the data collected from experience or through observations (Flood & Issa, 2010). Modeling systems then develop functions that can map an input vector to an output vector. To form logical and valid conclusions, the statistical methods commonly used include regression analysis, t-test, chi square, and ANOVA (Wikipedia, 2013). The output of the empirical model is often the focus of empirical studies, but Flood and Issa (2010) pointed out that the internal structure of empirical models also has a potential for exploitation. Empirical studies incorporate six steps: strategizing, data collection and evaluation, model development, model evaluation and final selection, final validation, and implementation and review (Flood & Issa, 2010). This set of procedures represents only a brief summary of the development of this methodology since the discussion of its application is beyond the scope of this thesis. Readers may refer to works such as *Empirical Modeling Methodologies for Construction* (Flood & Issa, 2010) and *Empirical Model Building* (Thompson, 1989) for further information about the implementation of empirical research.

Empirical studies can help researchers develop a deeper or more generalized understanding of a system (Flood & Issa, 2010), and dynamic empirical models also provide researchers with insight into the time-dependent behaviour of a system. If a problem lacks sufficient theoretical framework but includes examples of its performance and behaviour, empirical studies can be applied to the problem. However, with empirical studies, the complexity of the problem is also limited due to the increase in the quantity of input variables caused by the number of fitting data examples required in order to develop the model. The implementation of empirical studies is somewhat time-consuming and expensive (Flood & Issa, 2010).

2.3.2.4 Case Studies

A case study is the intensive analysis of a particular matter over a specific time period . This methodology assists researchers in exploring a phenomenon in its actual context using a number of data sources (Yin, 2003). The cases selected are usually representative, with conditions similar to those used in the statistical sampling so that the cases employed in the research can demonstrate particular facets of a specific topic (Fellows & Liu, 2008). Yin (2003) categorized three types of case studies. The first, called an exploratory case study, is used to examine situations in which the intervention being evaluated has no clear, single set of results. The second type, designated a descriptive case study, describes a research subject and its real-life context. The third, termed a multiple-case study, helps researchers discover the differences between and within cases. In the 1990s, Stake (1995) offered a different categorization of three types of case studies. He called the first one intrinsic case study, a useful method for researchers who have a genuine interest in a case in which the intent is better understood. He pointed out that, because the interest of the researcher is in the case itself, the purpose of this approach was not to build theories (Stake, 1995). The second type he named instrumental case studies. This approach is used to complete an activity rather than to acquire an understanding of a particular phenomenon. This method plays a supportive role by helping researchers understand more deeply and in further context. The last one is labelled collective case studies, with a methodology similar to that of the multiple-case studies mentioned by Yin (2003).

The advantage of case studies is that they allow researchers to explore individuals or organizations using complex interventions, relationships, communities, or programs (Yin, 2003). However, the level of rigour obtainable with case studies is always controversial.

2.3.2.5 Surveys

Survey methodology is the sampling of individuals from a population for the purpose of description or to identify predictive patterns of influence or the relationships among variables (Sapsford, 2007). The first step in conducting a survey is usually to select the samples. The researchers must then choose the mode of data collection: telephone, mail (post), online surveys, personal in-home surveys, personal mall- or street-intercept surveys, or a combination (Wikipedia, 2013). After the research data have been acquired, conclusions are tested based on planned comparisons (Sapsford, 2007). The key to the successful application of this methodology is the careful selection of the sample members, the evaluation and testing of the survey questions, the choice of an appropriate mode, the training and supervising of the interviewers, and the analysis and mitigation of the effects of any errors identified.

The survey methodology has obvious advantages. Compared to other methodologies mentioned in this thesis, surveys are relatively easy to conduct, and statistical analysis can be applied to the data in order to determine their validity and statistical significance. Fuzzy construction opinions can also be converted into hard data. In other words, qualitative data can be translated into quantitative data (Sapsford, 2007). However, all sample surveys are subject to the following types of errors: coverage, nonresponse, sampling, and measurement (Groves, 1989). These kinds of errors result from the effect of the interviewers on the respondents' answers, the inability of some respondents to answer questions, language errors in the survey design, and the impact of the mode of data collection (Groves, 1989).

2.3.2.6 Functional Demonstration of Algorithms, Modeling and Simulation

Modeling is the process of establishing a model that represents a specific object, process, or phenomenon that is to be simulated. Simulation is defined as the process of executing a model (Petty, 2009). Petty (2009) stated that in modeling and simulation, validation is used to determine how accurately the model represents the object, process, or phenomenon. The validation of the model and simulation is one of the important aspects of completing a project. Dr. Carl T. Haas and the author categorized the methodology, “functional demonstration”, in this research. A functional demonstration is a common methodology that refers to the process or evidence that demonstrates that an algorithm or model works. For example, the model produces specific results. The researcher then changes some of the variables and observes the new results, which may happen to match what actually occurs in that specific situation. After calibration and completing additional tests, the model is finally completely validated. Functional demonstration thus represents validation with respect to logic, input, assumptions, and output. In the case of algorithms, functional demonstration shows that the algorithms works or is correct for a wide range of inputs.

One advantage of modeling and simulation is that the cost is lower than with empirical testing and trials (Burbank, Kasch, & Ward, 2011). On the other hand, however, a higher level of confidence in the validation results is always associated with empirical studies than with functional demonstration, or with functional demonstration over a wide enough set of inputs that the subsequent evaluation of functionality is essentially empirical.

2.3.2.7 Archival Data Analysis

Archival data analysis is also known as archival research. The goal is to discover and extract from original archival data the information that will be useful as evidence. Archival data refer to data that were created previously or that are collected concurrently but independently of the purpose of the research (Lucko & Mitchell, 2010). Sources of archival data may include private data sets, private records, and public data sets (Archival Data, 2010). Private data sets refer to data previously collected by other researchers or agencies for other studies or collected by the researcher himself/herself for a previous study. Researchers must obtain permission in order to access private data sets. In contrast, public data sets are collected differently: government agencies collect the data, and academic institutions make them available to the public. The intent of private record collection differs from that associated with either of the other two types of data. Private records are collected for an individual's own sake and include such items as student records, medical records, and credit histories. In CEM, this methodology is suitable for areas that may include but are not limited to productivity studies, safety studies, and hazard analysis (Lucko & Mitchell, 2010). The key to the successful application of this methodology in CEM is valid preparation of the data, which includes validating sample sizes, unifying the format, and reconstructing missing values (Lucko & Mitchell, 2010).

In CEM, archival data are not always consistent due to the lack of a standard data-collection format across companies (Mitchell, 1998). This weakness results in archival research being generally more complicated and time-consuming than library and internet research. Researchers must search through numerous documents in order to find materials relevant to their topics, and some documents might be restricted due to confidentiality issues (Lucko & Mitchell, 2010). However, if conducted successfully, each new archival data study can provide researchers with additional reliable information to support their findings.

2.3.2.8 Summary

In general, the literature contains numerous examples of validation methodologies. The difficulty lies in finding reports of validation methodologies in the context of CEM. Appropriate reports must be able to guide researchers or indicate trends in the utilization of a validation methodology within the rigour associated with the CEM community. Although the *Journal of Construction Engineering and Management* published by the American Society of Civil Engineers produced a special issue about the dialogue related to the rigorous application of methodologies in CEM, the focus was on research methodologies generally rather than specifically on validation methodologies. As well, the articles examined were limited to manuscripts that were published in the *Journal of Construction Engineering and Management*, which could result in biased final research results. The above literature review suggests the necessity of conducting a comprehensive study of the trends in CEM validation methodologies. As a brief summary, Table 2-2 presents a synthesis of the basic information related to CEM validation methodologies.

Table 2-2 Summary of CEM Validation Methodologies

Category of Validation Methodology	Features/Key Words	Advantages	Disadvantages
Experimental Studies	• Sets of experimental data • Statistical analysis • Grouping	• Scientific basis • Legitimacy • Ability to adjust if answers are inconclusive	• Possibility of bias • Relatively high cost • Safety concerns
Observational Studies	• Audio-visual technologies (e.g., cameras, videos, microphones) • Preset framework instead of randomization	• Actual performance and properties • Ease of use and low cost • First-hand information	• Lack of statistical properties • Extensive time required • Subjectivity of researchers • Ethical problems
Empirical Studies	• Model development and evaluation • Statistical analysis	• Insight into time-dependent behaviour • Freedom from theoretical frameworks	• Inability to be applied to complex problems • Extensive and time and cost
Case Studies	• Intensive analysis of a particular matter(s) • Demonstration of a particular facet of a specific topic	• Collection of details • Ease of conducting • Exploratory, constructive, and confirmatory	• Lack of rigorousness • Difficulty of generalizing from a single case • Difficult of determining a definite cause/effect
Survey	• Sampling • Data collection: telephone, mail (post), online surveys, etc.	• Convenient data collection • Possibility of statistical analysis • Low cost	• Errors resulting from respondents' inability to answer questions, poor language of designs, etc.

Table 2-2 Summary of CEM Validation Methodologies (Continued)

Category of Validation Methodology	Features/Key Words	Advantages	Disadvantages
Functional Demonstration	• Validation with respect to logic, input, assumptions, and output • Involvement of modeling and simulation, algorithms, machines or programs	• Low cost • Legitimacy	
Archival Data Analysis	• Archival data • Use for productivity studies, safety studies, hazard analysis, etc.	• Reliability • Data that are already collected	• Inconsistency • Extensive time required • Restricted access

2.4 Scientific Versus Business Validation

Scholarly validation is usually more rigorous and scientific than business validation. The methodologies associated with scientific validation require careful design and sound evidence based on a scientific process such as statistical analysis or hypothesis testing. Scholarly researchers are unable to draw conclusions until such a rigorous and scientific validation process is complete. In contrast, journalists and authors of some business and investment books are not required to undertake scientific or rigorous processes in order to validate their conclusions or main ideas. For example, they may easily demonstrate the validity of their books or articles by interviewing a few successful business people and then citing the conversation as proof of specific statements. They are not required to conduct any testing or analysis of the data in order to determine whether or not the approaches/statements are truly functional.

2.5 Engineering versus Management in Construction

The construction industry comprises five sectors: residential construction, commercial construction, heavy civil construction, industrial construction, and environmental construction (Jackson, 2010). Engineering and management are both key components of these sectors. However, construction engineering and construction management are completely different in many ways even though they can also overlap on occasion. This section introduces and compares construction engineering and construction management.

2.5.1 Construction Engineering

Engineering for construction, also known as construction engineering, involves the application of scientific and practical knowledge for the designing, planning, and construction of infrastructure such as highways, bridges, airports, railroads, buildings, dams, and utilities (Wikipedia, 2013).

At the educational level, knowledge about construction engineering is usually taught through a variety of civil engineering courses, such as engineering mechanics, engineering design, general science, and mathematics.

2.5.2 Construction Management

Construction management, also known as construction project management (CPM) is defined as “a professional management practice that is applied to construction projects from project inception to completion for the purpose of controlling time, cost, scope and quality” (CMAA, 2010). Construction management includes the overall planning, scheduling, coordination, and control from the very beginning to the end of a project. The knowledge required encompasses an understanding of construction and building, technology, public safety, customer resources, human resources, mathematics, etc. (Jackson, 2010).

Three concerns typically associated with CPM are time, cost, and quality. Focusing on these concerns, construction managers must estimate the time and cost of a project, administer the contract, manage the job site and construction operations, plan and schedule the project, monitor project performance, and manage project quality (Jackson, 2010).

2.5.3 Comparison of Engineering and Management with Respect to Construction

In construction, both engineering and management relate to construction topics but the focus, concerns, and method of dealing with problems varies greatly. Engineers concentrate on the correctness of specific projects, and their goal is to make predictions with certainty (Cerri, 2008). In construction, engineers concentrate on work such as the design of a construction site and on plans and drawings for transportation, oil and gas, construction site supervision, etc. In contrast, construction managers focus on the planning, scheduling, coordination, and control of a project from inception to completion. When addressing problems, construction engineers operate in a more straightforward manner than construction managers, who usually work and think in a “fuzzy” zone where the goal is the most optimal decision based on consideration of diverse possible circumstances. While construction engineers look at a problem and try to eliminate all uncertainties from the calculation, the variables construction managers employ are unpredictable, changeable, and uncertain (Cerri, 2008). The following simplified example illustrates the difference between a pure construction engineering perspective and a pure construction management viewpoint.

Example: Construct a roadway connecting City A to City B.

In the pure view of an engineering team, the construction of the road is determined as a function of several parameters. The output variable is the construction of a road that connects City A to City B, a goal that is quite straightforward. The basic input variables, which are considered parameters that the engineering team might take into account, are conditions related to landscape, traffic flows, materials and quality of materials, expected service life, and installation techniques.

In the pure view of a management team, three key issues in the construction of the roadway are time, cost, and quality. No simple functions are available for use by construction managers. Their goal is to construct the roadway within the shortest time, at the lowest cost, and with the highest quality. Of course, in reality, achieving all three goals simultaneously is impossible. The construction management team therefore attempts to develop several scenarios and then chooses one based on consideration of a variety of factors. The mitigation of the environmental and social impact is an additional essential factor to be addressed in the management of construction projects.

In the real world, successful construction projects are the result of neither the engineering side nor the management side alone. Only through a combination of both engineering and management perspectives can construction issues be effectively resolved.

2.6 Productivity in Construction Engineering and Management

The basic concept of labour productivity is relatively simple and is defined as the ratio of output to input. A number of the articles examined in order to identify validation methodologies for this research were directed at labour productivity because it represents a major CEM concern and is receiving increasing attention in the industry. Labour productivity is influenced primarily by practices, influencing factors, and technologies. This section provides a brief introduction to these three factors.

2.6.1 Practices

The practices discussed here were selected according to the Construction Industry Institute's (CII) *The Best Practices* (CII, 2010) and *CII Best Practices Productivity Improvement Index* (RT 252-c, 2010). Practices that are well known and we generally considered to positively influence productivity are also included here. This is a representative list instead of an exhaustive list. Brief descriptions of the ten categories of practices that influence labour productivity are presented in the next subsections.

2.6.1.1 Constructability

CII has defined constructability as "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives" (CII, 1986). The benefits of this practice include but are not limited to improving productivity, reducing the overall project cost, improving project security and safety, and enhancing project team relationships (CII, 2010).

2.6.1.2 Zero Accident Techniques

Zero accidents, also known as safety, is one of the most important drivers of improved labour productivity in CEM (CII, 2010). It includes site-specific safety programs along with implementation, auditing, and incentives for creating a safe environment that results in zero accidents (CII, 2010). The benefits of this practice include but are not limited to the protection of workers' health and lives as well as the reduction of insurance costs.

2.6.1.3 Resource Leveling

Resource leveling is a project management technique for making resource demands as smooth as possible given the daily availability of the resource. The benefits of this practice include the indirect reduction of the total cost through avoiding the hiring and firing of people on a short-term basis and through maintaining the original duration of the project as specified in the early schedule (Koulinas & Anagnostopoulos, 2012).Since it can also result in average longer term employment on a project, it is understood by many people as a way of improving productivity as well.

2.6.1.4 Alignment

Alignment refers to "the condition in which appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives" (CII, 2010). The major benefit of this practice is the assurance that project participants on the same team are working toward a common goal (CII, 2010). This is a known best practice for improving project cost, schedule and safety performance, but its impact on productivity is not known.

2.6.1.5 Knowledge Management

Knowledge management, which is similar to lessons learned, entails the effective management of the knowledge obtained from either successful or negative experience in order to improve future performance (CII, 2010). This practice facilitates the improvement of processes and procedures in a continual way and affords a strong advantage in a competitive industry (CII, 2010).

2.6.1.6 Risk Management

Risk management is used for measuring the impact of potential risks such as uncertain events or conditions that have a positive or negative effect on costs and time of the project in construction industry (Schatteman, Herroelen, Vonder, & Boone, 2006). It is one of the vital factors for success in construction projects. Effective risk management can protect projects against anticipated disruptions and increase the stability of project schedules. Therefore, it can have a significant impact on productivity.

2.6.1.7 Contract and Project Delivery

Project delivery means that an agency or owner enters into a legal agreement with one or more entities or parties in order to apply project management techniques to the organization and design of financial issues, construction, and operations and to the provision of maintenance services for a project (Wikipedia, 2011). Common methods of project delivery include Design-Bid-Build, Design-Build, Build-Operate-Transfer, and Turnkey Project Delivery. Impact of contract method on project performance has been studies but less on productivity.

2.6.1.8 Craft Training

In light of the fact that the construction industry relies on skilled craft workers, the goal of craft training is the development of such workers. Sources of craft training include apprenticeships, firm-sponsored training, community colleges and vocational-technical schools, and military training (Wang, Goodrum, Haas, & Glover, 2008). It is understood that better trained workers are more productive, all other things being equal.

2.6.1.9 Site Layout

Appropriate site layout planning, especially dynamic site layout planning, allows the project manager to improve the organization of the construction site (CII: Research Team 252, 2011). This process is usually conducted with the use of technology and software applications. An appropriate site layout unquestionably helps ensure the safety of the working environment and facilitates effective and efficient operation, and it can improve productivity.

2.6.1.10 Short-Term Scheduling

Short-Term, Scheduling indicates project schedules designed with intervals of one, two, or three weeks. Short-term scheduling helps contractors to maintain in-time control of the project and ensures that the project is on the right track with respect to the overall schedule. It is often neglected, yet it can have a significant impact on productivity.

2.6.2 Influencing Factors

This subsection introduces factors that affect labour productivity. Ten major factors have been selected and are described in the following subsections.

2.6.2.1 Adverse Weather

Adverse weather, such as temperature, humidity, snowfall, or the effects of high elevation, usually has a negative impact on construction productivity. In *Calculating Lost Labour Productivity in Construction Claims,* Schwartzkopf (2004) defined adverse weather as conditions created by natural forces that are detrimental to the construction of the project. Outside operations, particularly those that involve earthmoving or materials that are sensitive to temperature and weather (e.g., concrete and mortar), are especially likely to be affected by adverse weather (Schwartzkopf, 2004).

2.6.2.2 Craft Density

Each factor has an optimal level at which the effect on productivity is positive. When the incidence of a factor falls above that level, productivity is adversely affected by that factor. A high level of craft density is called trade stacking, or overcrowding. Trade stacking is always a concern for contractors: as the construction site grows crowded with numerous tradespeople, the workspace becomes congested. A simple overlapping of construction sequences does not normally cause labour productivity losses. Rather, it is the crowding of personnel in one particular work area that contributes to lost productivity (Schwartzkopf, 2004). In its *Modification Impact Evaluation Guide*, the U.S. Army Corps of Engineers (1979) states that crowding can be considered a form of acceleration because it requires the contractor either to accomplish a fixed amount of work within a shorter time frame, or to accomplish more work within a fixed time frame. In other words, project acceleration is one of the main causes of trade stacking. Other causes can include cramped workspaces, stored materials that impede work, and the performance of work out of sequence (Thomas, Riley, & Sinha, 2006).

2.6.2.3 Overmanning

Overmanning is the term most often applied when the number of men on a crew is above the optimum for a project, a situation that often causes productivity losses. The optimum number for a crew is defined as the minimum number of workers required to perform the task within the allocated time frame (The U.S. Army Corps of Engineers, July 1979). The number for each type of work depends on the technology being used. Increasing the number of craftsmen usually produces a higher cost unit as well as a greater rate of progress. This effect is in line with the economic theory of diminishing marginal utility. When additional workers are added beyond the optimum crew, each new worker increases crew productivity to a lesser extent than a previously added worker. Carried to the extreme, adding more workers eventually contributes nothing to overall crew productivity (The U.S. Army Corps of Engineers, July 1979). As well, the contractor's lack of awareness of the impact of overmanning may result in finger-pointing on the part of the estimating and execution teams (Hanna, Chang, Lackney, & Sullivan, 2005). The increased number of workers that result from overmanning also causes physical conflict, a high density of craftsmen, congestion, and lack of supervision. Shortages of materials, tools, and equipment might occur, and engineering questions or requests for clarification might not be provided in time due to the greater demand (Hanna, Chang, Lackney, & Sullivan, 2005). All the above effects of overmanning further increase labour productivity losses.

2.6.2.4 Overtime

Overtime is defined as the time worked beyond 40 hours per week. Overtime is frequently employed in the construction industry for a number of reasons (Schwartzkopf, 2004). First, it can be used to handle unexpected problems or to finish time-critical work. Second, it becomes necessary in order to address problems created by delays or project accelerations. It can also be used as an approach for attracting the required number of workers. Sometimes, it may be employed in order to take advantage of favourable weather or to maximize the use of equipment in cases when the payment of a premium for labour is less expensive than the cost of the equipment. It can also be implemented as a means of making full use of limited workspace. However, overtime can have a series of detrimental effects on costs, labour productivity, and labour efficiency. In this context, efficiency refers to the relative loss of productivity compared to a specific baseline (Thomas & Raynar, 1997). The reasons for this negative impact include the fatigue generated by the extended work hours, disruptions in the work environment, higher accident rates, poor work quality, the attraction of less qualified workers, and shortages of resources (Schwartzkopf, 2004).

2.6.2.5 Shift Work

Shift work is defined as hours worked by a separate group of workers whose work on a project begins after the first same-trade workforce to arrive has retired for the day (Hanna, Chang, Sullivan, &

Lackney, 2008). Because only a few studies focus on shift work, the nature of its impact on labour productivity remains a topic of debate among researchers. Generally, the type of work involved, the scheduling, and the project type have a significant effect on whether shift work causes productivity losses (Schwartzkopf, 2004). CII conducted a research project related to this topic in 1988 but failed to reach a conclusion because the sample size was too small (Construction Industry Institute, 1988). A study conducted by Hanna, Chang, et al. showed that shift work has the potential to be both beneficial and detrimental with respect to construction labour productivity (Hanna, Chang, Sullivan, & Lackney, 2008). The authors developed a model for quantifying productivity losses and concluded that the change in productivity ranges from a gain of 11 % to a loss of 17 %, depending on the amount of shift work involved. The model was validated with the use of the cross-validation method, and the model results are quite similar to those determined by Waldron (Waldron, 1968).

2.6.2.6 Change Orders

A change is defined as a modification in the original scope of work, in the contract schedule, or in the cost of the work. A change order is considered a formal modification that incorporates a change into the contract (Schwartzkopf, 2004). Changes can arise for a number of reasons, such as a change in scope caused by user amendments, schedule delays, or an incomplete design. Changes are normal and expected in construction, with a range that typically varies from 6 % to 10 % being considered reasonable (Committee on Construction Change Orders, Building Research Board, National Research Council, 1986). When a change occurs, it has two major effects: a cost impact and a schedule impact (Schwartzkopf, 2004). However, whether labour productivity is impacted by change orders depends on a number of variables, including whether a project is mostly civil, mechanical or electrical, the percentage of the changes, and the estimated manpower compared to the actual peak manpower (Hanna, Camlic, Peterson, & Nordheim, 2002).

2.6.2.7 Absenteeism

Absenteeism is defined as the failure of craftsmen to appear for work for reasons other than holidays or vacations. There are two types of absenteeism: voluntary and involuntary (Hanna, Menches, Sullivan, & Sargent, 2005). Both types have an adverse impact on productivity. Absenteeism can be caused by several factors, one of which is a long commute (Ommeren & Gutiérrez-i-Puigarnau, 2009). Ommeren and Gutiérrez-i-Puigarnau (2009) conducted empirical tests and concluded that worker absenteeism was negatively affected by the length of the commute, with a significance level of 1 %.

Other top reasons for absenteeism include illnesses, medical appointments, lack of interest or responsibility, an unsafe working environment, poor supervision, excessive overtime, and poor overall management (Hanna, Menches, Sullivan, & Sargent, 2005).

2.6.2.8 Learning Curves

Also known as an experience curve, a learning curve is often described as the amount by which the labour input, such as the number of man-hours required to perform a repetitive activity, decreases with the number of repetitions (Schwartzkopf, 2004). Learning curves are applicable primarily with respect to unit price contacts, for example, for highway projects or other heavy construction work. Thomas defined a learning curve as a graph of proficiency versus practice (Thomas H. R., 2009).

2.6.2.9 Equipment Availability

Equipment availability is directly related to the amount of waiting or idle time that results in labour productivity losses as measured by activity analysis work sampling. Although studies of the relationships between equipment availability and productivity are few, similar research conducted in manufacturing may apply. Rivas et al. (2011) conducted a case study for which they circulated a set of questionnaires to both direct workers and mid-level employees at a Chilean construction company. The survey results showed that the factors that most influenced labour productivity include materials, tools, design interpretation, equipment, and trucks. The survey indicated that waiting for materials, tools, design interpretation, equipment, and trucks represented 59 % of the total waiting time and that because the waiting time was so long, workers lacked the coordination they needed to work together as a team (Rivas, Borcherding, González, & Alarcón, 2011). These findings are consistent with those of Alarcón and Calderón (2003) in their study conducted in the U.S. Dai and Goodrum and Dai et al. (2009) also indicated that construction equipment was the top factor that affects construction labour productivity.

2.6.2.10 Availability of Materials

Productivity is adversely affected when materials are unavailable for craft workers. Five typical materials management conditions that may have an adverse impact on productivity include the organization of storage areas, housekeeping, the planning of materials delivery, the availability of materials, and the handling and distribution of materials (Thomas, Sanvido, & Sanders, 1989). Thomas et al. (1989) also indicated that the problem of the unavailability of materials generally has three causes: running out of materials, crew slowdowns in anticipation of shortages in materials, and rework when materials arrive.

2.6.3 Technology

It is obvious that advanced technology, such as a faster nail gun, more flowable concrete, or automated materials tracking, can improve productivity based on ease of use. In this subsection, three classes of advances in technology are introduced: information technology (IT), materials, and tools and equipment.

2.6.3.1 Information Technology

Despite little evidence, it is reasonable to believe that IT may eventually have a significant net positive impact on construction projects. Wood & Alvarez (2005) predicted that the field of construction would be more "intelligent and integrated" in the future because materials, tools, equipment, and people would gradually become elements of a fully sensed and monitored environment. Hazardous and labour-intensive manual tasks will become more efficient and less troublesome through the automation of construction processes. However, one result will also be a large volume of data that must be processed and shared across multiple systems (Zhai, Goodrum, Haas, & Caldas, 2009).

2.6.3.2 Advances in Materials

In 2009, the CII Research Team 252 (RT 252) developed innovative materials, including modular pipe supports, quick pipe-coupling systems, and quick steel-connection systems (CII: Research Team 252, 2009). In 2011, RT 252 analyzed another three significant concrete innovations: self-consolidating concrete, modular formwork, and Grade 100 steel reinforcement (CII: Research Team 252, 2011). According to the RT 252 (2009) summary report, an exceptional innovation such as quick pipe-coupling systems can help solve typical project problems related to redoing the piping, which can account for as much as 13.3 % of the total cost. Such innovations can significantly improve productivity and make an enormous difference with respect to the success of a project.

2.6.3.3 Advances in Tools and Equipment

Innovations in tools and equipment are proliferating. Examples of popular items in this area include automated earthmoving equipment and automated crane control and monitoring. RT 252 (2009) indicated that mechanical innovations can substantially improve productivity. The data in the RT 252 summary report (CII: Research Team 252, 2009) demonstrated that "stakeless" earthmoving improves productivity by 50 %. Other advanced equipment techniques include 2D/3D laser scanning, GPS, and a visual tracking algorithm for cranes. Tools advances improve productivity by delivering more power, functional range, and mobility, while reducing weight and vibrations.

2.7 Meta-Analysis

As mentioned in section 2.2, meta-analysis is very popular among researchers in the fields of education, human resources management, medical science, physics, and psychology. However, potential CEM applications of meta-analysis remain largely unexplored. In this section, the definition of meta-analysis, the associated procedures, its advantages and disadvantages and one existing CEM example are reviewed.

2.7.1 Definition of Meta-Analysis

Any individual topic is often the focus of numerous studies and papers. Researchers usually conduct a traditional literature review, which is similar to a summary of previous research in the area of investigation. This kind of traditional literature review can serve only as a background study since it lacks intensive analysis and scientific proof that indicate the confidence level of the conclusion. In contrast, meta-analysis requires the careful collection of a wide range of data and their intensive statistical analysis. Researchers can then obtain a synthesized review. Glass (1976) defined meta-analysis as "the analysis of analyses," which refers to the systematic statistical analysis of a number of individual results from studies conducted in the same area and for the same purpose.

2.7.2 Meta-Analysis Procedures

Meta-analysis involves several procedures. First, researchers must be clear about the research question, based on which they set the criteria for the selection of studies and then search the relevant literature manually or by computer, or both. After the studies have been discovered, the next step, and one of the most important, is a homogeneity test. To illustrate the concept of this type of test, another term must first be understood: effect size. Effect size refers to the degree to which the null hypothesis is false (Cohen, 1977). In other words, if the effect size index is 0, the conclusion is that the difference between the control group and the experimental group (with treatment) is insignificant, which is undesirable. To synthesize individual studies quantitatively through meta-analysis, each study selected must provide a sample estimate with an effect size representative of the population effect size (Wolf, 1986). The goal of the homogeneity test is to determine whether all of the individual studies are actually evaluating the same hypothesis; i.e., all of the individual studies must provide a common (homogeneous) estimate of the effect size. The last step is to synthesize all of the individual results. Figure 2-1 provides a summary of the procedures.

2.7.3 Advantages and Disadvantages

The advantages and disadvantages of meta-analysis are described below.

2.7.3.1 Advantages

Meta-analysis offers a quantitative method that enables researchers to analyze past studies. Its primary advantages can be summarized as follows:

- Efficiently summarizes a large collection of independent studies (Green & Hall, 1984)
- Provides stronger, more reliable, and more objective conclusions than those provided through traditional literature reviews (Wolf, 1986)
- Highlights gaps in the literature and provides insight into new research directions (Green & Hall, 1984)
- Indicates the presence of bias in a publication (Green & Hall, 1984)
- Reveals possible/potential interactional relationships or trends (Green & Hall, 1984)

2.7.3.2 Disadvantages

No research method is without critics, and because it relies on past studies, meta-analysis also has limitations. The main disadvantages are as follows (Glass G. V., 1981):

- Mixing "apples and oranges": Researchers may find that they are attempting to compare and aggregate studies that include different measuring techniques, definitions of variables, and subjects.
- File drawer problem: Meta-analysis relies heavily on published studies, but studies that show insignificant results are usually unpublished, thus creating an inherent bias in meta-analysis results.
- Lack of consistent quality: Poorly designed studies may be mixed with well-designed studies.

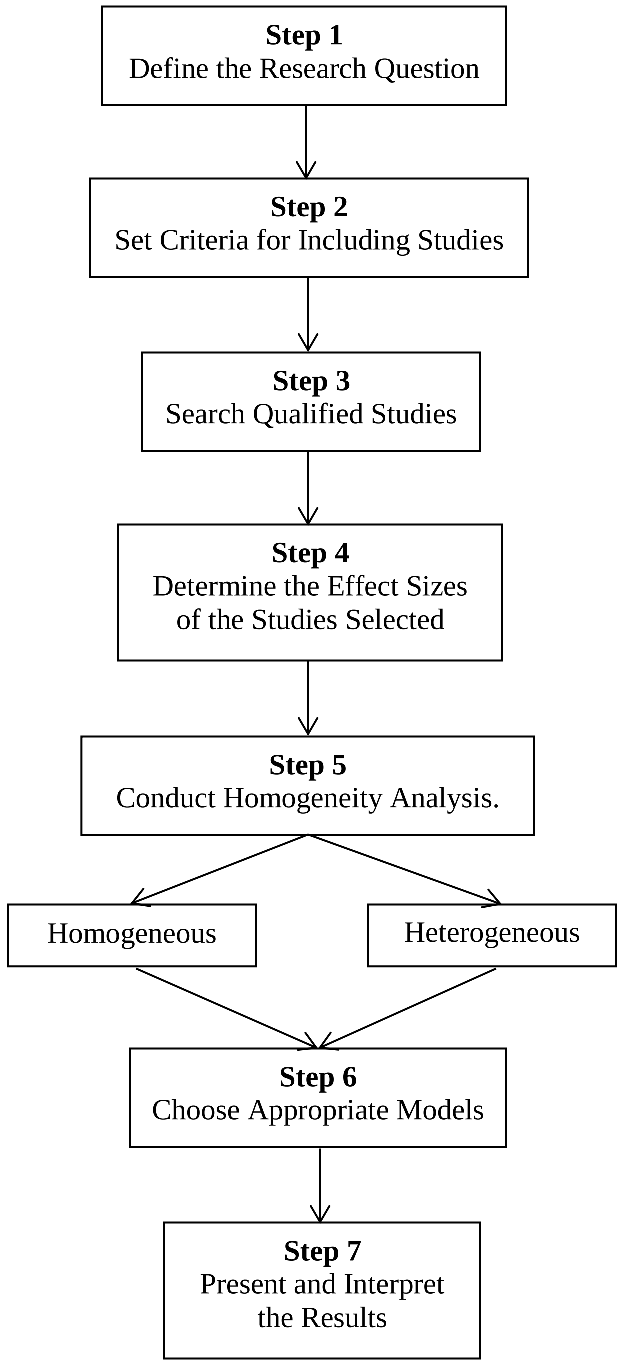

Figure 2-1 Meta-Analysis Procedures

2.7.4 The Only Known Example of Meta-Analysis in CEM

We didn't find out any articles reporting Meta-Analysis methodology in the selected categories. Meanwhile, we didn't conduct meta-analysis for the thesis, because we were not able to find adequate number of qualified studies in any categories. In later chapters, we'll explain the reasons in detail.

The only successful example of meta-analysis we have ever seen in CEM was the one conducted by Horman and Kenley (2005). The researchers provided a synthesis of the findings across all the studies that focused on topics of wasted time in construction activities by applying the methodology of meta-analysis. The meta-analytic method adopted consists of search, coding, and statistical procedures. The information regarding 18 manuscripts with 24 relevant studies was collected and coded. The conclusion that the proportion of available time used in wasteful activity was 49.6% at a standard deviation of 11.9% was drawn via statistical analysis of the collected information.

Outside areas of CEM, good examples of meta-analysis can be found in the book Bad Science (Goldacre, 2010). In the book, the author teaches readers how to evaluate placebo effects, double-blind studies, and sample size by conducting meta-analysis, so that the audience can recognize bad science when they see it. These examples can help us better understand Meta-Analysis methodology.

2.8 Search Engines

A major component of the research presented in this thesis was to search for as many qualified papers as possible in order to obtain a large sample for the analysis of the validation methodologies. One of the most efficient methods is to use search engines, which are information retrieval systems designed to help people find information stored on a computer system (Wikipedia, 2013). Databases such as Scopus and the one maintained by the American Society of Civil Engineers are quite useful for CEM researchers who wish to search journal papers, conference papers, etc. University library systems are also helpful for finding related books or articles.

2.9 Summary

This chapter has introduced and reviewed the available information related to validation methodologies, engineering and management as related to construction, three classes of sources of influence on labour productivity, and the basics of meta-analysis and search engines. Based on the entire literature review, it appears that researchers lack quantification with respect to dominant CEM validation methods. Justifying and improving current validation approaches in this field are thus imperative.

Chapter 3
Methodology of the Research

3.1 Introduction

To collect data related to CEM validation methodologies, analysis tables of methodologies were carefully designed, and the papers to be examined were carefully selected. This chapter describes the development of the table structure and the method of classifying the articles.

3.2 Structural Design of the Analysis Tables

3.2.1 Columns

Each analysis table was designed to have four main columns: the sequence number of the paper, the year of publication, the code name of the article, and the methodologies included.

3.2.1.1 The Sequence Number of Papers

Sequencing papers in an appropriate order always results in a clear, logical analysis. The papers examined for each specific topic are sequenced in reverse chronological order. In other words, the newest publication is positioned at the top of the analysis table and assigned the number 1. The total number of papers examined is thus easy to ascertain. The sequence number is also an important component of the "Code Name" column, as explained in subsection 3.2.1.3. The sequence number column is headed "#" in the table.

3.2.1.2 Year of Publication

Domain validation methodologies may vary yearly. It was important to collect details about the publication dates so that variations in the percentage of each methodology during specific periods can be analyzed. The "Year" column also serves as the basis of the ordering of the sequence numbers of the papers listed in the # column.

3.2.1.3 Code Name of Each Article

Each article examined was given a unique two-part code name. The first part is the abbreviation of the category. The index of abbreviations for each category is introduced in subsection 3.2.2. The second part is the sequence number of the article mentioned above. For example, "CN" is the abbreviation for "Constructability." If the paper belongs to the Constructability category and its sequence number is 1, its code name is CN-1. Coding names for articles provides two advantages: convenience and neatness. First, the codes make it easy and convenient for readers to recognize the category to which the article belongs. Second, coding saves space in the table. The rather long titles of some articles would require additional rows, which would render the table unreadable.

3.2.1.4 Validation Methodologies

The validation methodologies column consists of 8 sub-columns: one each for the seven common types of validation methodologies and a last sub-column designated "Other." The common types represented by the first seven headings have been introduced in section 2.3: Experimental Studies, Observational Studies, Empirical Studies, Case Studies, Surveys, Functional Demonstrations, and Archival Data Analysis. The Other sub-column is used to indicate any methodologies outside of the first seven. The information about each methodology matches that presented in Table 2-2. If the methodology has been applied in the study described in the article examined, a 1 is entered in the corresponding cell. Otherwise, the corresponding cell is left blank. It's possible that some articles are applied more one validation methodology. In this case, we are allowed to enter 1 in multiple corresponding cells.

3.2.2 Categories of Sources

As mentioned in section 2.6, the papers examined are from three main categories of sources: practices, factors, and technologies.

The practices category includes 10 sub-categories: constructability, zero accident techniques, resource leveling, alignment, knowledge management, risk management, contract and project delivery, craft training, site layout, and short-term scheduling. Introductions to these sources have been presented in subsection 2.6.1.

The category indicating factors that can adversely affect productivity is for denoting papers related to factors such as adverse weather, craft density, overmanning, etc. Information about this category can be found in subsection 2.6.2.

The technologies category includes papers related to information technology, advances in materials, and advances in tools and equipment. Details about this category are provided in subsection 2.6.3.

To facilitate the coding of each article, each category was given a unique abbreviation according to the index shown in Table 3-1.

Table 3-1 Index of Category Abbreviations

Name of Category	**Abbreviation**
Constructability	CN
Zero Accident Technique	ZA
Resource Leveling	RL
Alignment	AL
Knowledge Management	KM
Risk Management	RM
Contract and Project Delivery	CP
Craft Training	CT
Site Layout	SL
Short-Term Scheduling	SS
Factors	FC
Technologies	TC

To illustrate the structure of the analysis tables, an example related to the analysis table for the Constructability category is shown as Table 3-2.

3.3 Principles of the Application of the Validation Methodology Classifications

The crucial element of this research was to determine which validation methodology or methodologies had been applied, as reported in the article. To enable a rigorous analysis, the following principles served as guidelines:

- Be clear about the definition of each methodology.
- Understand the features of each methodology.
- Examine each article and analyze its structure.
- Match the characteristics of the methodology described in the article to the features of a particular methodology.

The first step was to acquire an understanding of validation methodologies, which have been introduced in section 2.3. Table 3-3 highlights the features of each validation methodology. To determine the type of validation methodology reported in each article, after the examination of each paper selected, the characteristics of the validation methodology described in the article were analyzed and compared with the information listed in Table 3-3. 20% of examined papers were classified with Dr. Carl T. Haas to confirm that the determination of the types of validation methodology was not overly subjective.

Table 3-2 Example of the Constructability Analysis Table

#	Year	Code Name	Validation Methodologies (If applicable, enter 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstrations	Archival Data Analysis	Others
1	2012	CN-1								
2	2010	CN-2								
3	2009	CN-3								
…	…	…								
N	1985	CN-N								

Table 3-3 Features of Each Validation Methodology

Category of Validation Methodology	Features/Key Words	Category of Validation Methodologies	Features/Key Words
Experimental Studies	• Sets of experimental data • Statistical analysis • Grouping	Survey	• Sampling • Data collection: telephone, mail (post), online surveys, etc.
Observational Studies	• Audio-visual technologies (e.g., cameras, videos, microphones) • Pre-set framework instead of randomization	Functional Demonstration	• Validation with respect to logic, input, assumptions, and output • Modeling and simulation, algorithm, machine, or program
Empirical Studies	• Model/hypothesis development and evaluation • Statistical analysis of empirical data	Archival Data Analysis	• Archival data from past studies • Usually productivity studies, safety studies, hazard analysis, etc.
Case Studies	• Intensive analysis of a particular matter • Demonstration of a particular facet of a specific topic	Other	

Chapter 4
Characterization of Research Practices

4.1 Introduction

This chapter presents analysis tables that contain data collected for each category. For each analysis table, one or two examples of the analysis process are also provided so that readers will acquire a better understanding of the classification principles mentioned in section 3.3.

4.2 Analysis Tables

4.2.1 Constructability Analysis Table

4.2.1.1 Introduction

For the Constructability category, 43 papers were examined. The time period associated with the articles ranges from 1986 to 2012. The topics include such areas as the impact of constructability on productivity, how to improve constructability, and barriers to constructability.

4.2.1.2 Analysis Process

The first step is to arrange the articles in reverse chronological order and to assign code names. Based on Table 3-1, the abbreviation for this category is CN, so the code names for this category all begin with CN. The index of code names for each article in this category is presented in Table 4-1.

Article CN-25 serves as an illustration of the process of analyzing the validation methodologies in this category. The first requirement is to understand the main idea of the article. The authors conducted research to discover ways to decrease the duration of construction projects without increasing the costs. They modeled and analyzed the effects of constructability reviews on the design phase, the construction phase, and the project duration. The results revealed that managing constructability reviews can help reduce the duration of highway projects. The second task was to scan the article to find the validation part of the research. In this paper, the section entitled “Model Testing and Behaviour” can be considered the description of the validation of the model. The authors validated the model from three perspectives: 1) structural similarity to the actual system; 2) reasonable behaviour over a wide range of input values; and 3) behavioural similarity to actual systems. The test results for all of these aspects were positive, which confirmed the validity of the model. An examination of Table 3-3, which lists the features of each validation methodology, shows that the characteristics of the methodology the authors described in their paper match the features of Functional Demonstration; 1) logic, input, and output and 2) validation for a specific model. After the validation methodology has been identified, the last step is to enter a 1 in the cell corresponding to that methodology.

The complete analysis table for the Constructability category is presented as Table 4-2. The rows shaded in grey indicate articles whose authors did not appear to apply rigorous validation methodologies.

Table 4-1 Code Name Index for the Constructability Category

#	Year	Article Title	Code Name
1	2012	Analysis and Measurement of Buildability Factors Influencing Rebar Installation Labour Productivity of In Situ Reinforced Concrete Walls	CN-1
2	2012	Change Orders and Lessons Learned: Knowledge from Statistical Analyses of Engineering Change Orders on Kentucky Highway Projects	CN-2
3	2012	A Design Structural Matrix Approach Displaying Structural and Assembly Requirements in Construction: A Timber Case Study	CN-3
4	2011	Factors Affecting Construction Labour Productivity in Kuwait	CN-4
5	2011	Analysis of the Higher Order Partial Correlation Between CII Best Practices and Performance of the Design Phase in Fast Track Industrial Projects	CN-5
6	2011	Effect of Temporary Shoring Location on Horizontally Curved, Steel, I-Girder Bridges during Construction	CN-6
7	2011	Performance Measurement Approach to Contracting and Delivering Design Services	CN-7
8	2011	A Compendium of Buildability Issues from the Viewpoints of Construction Practitioners	CN-8
9	2010	Spatio-Temporal Analysis for Improving Constructability of Transportation Projects	CN-9
10	2010	Tolerance and Constructability of Soldier Piles in Slurry Walls	CN-10
11	2010	Organizational Divisions in BIM-Enabled Commercial Construction	CN-11
12	2010	Impact of Employee, Management, and Process Issues on Constructability Implementation	CN-12
13	2009	"Lean" Comparison Using Process Charts of Complex Seismic Retrofit Projects	CN-13
14	2009	Early Contractor Involvement in Design and Its Impact on Construction Schedule Performance	CN-14
15	2008	Case Study and Statistical Analysis of Utility Conflicts on Construction Roadway Projects and Best Practices in Their Avoidance	CN-15

Table 4-1 Code Name Index for the Constructability Category (Continued)

#	Year	Article Title	Code Name
16	2007	Constructability Rankings of Construction Systems Based on the Analytical Hierarchy Process	CN-16
17	2006	Project Designers' Role in Improving Constructability of Indonesian Construction Projects	CN-17
18	2006	Constructability Practices to Manage Sustainable Building Knowledge	CN-18
19	2005	Constructability State of Practice Report	CN-19
20	2005	Organizing Constructability Knowledge for Design	CN-20
21	2005	Building Better: Technical Support for Construction	CN-21
22	2004	Providing Cost and Constructability Feedback to Designers	CN-22
23	2004	A Review of Constructability Barriers and Issues in Highway Construction	CN-23
24	2004	POST: Product Oriented Scheduling Technique for Constructability Analysis	CN-24
25	2004	Managing Constructability Reviews to Reduce Highway Project Durations	CN-25
26	2004	Component State Criteria Representation to Incorporate Construction Program Knowledge for Constructability Analysis	CN-26
27	2002	Constructability Analysis in the Design Firm	CN-27
28	2001	Benefits of Constructability on Construction Projects	CN-28
29	1994	Model for Constructability Approach Selection	CN-29
30	1994	Barriers to Constructability Implementation	CN-30
31	1994	Constructability Related to TQM, Value Engineering, and Cost/Benefits	CN-31
32	1994	Constructability Programs: Method for Assessment and Benchmarking	CN-32
33	1993	Project-Level Model Process for Implementing Constructability	CN-33
34	1993	Fossil Power Plant Constructability: Applications of CII Concepts	CN-34
35	1993	Documented Constructability Savings for Petrochemical-Facility Expansion	CN-35
36	1993	Comparison of Two Corporate Constructability Programs	CN-36
37	1991	Factors Affecting Masonry-Labour Productivity	CN-37
38	1991	Constructability and Constructability Programs: White Paper	CN-38
39	1988	Constructability Improvement During Field Operations	CN-39
40	1987	Constructability Concepts for Engineering and Procurement	CN-40
41	1987	Designing Plans for Constructability	CN-41
42	1986	Industrial Project Constructability Improvement	CN-42
43	1986	Impacts of Constructability Improvement	CN-43

Table 4-2 Analysis Table for the Constructability Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2012	CN-1			1					
2	2012	CN-2			1					
3	2012	CN-3								
4	2011	CN-4								
5	2011	CN-5					1		1	
6	2011	CN-6						1		
7	2011	CN-7				1				
8	2011	CN-8								
9	2010	CN-9				1				
10	2010	CN-10				1				
11	2010	CN-11								
12	2010	CN-12								
13	2009	CN-13								
14	2009	CN-14						1		
15	2008	CN-15				1				
16	2007	CN-16								
17	2006	CN-17					1			
18	2006	CN-18				1				
19	2005	CN-19								
20	2005	CN-20				1				
21	2005	CN-21								
22	2004	CN-22								

Table 4-2 Analysis Table for the Constructability Category (Continued)

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
23	2004	CN-23								
24	2004	CN-24								
25	2004	CN-25						1		
26	2004	CN-26								
27	2002	CN-27			1					
28	2001	CN-28					1			
29	1994	CN-29						1		
30	1994	CN-30					1			
31	1994	CN-31								
32	1994	CN-32	1							
33	1993	CN-33								
34	1993	CN-34								
35	1993	CN-35				1				
36	1993	CN-36								
37	1991	CN-37			1					
38	1991	CN-38								
39	1988	CN-39								
40	1987	CN-40								
41	1987	CN-41								
42	1986	CN-42								
43	1986	CN-43								

4.2.2 Zero Accident Techniques Analysis Table

4.2.2.1 Introduction

For the Zero Accident Techniques category, 37 papers were examined. The time period ranges from 1991 to 2012. This category includes topics such as the cost of construction injuries, safety management, and the difficulties of implementing safety practices.

4.2.2.2 Analysis Process

Since, according to Table 3-1, the abbreviation for this category is ZA, the code names for this category all start with ZA. The code name index for this category is presented in Table 4-3.

To illustrate the process of analyzing the validation methodologies for this category, article ZA-29 was chosen as an example. The authors of this article described the adaptation process of a case-based reasoning (CBR) approach for the identification of construction safety hazards, with the goal of utilizing past knowledge in the form of previous cases related to the identification and incidence of hazards in order to improve the efficiency and quality of the identification of new hazards. The authors also proposed a three-step adaption process for hazard identification. In this paper, the section called "Case Study" was considered to be the description of the validation of the adaptation mechanism. The authors utilized real data from the LTA and from the Mine Safety and Health Administration and then conducted intensive analysis, following which they concluded that the feasibility of the proposed adaptation techniques had been validated. Based on Table 3-3, the characteristics of the methodology applied by the authors match those of the Case Study methodology. The matching features include 1) the intensive analysis of a particular matter and 2) the demonstration of a particular facet of a specific topic.

The complete analysis table for the Zero Accident Techniques category is presented as Table 4-4. The rows shaded in grey indicate articles in which the authors didn't apply rigorous validation methodologies.

Table 4-3 Code Name Index for the Zero Accident Techniques Category

#	Year	Article Title	Code Name
1	2012	Off-Site Construction of Apartment Buildings	ZA-1
2	2012	Integrative Model for Quantitative Evaluation of Safety on Construction Sites with Tower Cranes	ZA-2
3	2012	Implementation of BBS and the Impact of Site-Level Commitment	ZA-3
4	2011	Developing a Versatile Subway Construction Incident Database (SCID) for the Safety Management	ZA-4
5	2011	Near Real-Time Motion Planning and Simulation of Cranes in Construction: Framework and System Architecture	ZA-5
6	2011	Political Skill for Developing Construction Safety Climate	ZA-6
7	2011	RFID-Based Real Time Locating System for Construction Safety Management	ZA-7
8	2011	Empirical Study to Investigate the Difficulties of Implementing Safety Practices in the Repair and Maintenance Sector in Hong Kong	ZA-8
9	2011	Design and Implementation of Hazard Management Information System for an ATM Based on B/S Mode	ZA-9
10	2011	Construction Safety in Design Process	ZA-10
11	2011	Use of Safety and Lean Integrated Kaizen to Improve Performance in Modular Homebuilding	ZA-11
12	2011	Using Workforce’s Physiological Strain Monitoring to Enhance Social Sustainability of Construction	ZA-12
13	2011	Interrelationships among Highly Effective Construction Injury Prevention Strategies	ZA-13
14	2011	Development and Implementation of a GIS-Based Safety Monitoring System for Hydropower Station Construction	ZA-14
15	2011	“Safety4Site” Commitment to Enhance Jobsite Safety Management and Performance	ZA-15
16	2010	Population and Initial Validation of a Formal Model for Construction Safety Risk Management	ZA-16
17	2010	Risk-Based Framework for Safety Investment in Construction Organizations	ZA-17
18	2010	Fostering a Strong Construction Safety Culture	ZA-18
19	2010	Localizing and Designing Computer-Based Safety Training Solutions for Hispanic Construction Workers	ZA-19
20	2010	The Relationship between the Maturity of Safety Management Practices and Performance	ZA-20
21	2010	System Dynamics Modeling of a Safety Culture Based on Resilience Engineering	ZA-21
22	2010	Interrelationships among Construction Injury Prevention Strategies: A Cross-Impact Analysis	ZA-22

Table 4-3 Code Name Index for the Zero Accident Techniques Category (Continued)

#	Year	Article Title	Code Name
23	2010	Health and Safety Management within Small- and Medium-Sized Enterprises (SMEs) in Developing Countries: Study of Contextual Influences	ZA-23
24	2010	Construction Safety in Kuwait	ZA-24
25	2009	Development and Initial Validation of Sustainable Construction Safety and Health Rating System	ZA-25
26	2009	Establishment of Construction Safety Early-Warning System for Mountainous Freeways	ZA-26
27	2009	Human Factors Analysis Classification System Relating to Human Error Awareness Taxonomy in Construction Safety	ZA-27
28	2009	Construction Safety Risk Mitigation	ZA-28
29	2009	Case-Based Reasoning Approach to Construction Safety Hazard Identification: Adaptation and Utilization	ZA-29
30	2009	Framework for Measuring Corporate Safety Culture and Its Impact on Construction Safety Performance	ZA-30
31	2009	Pro-Active-Real-Time Personnel Warning System	ZA-31
32	2007	Design, Development, and Deployment of a Rapid Universal Safety and Health System for Construction	ZA-32
33	2006	Safety Management in Construction: Best Practices in Hong Kong	ZA-33
34	2006	Case for Drug Testing of Construction Workers	ZA-34
35	2005	Increasing Engineers' Role in Construction Safety: Opportunities and Barriers	ZA-35
36	2004	Safety Constructability: Designer Involvement in Construction Site Safety	ZA-36
37	1991	Costs of Construction Injuries	ZA-37

Table 4-4 Analysis Table for the Zero Accident Techniques Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2012	ZA-1				1				
2	2012	ZA-2	1					1		
3	2012	ZA-3								
4	2011	ZA-4								
5	2011	ZA-5						1		
6	2011	ZA-6			1		1			
7	2011	ZA-7				1				
8	2011	ZA-8								
9	2011	ZA-9								
10	2011	ZA-10							1	
11	2011	ZA-11				1				
12	2011	ZA-12	1							
13	2011	ZA-13					1			
14	2011	ZA-14				1				
15	2011	ZA-15								
16	2010	ZA-16				1				Delphi
17	2010	ZA-17				1				
18	2010	ZA-18								
19	2010	ZA-19				1				
20	2010	ZA-20				1	1			
21	2010	ZA-21								

Table 4-7 Analysis Table for the Zero Accident Techniques Category (Continued)

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
22	2010	ZA-22								
23	2010	ZA-23					1			
24	2010	ZA-24								
25	2009	ZA-25			1		1			
26	2009	ZA-26				1				
27	2009	ZA-27								
28	2009	ZA-28								
29	2009	ZA-29				1				
30	2009	ZA-30								
31	2009	ZA-31					1			
32	2007	ZA-32				1				
33	2006	ZA-33					1			
34	2006	ZA-34				1				
35	2005	ZA-35								
36	2004	ZA-36								
37	1991	ZA-37								

4.2.3 Resource Leveling Analysis Table

4.2.3.1 Introduction

For the Resource Leveling category, 27 papers from 1989 to 2012 were examined. Topics in this category cover areas such as how to optimize resource leveling, algorithms for resource leveling, and cost efficiencies regarding resource leveling. Typically, the authors of most papers validated that the levelling made the cost of projects cheaper and the projects go faster.

4.2.3.2 Analysis Process

From Table 3-1 the abbreviation for this category is RL, so the code names for this category start with RL. The code name index for this category is presented in Table 4-5.

Article RL-16 is an example that illustrates the process of analyzing the validation methodologies of this category. The authors presented a permutation-based elitist genetic algorithm. It was described as an efficient optimal solution algorithm for project networks with 60 activities or more. The algorithm also overcame the drawbacks associated with exact solution approaches for large-sized project networks. In this paper, the "Computational Experiments" section presented the validation of the generic algorithm. The authors ran computational experiments to demonstrate the performance of the proposed algorithm, including an assessment of the effects of the parameters on its performance and a comparison of its results with those of the well-known optimum and lower bound solutions. The authors analyzed the results statistically and proved the accuracy of the algorithms. Based on Table 3-3, the characteristics of the methodology applied match the features of Experimental Studies: 1) sets of experiments and 2) statistical analysis.

The complete analysis table for the Resource Leveling Category is presented as Table 4-6. The rows shaded in grey indicate articles whose authors didn't apply rigorous validation methodologies.

Table 4-5 Code Name Index for the Resource Leveling Category

#	Year	Article Title	Code Name
1	2012	Simulation-Based Auction Protocol for Resource Scheduling Problems	RL-1
2	2011	Construction Resource Allocation and Leveling Using a Threshold Accepting Based Hyper-heuristic Algorithm	RL-2
3	2011	Heuristic Method for Satisfying Both Deadlines and Resource Constraints	RL-3
4	2011	Cost Optimization Model for the Multi-Resource Leveling Problem with Allowed Activity Splitting	RL-4

Table 4-5 Code Name Index for the Resource Leveling Category (Continued)

#	Year	Article Title	Code Name
5	2011	Multi-Objective Optimization of Resource Leveling and Allocation During Construction Scheduling	RL-5
6	2011	Efficient Hybrid Genetic Algorithm for Resource Leveling via Activity Splitting	RL-6
7	2011	Integrating Efficient Resource Optimization and Linear Schedule Analysis with Singularity Functions	RL-7
8	2011	A Fuzzy Enabled Hybrid Genetic Algorithm-Particle Swarm Optimization Approach to Solve Time-Cost-Resource Optimization Problems in Construction Project Planning	RL-8
9	2010	Minimum Moment Method for Resource Leveling Using Entropy Maximization	RL-9
10	2010	Scheduling Resource-Constrained Projects with Ant Colony Optimization Artificial Agents	RL-10
11	2010	Comparing Schedule Generation Schemes in Resource-Constrained Project Scheduling Using Elitist Genetic Algorithm	RL-11
12	2010	Optimizing Resource Utilization during the Recovery of Civil Infrastructure Systems	RL-12
13	2009	Optimizing Resource Leveling in Construction Projects	RL-13
14	2009	Stochastic Time-Cost-Resource Utilization Optimization Using Non-Dominated Sorting Genetic Algorithm and Discrete Fuzzy Sets	RL-14
15	2009	Simulation Approach to Evaluating Cost Efficiency of Selective Demolition Practices: Case of Hong Kong’s Kai Tak Airport Demolition	RL-15
16	2008	Permutation-Based Elitist Genetic Algorithm for Optimization of Large-Sized Resource-Constrained Project Scheduling	RL-16
17	2008	Critical Path Scheduling under Resource Calendar Constraints	RL-17
18	2007	Project Planning for Construction under Uncertainty with Limited Resources	RL-18
19	2007	Schedule Analysis under the Effect of Resource Allocation	RL-19
20	2006	Non-Unit-Based Planning and Scheduling of Repetitive Construction Projects	RL-20
21	2006	Work Continuity Constraints in Project Scheduling	RL-21
22	2006	Particle Swarm Optimization for Preemptive Scheduling under Break and Resource-Constraints	RL-22
23	2005	Evaluation of the Resource-Constrained Critical Path Method Algorithms	RL-23
24	1991	Time-Constrained Resource Leveling	RL-24
25	1991	Optimal Allocation of Project Management Resources for Achieving Success	RL-25
26	1990	Packing Method for Resource Leveling (Pack)	RL-26
27	1989	Resource Leveling in Construction by Optimization	RL-27

Table 4-6 Analysis Table for the Resource Leveling Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave the cell blank.)							
			Experimental Studies	**Observational Studies**	**Empirical Studies**	**Case Studies**	**Surveys**	**Functional Demonstration**	**Archival Data Analysis**	**Others**
1	2012	RL-1						1		
2	2011	RL-2						1		
3	2011	RL-3						1		
4	2011	RL-4						1		
5	2011	RL-5						1		
6	2011	RL-6						1		
7	2011	RL-7						1		
8	2011	RL-8						1		
9	2010	RL-9						1		
10	2010	RL-10						1		
11	2010	RL-11								
12	2010	RL-12						1		
13	2009	RL-13						1		
14	2009	RL-14						1		
15	2009	RL-15						1		
16	2008	RL-16	1							
17	2008	RL-17						1		
18	2007	RL-18						1		
19	2007	RL-19						1		
20	2006	RL-20						1		
21	2006	RL-21						1		
22	2006	RL-22						1		
23	2005	RL-23								
24	1991	RL-24								
25	1991	RL-25			1					
26	1990	RL-26								
27	1989	RL-27								

4.2.4 Alignment Analysis Table

4.2.4.1 Introduction

For the Alignment category, 22 papers were examined, with a publication period ranging from 1998 to 2011. This category includes topics such as the development of models for the alignment of construction project teams, how to implement alignment practices, and the assessment of alignment.

4.2.4.2 Analysis Process

Since AL is the abbreviation for this category, based on Table 3-1, the code names for this category start with AL. The code name index for this category is presented in Table 4-7.

Article AL-15 can be used as an illustrative example for this category. The authors proposed a model for partnering, which was derived from reports and theories previously published in the literature. The goal of the model was to help project managers concentrate on the aspects of team processes necessary for creating a high degree of cooperation and performance. In this paper, it was the “Validation of Model of Partnering” section. To validate the model, the authors conducted archival research. Numerous past studies supported the proposed model, so it was considered to be validated. Based on Table 3-3, the characteristics of the methodology applied match the typical features of Archival Data Analysis: utilization of research results from past studies that supported the validity of the model.

The complete analysis table for the Alignment category is presented as Table 4-8. The rows shaded in grey indicate articles whose authors didn’t apply rigorous validation methodologies.

Table 4-7 Code Name Index for the Alignment Category

#	Year	Article Title	Code Name
1	2011	Fuzzy Similarity Consensus Model for Early Alignment of Construction Project Teams on the Extent of Their Roles and Responsibilities	AL-1
2	2011	Project Network Interdependency Alignment: New Approach to Assessing Project Effectiveness	AL-2
3	2011	Goal and Process Alignment during the Implementation of Decision Support Systems by Project Teams	AL-3
4	2011	Analysis of the Higher Order Partial Correlation between CII Best Practices and Performance of the Design Phase in Fast Track Industrial Projects	AL-4
5	2011	Multi Country Perspectives of Relational Contracting and Integrated Project Teams	AL-5

Table 4-7 Code Name Index for the Alignment Category (Continued)

#	Year	Article Title	Code Name
6	2011	Contract Administration Guidelines for Managing Conflicts, Claims, and Disputes under World Bank Funded Projects	AL-6
7	2011	Partnering: What Must Be Done to Avoid Failure	AL-7
8	2010	Assessment of Responsibilities of Project Teams for Owner Managing Contractor Tasks — A Fuzzy Consensus Approach	AL-8
9	2010	Personal Construct-Based Factors Affecting Interpersonal Trust in a Project Design Team	AL-9
10	2010	Project Organizations as Social Networks	AL-10
11	2009	Enhancing Total Quality Management by Partnering in Construction	AL-11
12	2009	Assessing Scope and Managing Risk in the Highway Project Development Process	AL-12
13	2009	Aligning Pre-Construction Planning and Project Management in the Electrical Construction Industry	AL-13
14	2009	Predictive Simulation as a Decision Support System to Manage A/E/C Global Teamwork	AL-14
15	2007	Conceptual Model of Partnering and Alliancing	AL-15
16	2007	Inter-Organizational Teamwork in the Construction Industry	AL-16
17	2004	Strategies for Successful Partnering Relationships	AL-17
18	2002	Incentive Mechanisms for Project Success	AL-18
19	2002	Construction Partnering Process and Associated Critical Success Factors: Quantitative Investigation	AL-19
20	2000	Team-Building in Construction	AL-20
21	1999	Leadership in the Construction Industry	AL-21
22	1998	Partnering Continuum	AL-22

Table 4-8 Analysis Table for the Alignment Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2011	AL-1						1		
2	2011	AL-2					1			
3	2011	AL-3								
4	2011	AL-4			1					
5	2011	AL-5								
6	2011	AL-6								
7	2011	AL-7								
8	2010	AL-8					1			
9	2010	AL-9								
10	2010	AL-10								
11	2009	AL-11				1	1			
12	2009	AL-12						1		
13	2009	AL-13								
14	2009	AL-14						1		
15	2007	AL-15							1	
16	2007	AL-16			1		1			
17	2004	AL-17								
18	2002	AL-18				1				
19	2002	AL-19			1					
20	2000	AL-20								
21	1999	AL-21								
22	1998	AL-22								

4.2.5 Knowledge Management Analysis Table

4.2.5.1 Introduction

For the Knowledge Management category, 28 papers were examined. The publication dates ranged from 2000 to 2012. This category includes topics such as the impact of knowledge management on construction projects, how to implement and enhance knowledge management, and the development of models for knowledge management.

4.2.5.2 Analysis Process

All of the code names begin with KM because the abbreviation for this category is listed as KM in Table 3-1. The code name index for this category is presented in Table 4-9.

The example used as an illustration of the analysis for this category is article KM-4. The authors postulated that knowledge management has a positive impact on construction projects. They investigated a sample of capital construction projects in order to validate a model for the assessment of the interrelationships of the application of IT, the adoption of knowledge management practices, and the success of a project. They also had the goal of evaluating the mediating role of the adoption of a knowledge management practice in the relationship between the application of IT and project performance, and they investigated whether the impact of knowledge management on project success is affected by the type of project. The part of the paper that described the validation of the research was the “Results and Analysis” section. To validate the model, the authors applied a structural equation modeling (SEM) approach. SEM is a statistical technique for testing and estimating causal relations using a combination of statistical data and qualitative causal assumptions. According to Table 3-3, the characteristics of this methodology match the features of Empirical Studies: 1) the development of a model and hypothesis and 2) statistical analysis.

The complete analysis table for the Knowledge Management category is presented as Table 4-10. The rows shaded in grey indicate papers whose authors didn’t apply rigorous validation methodologies.

Table 4-9 Code Name Index for the Knowledge Management Category

#	Year	Article Title	Code Name
1	2012	Epistemology of Construction Informatics	KM-1
2	2012	Enhancing Knowledge Management for Engineers Using Mind Mapping in Construction	KM-2
3	2012	Developing Project Communities of Practice-Based Knowledge Management System in Construction	KM-3
4	2012	Assessing Impacts of Information Technology on Project Success Through Knowledge Management Practice	KM-4
5	2012	An Integrated Proactive Knowledge Management Model for Enhancing Engineering Services	KM-5
6	2011	Information Management in UK Based Architecture and Engineering Organisations — Drivers, Constraining Factors and Barriers	KM-6
7	2011	Case Study of Knowledge Management Implementation in a Medium-Sized Construction Sector Firm	KM-7
8	2011	Motivating Knowledge Sharing in Engineering and Construction Organizations: The Power of Social Motivations	KM-8
9	2010	The Embedment of a Knowledge Management Program in an AEC Organization	KM-9
10	2010	Integrated Knowledge Management Model and System for Construction Projects	KM-10
11	2009	Measuring the Impact of Rework on Construction Cost Performance	KM-11
12	2009	Identification of Effective Management Practices and Technologies for Lessons Learned Programs in the Construction Industry	KM-12
13	2009	Knowledge Management in Construction Companies in the UK	KM-13
14	2009	Collaborative Knowledge Management—A Construction Case Study	KM-14
15	2009	Developing a Knowledge Management System for Improved Value Engineering Practices in the Construction Industry	KM-15
16	2008	Knowledge Management Model for Construction Projects	KM-16
17	2008	Managing Construction Project Change: A Knowledge Management Perspective	KM-17
18	2007	The Application of Knowledge Management Practices in the Procurement and Construction of Cleanroom Projects	KM-18
19	2007	Knowledge Management to Learning Organization Connection	KM-19
20	2007	Developing a Knowledge Map for Construction Scheduling Using a Novel Approach	KM-20
21	2006	Enhancing Knowledge Exchange Through Web Map-Based Knowledge Management System in Construction: Lessons Learned in Taiwan	KM-21

Table 4-9 Code Name Index for the Knowledge Management Category (Continued)

#	Year	Article Title	Code Name
22	2005	Knowledge Management Practices in Large Construction Organisations	KM-22
23	2004	Towards a Framework for Integrating Knowledge Management Processes into Site Management Practices	KM-23
24	2004	Developing an Activity-Based Knowledge Management System for Contractors	KM-24
25	2003	Knowledge Mining of Information Sources for Research in Construction Management	KM-25
26	2003	An Ontology for Construction Knowledge Management Framework for Performance Improvement of Construction Project Managers	KM-26
27	2002	Knowledge Management for the Construction Industry: The E-Cognos Project	KM-27
28	2000	Knowledge Management Strategy for Construction: Key IT and Contextual Issues	KM-28

Table 4-10 Analysis Table for the Knowledge Management Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2012	KM-1								
2	2012	KM-2				1	1	1		
3	2012	KM-3					1			
4	2012	KM-4			1					
5	2012	KM-5						1		
6	2011	KM-6								
7	2011	KM-7								
8	2011	KM-8								
9	2010	KM-9				1				
10	2010	KM-10						1		
11	2009	KM-11			1					
12	2009	KM-12								
13	2009	KM-13				1				
14	2009	KM-14				1				
15	2009	KM-15			1			1		
16	2008	KM-16								
17	2008	KM-17								
18	2007	KM-18								
19	2007	KM-19								
20	2007	KM-20								
21	2006	KM-21				1				

Table 4-10 Analysis Table for the Knowledge Management Category (Continued)

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
23	2004	KM-23								
24	2004	KM-24						1		
25	2003	KM-25				1				
26	2003	KM-26								
27	2002	KM-27								
28	2000	KM-28								

4.2.6 Risk Management Analysis Table

4.2.6.1 Introduction

For the Risk Management category, 29 papers were examined, with publication dates ranging from 2003 to 2011. This category includes topics such as the relationship between risks and costs, how to implement risk management, and the assessment of construction risks.

4.2.6.2 Analysis Process

Since the abbreviation for this category is RM, based on Table 3-1, the code names for this category start with RM. The code name index for this category is presented in Table 4-11.

Article RM-4 illustrates the analysis process for this category. The authors attempted to extend previous studies of risk management and presented an ontology for relating risk-related concepts to cost overruns. The ontology formed the basis of a multi-agent system that can be used to simulate the process of negotiation among project participants with respect to a variety of elements related to risks. It was constructed based on interactions with Turkish contractors who work in international markets and on an extensive review of the literature relevant to risk-related concepts. The validation of the model involved an interactive workshop and interviews with industry practitioners. According to the features listed in Table 3-3, the characteristics of the authors' methodology match those typical of Surveys: interviews with 25 industry practitioners from 18 construction companies.

The complete analysis table for the Risk Management category is presented as Table 4-12. The rows shaded in gray indicate articles whose authors didn't apply rigorous validation methodologies.

Table 4-11 Code Name Index for the Risk Management Category

#	Year	Article Title	Code Name
1	2011	Risk Management of Long Term Infrastructure Projects "PPP-BOT Projects" by Using Uncertainty, Probabilistic and Stochastic Methods and Models	RM-1
2	2011	National-Level Infrastructure Risk Evaluation Framework and Best Practices	RM-2
3	2011	Probabilistic Performance Risk Evaluation of Infrastructure Projects	RM-3
4	2011	Ontology for Relating Risk and Vulnerability to Cost Overrun in International Projects	RM-4
5	2011	Risk Assessment Methodology for a Deep Foundation Pit Construction Project in Shanghai, China	RM-5
6	2011	Identification of Risk Paths in International Construction Projects Using Structural Equation Modeling	RM-6

Table 4-11 Code Name Index for the Risk Management Category (Continued)

#	Year	Article Title	Code Name
7	2011	Risk Allocation in the Operational Stage of Private Finance Initiative Projects	RM-7
8	2011	Construction Risk Assessment Using Site Influence Factors	RM-8
9	2011	Development of a Methodology for Understanding the Potency of Risk Connectivity	RM-9
10	2011	Risk Planning and Management for the Panama Canal Expansion Program	RM-10
11	2011	Empirical Study of Risk Assessment and Allocation of Public-Private Partnership Projects in China	RM-11
12	2011	Risk and Price in the Bidding Process of Contractors	RM-12
13	2011	Relational Risk Management in Construction Projects: Modeling the Complexity	RM-13
14	2011	Risks, Contracts, and Private-Sector Participation in Infrastructure	RM-14
15	2011	Bootstrap Technique for Risk Analysis with Interval Numbers in Bridge Construction Projects	RM-15
16	2010	Understanding and Improving Your Risk Management Capability: Assessment Model for Construction Organizations	RM-16
17	2010	Evaluation of Risk Factors Leading to Cost Overrun in Delivery of Highway Construction Projects	RM-17
18	2010	Risk assessment of construction projects	RM-18
19	2010	Population and Initial Validation of a Formal Model for Construction Safety Risk Management	RM-19
20	2010	Political, Economic, and Legal Risks Faced in International Projects: Case Study of Vietnam	RM-20
21	2010	Empirical Study of the Risks and Difficulties in Implementing Guaranteed Maximum Price and Target Cost Contracts in Construction	RM-21
22	2009	Managing Construction Projects Using the Advanced Programmatic Risk Analysis and Management Model	RM-22
23	2009	Managing Construction Projects Using the Advanced Programmatic Risk Analysis and Management Model	RM-23
24	2009	Contractors’ Claims Insurance: A Risk Retention Approach	RM-24
25	2008	Construction Project Risk Assessment Using Existing Database and Project-Specific Information	RM-25
26	2008	Construction Project Network Evaluation with Correlated Schedule Risk Analysis Model	RM-26
27	2008	Methodology for Integrated Risk Management and Proactive Scheduling of Construction Projects	RM-27
28	2008	Risk and Resilience to Enhance Sustainability with Application to Urban Water Systems	RM-28
29	2003	Evaluating Risk in Construction–Schedule Model (ERIC–S): Construction Schedule Risk Model	RM-29

Table 4-12 Analysis Table for the Risk Management Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2011	RM-1						1		
2	2011	RM-2						1		
3	2011	RM-3						1		
4	2011	RM-4					1			
5	2011	RM-5						1		
6	2011	RM-6								
7	2011	RM-7								
8	2011	RM-8						1		
9	2011	RM-9						1		
10	2011	RM-10						1		
11	2011	RM-11								
12	2011	RM-12								
13	2011	RM-13								
14	2011	RM-14								
15	2011	RM-15						1		
16	2010	RM-16	1				1	1		
17	2010	RM-17								
18	2010	RM-18						1		
19	2010	RM-19								
20	2010	RM-20								
21	2010	RM-21						1		

Table 4-12 Analysis Table for the Risk Management Category (Continued)

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
23	2009	RM-23						1		
24	2009	RM-24						1		
25	2008	RM-25						1		
26	2008	RM-26						1		
27	2008	RM-27						1		
28	2008	RM-28								
29	2003	RM-29								

4.2.7 Contract and Project Delivery Analysis Table

4.2.7.1 Introduction

For the Contract and Project Delivery category, 40 papers were examined, with publication dates ranging from 2005 to 2012. This category includes topics such as methods of contract and project delivery; the relationship between costs and duration, and contract and project delivery; and comparisons of methods of contract and project delivery.

4.2.7.2 Analysis Process

According to Table 3-1, the abbreviation for this category is CP, so all of the code names in this category start with CP. The code name index for this category is presented in Table 4-13.

To illustrate the analysis process for this category, article CP-13 was chosen as an example. The authors adopted the evaluation metrics defined in a few recent studies in order to show the extent to which project sustainability goals are affected by the relationships among and the influence of project delivery attributes, such as owner commitment, team integration, and contractual relationships. They concluded that the attributes that are crucial for the delivery process are strong owner commitment to sustainability, integration in the delivery process through the early involvement of the contractor, and the early inclusion of green strategies. In this paper, the “Methods” section was considered to be the explanation of the validation. To validate the data, three main participants from each case study selected (research methodology) were invited to complete e-mail and telephone surveys. Based on Table 3-3, the characteristics of the methodology match the features of Surveys: 1) sampling and 2) use of e-mail and the telephone for the surveys.

The complete analysis table for the Contract and Project Delivery category is presented as Table 4-14. The rows shades in grey indicate articles whose authors didn’t apply rigorous validation methodologies.

Table 4-13 Code Name Index for the Contract and Project Delivery Category

#	Year	Article Title	Code Name
1	2012	Off-Site Construction of Apartment Buildings: A Case Study	CP-1
2	2012	Performance Comparison of Large Design-Build and Design-Bid-Build Highway Projects	CP-2
3	2011	Integrated Project Delivery Method for Trenchless Projects	CP-3
4	2011	Alternative Project Delivery Methods for Water and Wastewater Projects: Do They Save Time and Money?	CP-4
5	2011	Integrating Risk Management Within the Project Delivery Process at Caltrans: A Transportation Project Case Study	CP-5
6	2011	A Dream of Ideal Project Delivery System	CP-6
7	2011	Global Project Delivery Systems Using BIM	CP-7
8	2011	Selection Model for Delivery Methods for Multifamily-Housing Construction Projects	CP-8
9	2011	Project Delivery Metrics for Sustainable High-Performance Buildings	CP-9
10	2011	Fuzzy Preference Relations Consensus Approach to Reduce Conflicts on Shared Responsibilities in the Owner Managing Contractor Delivery System	CP-10
11	2011	New Operating System for Project Management: Consequences and Opportunities	CP-11
12	2011	Selection of Project Delivery Method in Transit: Drivers and Objectives	CP-12
13	2011	Project Delivery Metrics for Sustainable, High-Performance Buildings	CP-13
14	2010	Integrated Project Delivery Case Study: Guidelines for Drafting Partnering Contract	CP-14
15	2010	Integrated Project Delivery: Next-Generation BIM for Structural Engineering	CP-15
16	2010	A Critical Analysis of Innovations in Construction Manager-at-Risk Project Delivery	CP-16
17	2010	Exploring the Validity of Qualitative Methods to Analyze Project Delivery of Sustainable, High Performance Buildings	CP-17
18	2010	A Unified Process Approach to Healthcare Project Delivery: Synergies Between Greening Strategies, Lean Principles and BIM	CP-18
19	2010	Governance Challenges of Infrastructure Delivery: The Case for Socio-Economic Governance Approaches	CP-19
20	2010	Guidelines for a Standard Project Partnering Contract	CP-20
21	2010	Integration of Container Terminal Design and Construction with Operations to Reduce the Project Delivery Cost and Shorten the Schedule	CP-21
22	2010	Evaluation of Risk Factors Leading to Cost Overrun in Delivery of Highway Construction Projects	CP-22
23	2010	Statistical Analysis on the Cost and Duration of Building Projects	CP-23

Table 4-13 Code Name Index for the Contract and Project Delivery Category (Continued)

#	Year	Article Title	Code Name
24	2010	Selecting Appropriate Project Delivery System: Fuzzy Approach with Risk Analysis	CP-24
25	2010	Piloting Evaluation Metrics for Sustainable High-Performance Building Project Delivery	CP-25
26	2010	Understanding Construction Industry Experience and Attitudes Toward Integrated Project Delivery	CP-26
27	2010	Counterfactual Analysis of Sustainable Project Delivery Processes	CP-27
28	2010	Integrated Project Delivery Case Study: Guidelines for Drafting Partnering Contract	CP-28
29	2009	Analysis of the Design-Build Delivery Method in Air Force Construction Projects	CP-29
30	2009	Sources of Changes in Design–Build Contracts for a Governmental Owner	CP-30
31	2009	A New Approach to Contracting Design Professionals	CP-31
32	2008	Relational Contracting and Teambuilding: Assessing Potential Contractual and Non-Contractual Incentives	CP-32
33	2008	Comparative Analysis of Owner Goals for Design/Build Projects	CP-33
34	2008	Emergency Contracting Strategies for Federal Projects	CP-34
35	2008	Comparative Analysis of Project Delivery Systems Cost Performance in Pacific Northwest Public Schools	CP-35
36	2007	Successful Delivery of Public-Private Partnerships for Infrastructure Development	CP-36
37	2006	Relative Effectiveness of Project Delivery and Contract Strategies	CP-37
38	2006	Construction Delivery Systems: A Comparative Analysis of Their Performance within School Districts	CP-38
39	2005	Constructing Relationally Integrated Teams	CP-39
40	2005	Reconstructing Cultures for Relational Contracting	CP-40

Table 4-14 Analysis Table for the Contract and Project Delivery Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2012	CP-1				1	1			
2	2012	CP-2								
3	2011	CP-3								
4	2011	CP-4								
5	2011	CP-5								
6	2011	CP-6						1		
7	2011	CP-7								
8	2011	CP-8						1		
9	2011	CP-9					1			
10	2011	CP-10					1			
11	2011	CP-11								
12	2011	CP-12					1			
13	2011	CP-13					1			
14	2010	CP-14								
15	2010	CP-15								
16	2010	CP-16					1			
17	2010	CP-17				1	1			
18	2010	CP-18						1		
19	2010	CP-19								
20	2010	CP-20								
21	2010	CP-21								

Table 4-14 Analysis Table for the Contract and Project Delivery Category (Continued)

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
23	2010	CP-23			1					
24	2010	CP-24						1		
25	2010	CP-25			1					
26	2010	CP-26								
27	2010	CP-27						1		
28	2010	CP-28								
29	2009	CP-29			1					
30	2009	CP-30			1					
31	2009	CP-31								
32	2008	CP-32								
33	2008	CP-33					1			
34	2008	CP-34								
35	2008	CP-35			1					
36	2007	CP-36			1					
37	2006	CP-37				1				
38	2006	CP-38			1			1		
39	2005	CP-39			1		1			
40	2005	CP-40			1					

4.2.8 Craft Training Analysis Table

4.2.8.1 Introduction

For the Craft Training category, 17 papers were examined; the publication dates range from 1987 to 2012. Topics in this category include such areas as the impact of craft training on construction projects, how to implement effective craft training, and the need of for craft training.

4.2.8.2 Analysis Process

Since the abbreviation for this category is CT, based on Table 3-1, the code names for this category all start with CT. The code name index for this category is presented in Table 4-15.

Article CT-8 was chosen as an example to illustrate the process for this category. The study was focused on addressing the issues related to training and allocating a construction project workforce. The authors developed a linear program model, called the Optimal Workforce Investment Model, as a means of providing an optimization-based framework. This model helps the managers of construction projects determine the most efficient method of matching the supply of and demand for labour through training, recruitment, and allocation. In this paper, the section entitled “Evaluation of Five Case Studies” was considered to be the explanation of the validation of the linear program model. To validate the model, the input data related to training and hiring costs were collected from the academic literature and from industry data. Five different cases were analyzed. The final output reflected the real-world scenarios. Based on Table 3-3, the characteristics of the methodology applied match the features typical of Case Studies and Functional Demonstration. The matching feature typical of Case Studies is the intensive analysis of particular matters. The features that match those of Functional Demonstration include 1) reliance on input and output data and 2) validation for a linear program model.

The complete analysis table for the Craft Training category is presented as Table 4-16. The rows shaded in grey indicate articles whose authors didn’t apply rigorous validation methodologies.

Table 4-15 Code Name Index for the Craft Training Category

#	Year	Article Title	Code Name
1	2012	Impact of a Construction Management Educational Intervention on the Expertise and Work Practice of Non-Construction Engineers	CT-1
2	2010	Differences in Perspectives Regarding Labour Productivity Between Spanish- and English-Speaking Craft Workers	CT-2
3	2009	Latent Structures of the Factors Affecting Construction Labour Productivity	CT-3
4	2009	Analysis of Observed Skill Affinity Patterns and Motivation for Multi-Skilling Among Craft Workers in the U.S. Industrial Construction Sector	CT-4
5	2009	Human Factors Analysis Classification System Relating to Human Error Awareness Taxonomy in Construction Safety	CT-5
6	2009	Emergency Preparedness Training and Education in Lombardy Region, Italy: Survey of Supply and Demand	CT-6
7	2008	Craft Training Issues in American Industrial and Commercial Construction	CT-7
8	2008	Linear Programming Approach to Optimize Strategic Investment in the Construction Workforce	CT-8
9	2008	Exploring Training Needs and Development of Construction Language Courses for American Supervisors and Hispanic Craft Workers	CT-9
10	2007	Leadership to Improve Quality Within an Organization	CT-10
11	2006	Construction Craft Workers' Perceptions of the Factors Affecting Their Productivity	CT-11
12	2004	Workers' Skills and Receptiveness to Operate Under the Tier II Construction Management Strategy	CT-12
13	2004	Mechanical Craft Training in Western Washington	CT-13
14	2003	A Revolutionary and Structured Approach to Construction Work Force Management: The Tier II Strategy	CT-14
15	1997	Improving Industry Performance Through Integrated Training Programs	CT-15
16	1988	Positive Effects of Training, Experience, and Feedback	CT-16
17	1987	Developing Planning Skills of Engineers in Management Training	CT-17

Table 4-16 Analysis Table for the Contract and Craft Training Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2012	CT-1					1			
2	2010	CT-2								
3	2009	CT-3			1		1			
4	2009	CT-4			1					
5	2009	CT-5								
6	2009	CT-6								
7	2008	CT-7			1		1			
8	2008	CT-8				1		1		
9	2008	CT-9					1			
10	2007	CT-10								
11	2006	CT-11			1					
12	2004	CT-12			1		1			
13	2004	CT-13								
14	2003	CT-14					1			
15	1997	CT-15								
16	1988	CT-16					1			
17	1987	CT-17			1					

4.2.9 Site Layout Analysis Table

4.2.9.1 Introduction

For the Site Layout category, 37 papers were examined, with publication dates ranging from 1988 to 2012. This category includes topics such as the optimization of site layout planning and models of site layouts. The authors of most papers validated that efficient site layout planning and models helps save the project cost and material travelling time.

4.2.9.2 Analysis Process

Since Table 3-1 lists SL as the abbreviation for this category, all of the code names for this category start with SL. The code name index for this category is presented in Table 4-17.

Article SL-6 illustrates the analysis process for this category. The authors developed an optimization model for solving the site layout planning problem from the perspectives of safety and environmental issues. They chose a generic algorithm as the basis of the optimization. To test the validity of the model, the authors applied it to a real-life construction project in the section of "Case Study". They input the parameters of the project and tested the model. The results obtained showed that satisfactory solutions were produced. Based on Table 3-3, the characteristics of the methodology match the features of Functional Demonstration:1) reliance on input and output data and 2) validation for an optimization model.

The complete analysis table for the Site Layout category is presented as Table 4-18. The rows shaded in grey indicate articles whose authors didn't apply rigorous validation methodologies.

Table 4-17 Code Name Index for the Site Layout Category

#	Year	Article Title	Code Name
1	2011	Floor-Level Construction Material Layout Planning Model Considering Actual Travel Path	SL-1
2	2010	Optimizing Material Procurement and Storage on Construction Sites	SL-2
3	2010	Optimizing Material Logistics Planning in Construction Projects	SL-3
4	2009	Conjoining MMAS to GA to Solve Construction Site Layout Planning Problem	SL-4
5	2009	Global Optimization of Dynamic Site Layout Planning in Construction Projects	SL-5
6	2008	Optimal Construction Site Layout Considering Safety and Environmental Aspects	SL-6
7	2008	Dynamic Site Layout Planning Using Approximate Dynamic Programming	SL-7
8	2008	New Mathematical Optimization Model for Construction Site Layout	SL-8

Table 4-17 Code Name Index for the Site Layout Category (Continued)

#	Year	Article Title	Code Name
9	2008	Particle Swarm Optimization for Construction Site Unequal-Area Layout	SL-9
10	2007	Generic Process Mapping and Simulation Methodology for Integrating Site Layout and Operations Planning in Construction	SL-10
11	2006	Optimizing Airport Construction Site Layouts to Minimize Wildlife Hazards	SL-11
12	2005	Computer-Aided Site Layout Planning	SL-12
13	2005	Trade-off Between Safety and Cost in Planning Construction Site Layouts	SL-13
14	2005	Layout Planning of Construction Sites Considering Multiple Objectives: A Goal-Programming Approach	SL-14
15	2004	An Evolutionary Algorithm for Solving the Geometrically Constrained Site Layout Problem	SL-15
16	2004	Designing a Decision Support System for Military Base Camp Site Selection and Facility Layout	SL-16
17	2003	Four-Dimensional Visualization of Construction Scheduling and Site Utilization	SL-17
18	2003	Dynamic Layout of Construction Temporary Facilities Considering Safety	SL-18
19	2002	Genetic Algorithms for Construction Site Layout in Project Planning	SL-19
20	2002	Site Layout Planning using Nonstructural Fuzzy Decision Support System	SL-20
21	2002	Genetic Algorithm for Solving Site Layout Problem with Unequal-Size and Constrained Facilities	SL-21
22	2001	GIS-Based Cost Estimates Integrating with Material Layout Planning	SL-22
23	2001	Genetic Algorithm for Optimizing Supply Locations Around Tower Crane	SL-23
24	2001	Improvement Algorithm for Limited Space Scheduling	SL-24
25	2000	A New 4D Management Approach to Construction Planning and Site Space Utilization	SL-25
26	1999	EvoSite: Evolution-Based Model for Site Layout Planning	SL-26
27	1998	Dynamic Layout Planning Using a Hybrid Incremental Solution Method	SL-27
28	1998	Site-Level Facilities Layout Using Genetic Algorithms	SL-28
29	1997	Space Planning Method for Multistory Building Construction	SL-29
30	1996	ArcSite: Enhanced GIS for Construction Site Layout	SL-30
31	1995	Construction-Site Layout Using Annealed Neural Network	SL-31
32	1994	Construction Site Applications of CAD	SL-32
33	1993	Interactive Dynamic Layout Planning	SL-33
34	1992	Site-Layout Modeling: How Can Artificial Intelligence Help?	SL-34
35	1992	SightPlan Model for Site Layout	SL-35
36	1991	SightPlan Experiments: Alternate Strategies for Site Layout Design	SL-36
37	1988	Site Design for Resource Recovery Facilities	SL-37

Table 4-18 Analysis Table for the Site Layout Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2011	SL-1						1		
2	2010	SL-2						1		
3	2010	SL-3						1		
4	2009	SL-4						1		
5	2009	SL-5						1		
6	2008	SL-6						1		
7	2008	SL-7						1		
8	2008	SL-8						1		
9	2008	SL-9						1		
10	2007	SL-10						1		
11	2006	SL-11						1		
12	2005	SL-12						1		
13	2005	SL-13						1		
14	2005	SL-14						1		
15	2004	SL-15						1		
16	2004	SL-16								
17	2004	SL-17								
18	2003	SL-18								
19	2003	SL-19						1		
20	2002	SL-20						1		
21	2002	SL-21						1		
22	2002	SL-22						1		

Table 4-18 Analysis Table for the Site Layout Category (Continued)

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
23	2001	SL-23						1		
24	2001	SL-24						1		
25	2001	SL-25						1		
26	1999	SL-26						1		
27	1998	SL-27						1		
28	1998	SL-28						1		
29	1997	SL-29						1		
30	1996	SL-30						1		
31	1995	SL-31						1		
32	1994	SL-32								
33	1993	SL-33						1		
34	1992	SL-34								
35	1992	SL-35						1		
36	1991	SL-36						1		
37	1988	SL-37								

4.2.10 Short-Term Scheduling Analysis Table

4.2.10.1 Introduction

In the Short-Term Scheduling category, only three papers were examined because not many CEM papers are related to this topic. However, researchers in the area of water and wastewater management have published a number of papers related to this topic. The three papers were published in 1994, 2011, and 2012. The articles were focused on how to conduct short-term scheduling.

4.2.10.2 Analysis Process

Since the abbreviation for this category is SS, as listed in Table 3-1, the code names for this category all start with SS. The code name index for this category is presented in Table 4-19.

Article SS-1 was chosen as an example to illustrate the analysis for this category. The authors proposed an approach for optimizing the short-interval scheduling of a project for constructing large-scale cascaded hydropower systems with multi-vibration zones of high head. The scheduling was designed to be based on an optimization framework that combined a progressive optimality algorithm with a vibration zone avoidance strategy. The authors applied this methodology to a real construction project in order to test its validity. To validate the approach, the framework developed was applied for several cascaded hydropower systems, and the results demonstrated its validity in the section of "Case Study". Based on the list in Table 3-3, the characteristics of the methodology match the features of Functional Demonstration; 1) reliance on input and output data and 2) validation of an algorithm.

The complete analysis table for the Short-Term Scheduling category is presented as Table 4-20. The rows shaded in grey represent articles whose authors didn't apply rigorous validation methodologies.

Table 4-19 Code Name Index for the Short-Term Scheduling Category

#	Year	Article Title	Code Name
1	2012	Short-Term Scheduling for Large-Scale Cascaded Hydropower Systems with Multi-Vibration Zones of High Head	SS-1
2	2011	Automated Generation of Construction Plans from Primitive Geometries	SS-2
3	1994	Portfolio Approach to Strategic Management of A/E Firms	SS-3

Table 4-20 Analysis Table for the Short-Term Scheduling Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2012	SS-1						1		
2	2011	SS-2						1		
3	1994	SS-3					1			

4.2.11 Factors Analysis Table

4.2.11.1 Introduction

For the Factors category, 40 papers were examined. The publication dates range from 1980 to 2013. This category includes topics such as how weather can adversely affect productivity, investigations of the loss of productivity due to accelerations, and how to apply equipment management practices. Typically, the authors of most papers validated impacts of factors on productivity.

4.2.11.2 Analysis Process

Since Table 3-1 specifies FC as the abbreviation for this category, the code names for this category all start with FC. The code name index for this category is presented in Table 4-21.

To illustrate the analysis process for this category, article FC-21 can be used as an example. The authors investigated the impact of overmanning on labour productivity for labour-intensive trades such as mechanical and sheet metal. They conducted a survey and performed a statistical analysis in order to determine a quantitative relationship between overmanning and labour productivity. They validated the results through cross-validation and a demonstration of the application of the proposed model. In this paper, the sections entitled “Validation” and “Case Study” were considered to be the descriptions of the validation. To validate the model, the authors applied cross-validation, which is a method of assessing how statistical analysis results can be generalized for an independent data set. In the case study, the authors applied the model to a real project and demonstrated its applicability. Based on the list in Table 3-3, the characteristics of the methodologies match the features of Empirical Studies and Functional Demonstration. The features that match Empirical Studies include 1) development of a model and hypothesis and 2) statistical analysis (cross-validation). The features that match Functional Demonstration include 1) reliance on input and output data and 2) validation for a model.

The complete analysis table of the Factors category is presented as Table 4-22. The rows shaded in grey represent articles whose authors didn’t apply rigorous validation methodologies.

Table 4-21 Code Name Index for the Factors Category

#	Year	Article Title	Code Name
1	2013	Optimizing Work-Rest Schedule for Construction Rebar Workers in Hot and Humid Environment	FC-1
2	2012	Relationship Between Floor Number and Labour Productivity in Multistory Structural Work: A Case Study	FC-2
3	2012	New Approach to Model Material-Related Problems Contributing to Project Delays Using Rotational Fuzzy Set	FC-3
4	2011	Calculating Loss of Productivity Due to Overtime Using Published Charts – Fact or Fiction	FC-4
5	2011	Understanding Construction Workforce Absenteeism in Industrial Construction	FC-5
6	2011	Analysis of Factors Influencing Productivity Using Craftsmen Questionnaires-Case Study in a Chilean Construction Company	FC-6
7	2011	Maintenance for Improving Manufacturing Equipment Availability Using Prognostics and Health Management	FC-7
8	2010	Analysis of Adverse Weather for Excusable Delays	FC-8
9	2010	Critical Investigation into the Applicability of the Learning Curve Theory to Rebar Fixing Labour Productivity	FC-9
10	2009	Probabilistic Duration Estimation Model for High-Rise Structural Work	FC-10
11	2009	Optimizing the Utilization of Multiple Labour Shifts in Construction Projects	FC-11
12	2009	Are Workers with a Long Commute Less Productive: An Empirical Analysis of Absenteeism	FC-12
13	2009	Assembly Line Team Sizing with Absenteeism	FC-13
14	2009	Overtime and Productivity in Electrical Construction	FC-14
15	2009	Construction Learning Curves	FC-15
16	2009	Factors Affecting Employee Productivity in the UAE Construction Industry	FC-16
17	2008	Impact of Shift Work on Labour Productivity for Labour Intensive Contractor	FC-17
18	2007	Impact of Occasional Overtime on Construction Labour Productivity: Quantitative Analysis	FC-18
19	2007	Improving Employees' Work-Life Balance in the Construction Industry	FC-19
20	2006	Fundamental Principles for Avoiding Congested Work	FC-20
21	2005	Overmanning Impact on Construction Labour Productivity	FC-21
22	2005	Impact of Extended Overtime on Construction Labour Productivity	FC-22
23	2005	Change Orders Impact on Labour Productivity	FC-23
24	2005	Factors Affecting Absenteeism in Electrical Construction	FC-24
25	2004	Labour Availability and Productivity Forecasting	FC-25
26	2004	Cumulative Effect of Project Changes for Electrical and Mechanical Construction	FC-26

Table 4-21 Code Name Index for the Factors Category (Continued)

#	Year	Article Title	Code Name
27	2004	Absenteeism and Turnover Impact on Labour Productivity for Electrical Contractors	FC-27
28	2003	Improving Labour Flow Reliability for Better Productivity as Lean Construction Principle	FC-28
29	2002	Overall Equipment Effectiveness	FC-29
30	1998	The Effect of Hot Weather on Construction Labour Productivity and Costs	FC-30
31	1996	Scheduled Overtime and Labour Productivity: Quantitative Analysis	FC-31
32	1995	Patterns of Construction—Space Use in Multistory Buildings	FC-32
33	1995	Quantitative Effects of Construction Changes on Labour Productivity	FC-33
34	1992	Effects of Scheduled Overtime on Labour Productivity	FC-34
35	1990	Consequential Equipment Costs Associated with Lack of Availability and Downtime	FC-35
36	1989	Impact of Material Management on Productivity A Case Study	FC-36
37	1987	A Model for Retiring, Replacing, or Reassigning Construction Equipment	FC-37
38	1986	Learning Curve Models of Construction Productivity	FC-38
39	1985	Climatic Effects on Construction	FC-39
40	1980	A Diurnal Type Scale Construction Consistency and Validation in Shift Work	FC-40

Table 4-22 Analysis Table for the Factors Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2013	FC-1						1		
2	2012	FC-2								
3	2012	FC-3					1			
4	2011	FC-4								
5	2011	FC-5					1			
6	2011	FC-6				1				
7	2011	FC-7								
8	2010	FC-8								
9	2010	FC-9								
10	2009	FC-10						1		
11	2009	FC-11						1		
12	2009	FC-12								
13	2009	FC-13								
14	2009	FC-14								
15	2009	FC-15								
16	2009	FC-16			1					
17	2008	FC-17			1			1		
18	2007	FC-18			1					
19	2007	FC-19	1				1			
20	2006	FC-20								
21	2005	FC-21			1			1		
22	2005	FC-22			1					

Table 4-22 Analysis Table for the Factors Category (Continued)

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
24	2005	FC-24								
25	2004	FC-25								
26	2004	FC-26			1			1		
27	2004	FC-27								
28	2003	FC-28				1				
29	2002	FC-29								
30	1998	FC-30								
31	1996	FC-31			1					
32	1995	FC-32				1				
33	1995	FC-33								
34	1992	FC-34							1	
35	1990	FC-35								
36	1989	FC-36			1					
37	1987	FC-37								
38	1986	FC-38			1					
39	1985	FC-39			1					
40	1980	FC-40			1		1			

4.2.12 Technologies Analysis Table

4.2.12.1 Introduction

For the Technologies category, 42 papers were examined, with publication dates ranging from 1988 to 2013. This category includes topics such as how automation in CEM can help improve productivity, an assessment of the impact of advanced technologies on construction projects, performance and the development and evaluation of building information modeling (BIM).

4.2.12.2 Analysis Process

Since Table 3-1 indicates that the abbreviation for this category is TC, the code names for this category all start with TC. The code name index for this category is presented in Table 4-23.

Article TC-31 illustrates the analysis process for this category. The authors presented an optimization model designed to assist a general contractor in optimizing the planning of earthmoving operations for heavy civil engineering projects. A genetic algorithm, linear programming, and geographic information systems were applied to the model to support its management functions. Two examples were analyzed in order to validate the model and illustrate its use by inputting the data associated with a real project from a cited article in “Application Examples” section. Based on the final results, the examples demonstrated the ability of the model to minimize both cost and time. Based on Table 3-3, the characteristics of the methodology match the features of Functional Demonstration: 1) reliance on input and output data and 2) validation for an algorithm.

The complete analysis table for the Technologies category is presented as Table 4-24. The rows shaded in grey indicate articles whose authors didn’t apply rigorous validation methodologies.

Table 4-23 Code Name Index for the Technologies Category

#	Year	Article Title	Code Name
1	2013	Generic Model for Measuring Benefits of BIM as a Learning Tool in Construction Tasks	TC-1
2	2013	GIS Method for Haul Road Layout Planning in Large Earthmoving Projects: Framework and Analysis	TC-2
3	2013	Integrating BIM and GIS to improve the Visual Monitoring of Construction Supply Chain Management	TC-3
4	2012	Advanced Formwork Method Integrated with a Layout Planning Model for Tall Building Construction	TC-4

Table 4-23 Code Name Index for the Technologies Category (Continued)

#	Year	Article Title	Code Name
5	2012	Aligning Building Information Model Tools and Construction Management Methods	TC-5
6	2012	Building Information Modeling–Based Analysis to Minimize Waste Rate of Structural Reinforcement	TC-6
7	2012	Construction Workspace Management- The Development and Application of a Novel nD Planning Approach and Tool	TC-7
8	2012	Development of an Optimum Pre-founded Column System for Top-Down Construction	TC-8
9	2012	Estimating Productivity of Earthmoving Operations Using Spatial Technologies1	TC-9
10	2012	Information Lifecycle Management with RFID for Material Control on Construction Sites	TC-10
11	2012	Information Retrieval from Civil Engineering Repositories: Importance of Context and Granularity	TC-11
12	2012	Integrated Building Information Model to Identify Possible Crane Instability Caused by Strong Winds	TC-12
13	2012	Mobile Information System for Sustainable Project Management	TC-13
14	2012	Near Real-Time Motion Planning and Simulation of Cranes in Construction: Framework and System Architecture	TC-14
15	2012	Optimization of In Situ Construction of Concrete Decks: Flexure Tests of Compact Splices of Reinforcement Between Phases	TC-15
16	2012	Optimizing the Schedule of Dispatching Earthmoving Trucks Through Genetic Algorithms and Simulation	TC-16
17	2012	Research on the Modification Control Integrated Technology of Construction Project	TC-17
18	2011	A Distributed Multi-Model-Based Management Information System for Simulation and Decision-Making on Construction Projects	TC-18
19	2011	Assessing Impacts of Information Technology on Project Success Through Knowledge Management Practice	TC-19
20	2011	Evolution of the i-Booth© Onsite Information Management Kiosk	TC-20
21	2011	Integrated Visualized Time Control System for Repetitive Construction Projects	TC-21
22	2011	Integrating Automated Data Acquisition Technologies for Progress Reporting of Construction Projects	TC-22
23	2011	Technical Comparisons of Simulation-Based Productivity Prediction Methodologies by Means of Estimation Tools Focusing on Conventional Earthmovings	TC-23
24	2011	Vision-Based Crane Tracking for Understanding Construction Activity	TC-24
25	2010	Interoperable Leveraging Building Information Modeling Technology in Construction Engineering and Management Education	TC-25

Table 4-23 Code Name Index for the Technologies Category (Continued)

#	Year	Article Title	Code Name
26	2010	Modularization Technology Development and Application for NPP in Korea	TC-26
27	2010	Multi-Agent-Based Simulation System for Construction Operations with Congested Flows	TC-27
28	2009	3D-GIS Based Earthwork Planning System for Productivity Improvement	TC-28
29	2009	Evaluating Industry Perceptions of Building Information Modeling (BIM) Impact on Construction	TC-29
30	2009	Integrating Resource Production and Construction Using BIM	TC-30
31	2009	Optimization of Earthmoving Operations in Heavy Civil Engineering Projects	TC-31
32	2009	Relationship Between Automation and Integration of Construction Information Systems and Labour Productivity	TC-32
33	2008	Building Industrialization: Robotized Assembly of Modular Products	TC-33
34	2008	Case Studies of BIM Adoption for Precast Concrete Design by Mid-sized Structural Engineering Firms	TC-34
35	2008	Construction Process Simulation and Safety Analysis Based on Building Information Model and 4D Technology	TC-35
36	2008	Multi-Objective Simulation-Optimization for Earthmoving Operations	TC-36
37	2004	Long-Term Impact of Equipment Technology on Labour Productivity in the U.S. Construction Industry at the Activity Level	TC-37
38	2004	Time Saving Technology Succeeds for Fairfield Underpass	TC-38
39	2002	Factors in Productivity and Unit Cost for Advanced Machine Guidance	TC-39
40	1998	Automation of Existing Tower Cranes: Economic and Technological Feasibility	TC-40
41	1993	Cranium-Device for Improving Crane Productivity and Safety	TC-41
42	1988	Partially Automated Grading: Construction Process Innovation	TC-42

Table 4-24 Analysis Table for the Technologies Category

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
1	2013	TC-1						1		
2	2013	TC-2						1		
3	2013	TC-3						1		
4	2012	TC-4						1		
5	2012	TC-5								
6	2012	TC-6						1		
7	2012	TC-7						1		
8	2012	TC-8						1		
9	2012	TC-9						1		
10	2012	TC-10	1							
11	2012	TC-11					1			
12	2012	TC-12						1		
13	2012	TC-13								
14	2012	TC-14						1		
15	2012	TC-15	1							
16	2012	TC-16						1		
17	2012	TC-17								
18	2011	TC-18						1		
19	2011	TC-19			1					
20	2011	TC-20								
21	2011	TC-21						1		
22	2011	TC-22								

Table 4-24 Analysis Table for the Technologies Category (Continued)

#	Year	Code Name	Validation Methodologies (If applied, enter a 1; otherwise, leave blank.)							
			Experimental Studies	Observational Studies	Empirical Studies	Case Studies	Surveys	Functional Demonstration	Archival Data Analysis	Others
24	2011	TC-24		1						
25	2010	TC-25								
26	2010	TC-26						1		
27	2010	TC-27						1		
28	2009	TC-28						1		
29	2009	TC-29								
30	2009	TC-30						1		
31	2009	TC-31						1		
32	2009	TC-32			1		1			
33	2008	TC-33						1		
34	2008	TC-34								
35	2008	TC-35								
36	2008	TC-36						1		
37	2004	TC-37			1				1	
38	2004	TC-38								
39	2002	TC-39								
40	1998	TC-40			1					
41	1993	TC-41	1							
42	1988	TC-42								

Chapter 5
Analysis and Discussion of Results

5.1 Introduction

The data acquired from the examination of numerous articles related to construction engineering and management (CEM) research are shown in Tables 4-1 to 4-24. This chapter presents the comprehensive analysis of the data that was conducted in order to determine trends in the application of validation methodologies in CEM studies. The analysis and discussion focused on three areas: 1) the most popular validation methodologies employed in each source category, 2) the source categories for which each specific validation methodology is most frequently used, 3) changes in the application of validation methodologies over time and 4) the relationship between the degree of validation and the number of citations. The methods by which the results of this analysis were validated are also described.

5.2 Distribution of Validation Methodologies in Each Source Category

5.2.1 Summary of Distribution Results

The distribution of validation methodologies in each source category is shown in Table 5-1. The percentage of the number of times each validation methodology was reported in a specific source category i was calculated as Equation 5-1.

$$\boldsymbol{p_{xi} = \frac{n_{xi}}{N_i} * 100\%} \qquad \textbf{(5.1)}$$

where p_{xi} indicates the percentage of validation methodology x in source category i, n_{xi} represents the number of articles reporting validation methodology x in source category i, and N_i indicates the total number of articles in category i. The detailed analysis and discussion of the results for each category are presented in the following subsections.

5.2.2 Analysis and Discussion of Distribution Results

This subsection includes a number of figures that display the distribution results for each validation methodology. The vertical axis indicates the percentage of the occurrence of each validation methodology relative to the total number of papers in the corresponding source category, and the horizontal axis identifies each validation methodology. For readability purposes, each methodology is represented by a letter, as shown in Table 5-1: A = Experimental Studies, B = Observational Studies, C = Empirical Studies, D = Case Studies, E = Surveys, F = Functional Demonstration, G = Archival Data Analysis and H = Unclear Validation.

Table 5-1 Summary of Validation Methodology Distribution Results for Each Source Category

	Validation Methodologies								
Source Category	Experimental Studies (A)	Observational studies (B)	Empirical Studies (C)	Case Studies (D)	Surveys (E)	Functional Demonstration (F)	Archival Data Analysis (G)	Unclear Validation (H)	Others
CN	2.27 %	0.00 %	9.09 %	15.91 %	9.09 %	9.09 %	2.27 %	52.27 %	
ZA	4.88 %	0.00 %	4.88 %	29.27 %	17.07 %	4.88 %	2.44 %	36.59 %	
RL	3.70 %	0.00 %	3.70 %	0.00 %	0.00 %	74.07 %	0.00 %	18.52 %	
AL	0.00 %	0.00 %	12.50%	8.33 %	16.67 %	12.50 %	4.17 %	45.83 %	
KM	0.00 %	0.00 %	10.00 %	23.33 %	6.67 %	13.33 %	0.00 %	46.67 %	
RM	0.00 %	0.00 %	3.23 %	0.00 %	6.45 %	54.84 %	0.00 %	35.48 %	
CP	0.00 %	0.00 %	18.60 %	6.98 %	20.93 %	13.95 %	0.00 %	39.53 %	
CT	0.00 %	0.00 %	28.57 %	4.76 %	33.33 %	4.76 %	0.00 %	28.57 %	
SL	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	81.08 %	0.00 %	18.92 %	
SS	0.00 %	0.00 %	0.00 %	0.00 %	33.33 %	66.67 %	0.00 %	0.00 %	
FC	2.22 %	0.00 %	24.44 %	6.67 %	8.89 %	15.56 %	2.22 %	40.00 %	
TC	6.82 %	2.27 %	11.36 %	0.00 %	4.55 %	45.45 %	2.27 %	27.27 %	

Legend:

Name of Category	Abbreviation	Name of Category	Abbreviation
Constructability	CN	Contract and Project Delivery	CP
Zero Accident Technique	ZA	Craft Training	CT
Resource Leveling	RL	Site Layout	SL
Alignment	AL	Short-Term Scheduling	SS
Knowledge Management	KM	Factors	FC
Risk Management	RM	Technologies	TC

5.2.2.1 Category Constructability

43 papers are examined in this category. The percentage of validation methodologies in Category Constructability is plotted in histogram which is shown in Figure 5-1.

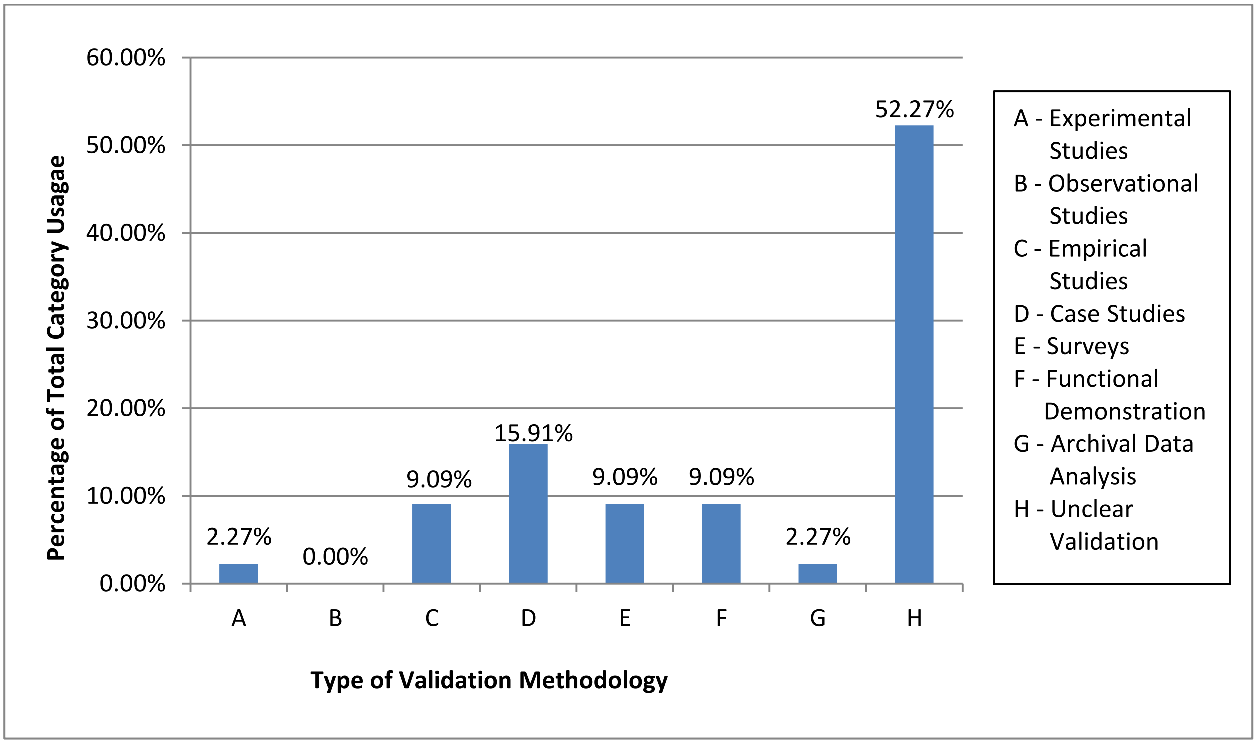

Figure 5-1 Distribution of Validation Methodologies Used in the Constructability Category

The figure clearly shows that more than half of the papers didn't mention clear validation methodology. The highest percentage of studies used the Case Studies methodology (D): 15.91 %. The second highest percentages are Empirical Studies (C), Surveys (E) and Functional Demonstration (F). Only a few papers applied the Experimental Studies (A), and Archival Data Analysis (G) methodologies, and none employed Observational Studies (B).

To explore why 52.27% of the papers reported validation methodology that was unclear, the content and structure of those papers were checked one by one. The goal of some was to illustrate or review a concept or an idea related to the topic of constructability. The authors of those papers, such as CN-12, CN-19, CN-21, and CN-23, applied research methodologies such as case studies or synthesized reviews in order to explain their ideas. Rigorously validating papers that are descriptive is not easy because quantitative data or similar cases/examples may be lacking. It is also possible that some authors who don't employ clear validation methodologies are unaware of the importance of the validation process. Another possible reason is that some research methodologies are quite scientific, and the authors may consider that their studies have been applied using a rigorous and scientific research approach so that the results have already been legitimated. For example, the authors of paper CN-36 compared two formal constructability programs, including the attributes of the two programs as well as the costs and benefits at both the corporate and project levels. The data related to attributes, costs, and benefits were collected from two organizations, and the analysis results, such as records of the attributes and calculations of ratios, were clearly presented in tables and figures. The authors concluded that the benefit/cost ratios for both programs show the potential return on investment of the constructability program. In this situation, when the results are convincing, researchers do not feel the need to implement a validation process.

The Case Studies methodology shows the highest percentage of usage of all of the validation methodologies, and with good reason. The most common topics in this category focus on the impact of constructability and improvements in constructability practices. As listed in Table 3-3, the major features of case studies include intensive analysis of a particular matter. To demonstrate the impact of and improvement in constructability practices, researchers conduct intensive analysis of specific cases, so that the Case Studies methodology is often the most appropriate technique. The uniqueness of construction projects means that experimental studies are rarely conducted, and the lack of quantitative data results in the infrequent use of archival data analysis. Observational studies involve the use of cameras and audio devices, which are unsuitable for this type of study.

5.2.2.2 Zero Accident Techniques Category

The percentages that represent the usage of the validation methodologies reported in the 37 Zero Accident Techniques papers were plotted as a histogram, as shown in Figure 5-2.

The figure shows that 36.59 % of the papers examined contain no mention of clear validation methodologies, which is the highest percentage. Of the methodologies employed, the Case Studies (D) methodology has the highest usage percentage: 29.27 %. The Surveys (E) methodology follows as the second highest percentage, with the percentages for the Experimental Studies (A), Empirical Studies (C), Functional Demonstration (F), and Archival Data Analysis (G) methodologies indicating relatively low usage. None of the papers examined reported the application of the Observational Studies (B) methodology.

The reasons for 36.59 % of the papers having reported validation methodology that was not clear are similar to those for the Constructability category. Many of the papers in this category are descriptive with respect to the topic of safety, and again, some authors may not appreciate the importance of validation. The Case Studies methodology has the highest percentage of usage, and Surveys has the second highest because, compared to other methods, case studies and surveys represent more appreciate and easier ways to validate the results of improvements in safety and the implementation of safety measures, which are the popular topics related to the Zero Accident Techniques category. As mentioned in subsection 2.3.2.5, appropriately designed surveys can help researchers convert qualitative data related to zero accident techniques into quantitative data. However, observational studies involve the use of cameras and audio devices, which have not been considered suitable for application in this area. An additional methodology not included in the seven types investigated is the Delphi method, which was employed for validating the results of the study presented in paper ZA-16.

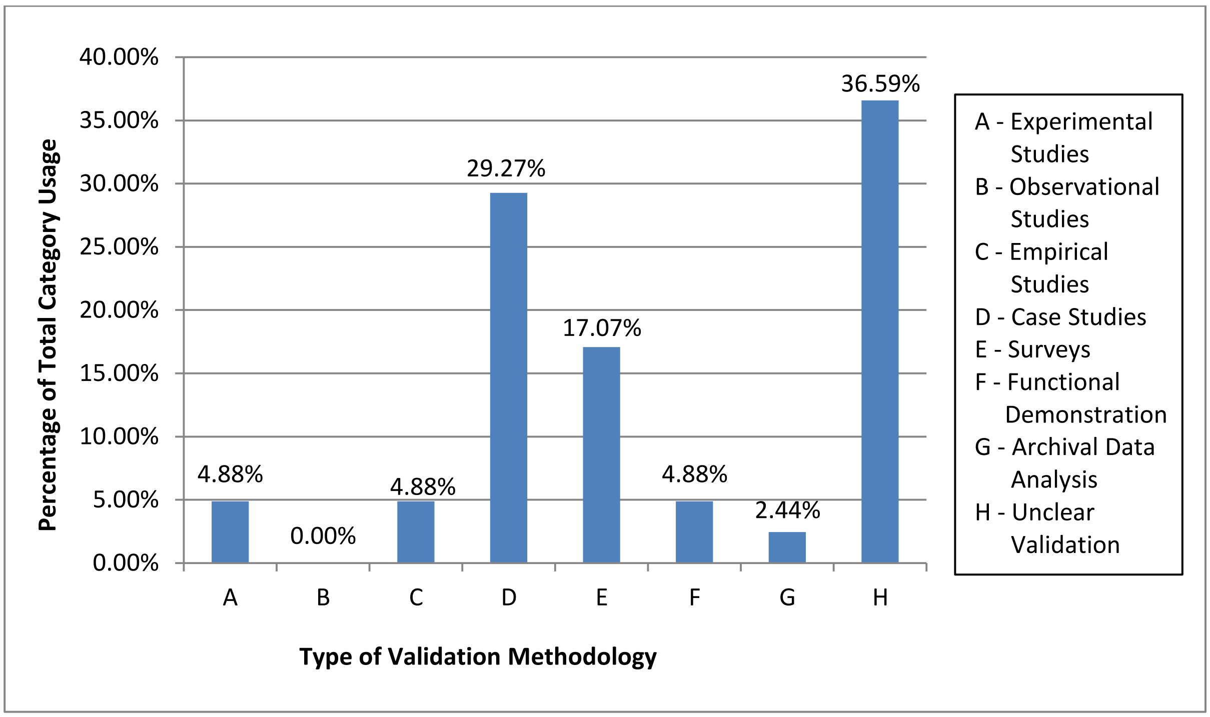

Figure 5-2 Distribution of Validation Methodologies Used in the Zero Accident Techniques Category

5.2.2.3 Resource Leveling Category

The percentages that represent the usage of the validation methodologies reported in the 28 Resource Leveling papers were plotted as a histogram, as shown in Figure 5-3.

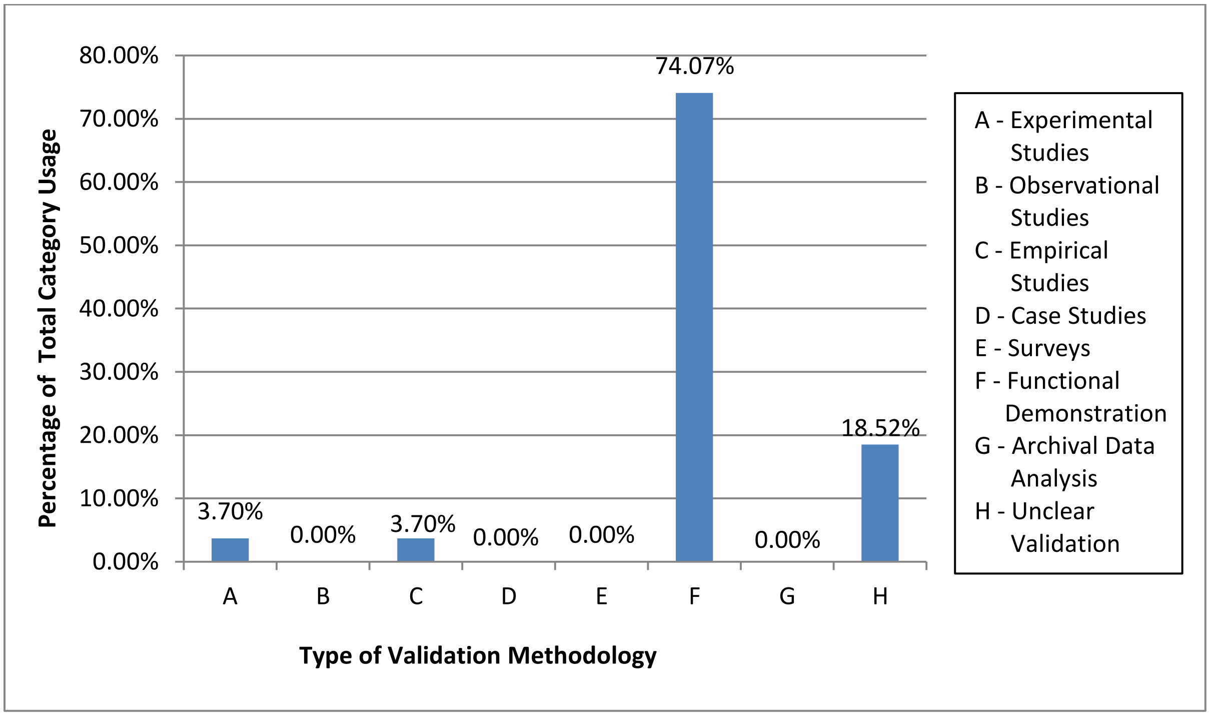

Figure 5-3 Distribution of Validation Methodologies Used in the Resource Leveling Category

As shown in Figure 5-3, in most of the studies examined the Functional Demonstration methodology (F) was applied in order to validate research results: 74.07 % of the papers. The papers that contained unclear validation methodologies represent 18.52 % of the total, a lower percentage than in the previous two categories. The Experimental Studies (A) and Empirical Studies (C) methodologies each show 3.70 % usage, and the application of other validation methodologies was not reported in the papers in this category.

As is quite obvious from Figure 5-3, most researchers applied the Functional Demonstration methodology. As indicated in Table 3-3, functional demonstration involves logic, input, assumptions, and output related to modeling and simulation, algorithms, or programs, etc. Of the 21 papers in this category in which the results were validated, 20 focused on topics that include modeling and simulation approaches and algorithms for resource leveling. Considering the features of functional demonstration, validating the results by this methodology would be easy and could be accomplished through three steps: first, collect data from specific real projects or obtain data from hypothetical examples; second, apply the data to the models, algorithms, or systems; and third, compare the results with the actual ones or evaluate the performance of the models, algorithms, or systems. Only one paper reported validation through the Experimental Studies methodology: RL-16. The author conducted computational experiments and obtained sets of data so that statistical analysis could be applied to the data. However, for the same reasons as in the other categories, 18.52 % of the papers didn't employ rigorous validation methodologies.

5.2.2.4 Alignment Category

The percentages that represent the usage of the validation methodologies reported in the 22 Alignment category papers were plotted as a histogram, as shown in Figure 5-4.

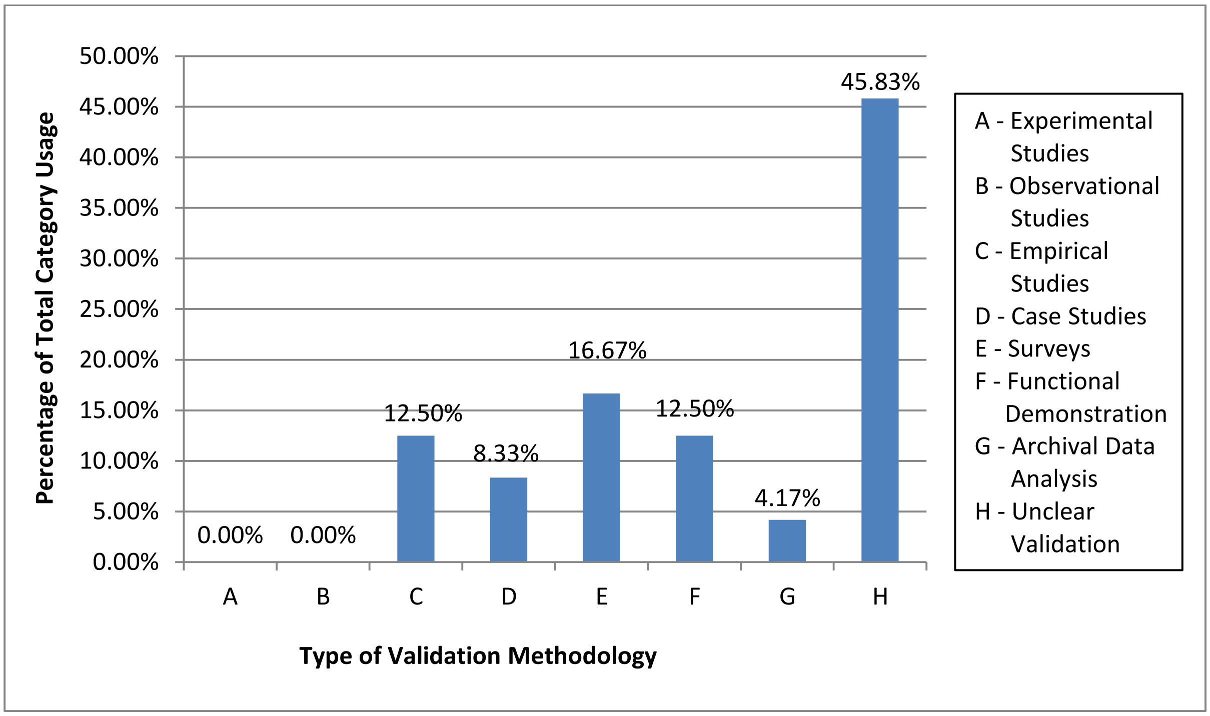

Figure 5-4 Distribution of Validation Methodologies Used in the Alignment Category

Figure 5-4 clearly shows that the results from half of the studies in this category were not rigorously validated. The Surveys methodology (E) was reported in 16.67 % of the papers, which ranks as the highest percentage compared with the other validation methodologies. The Empirical Studies (C) and Functional Demonstration (F) methodologies were each used in 12.5 % of the studies; the Case Studies (D) methodology was used in 8.33 %, and the Archival Data Analysis methodology in 4.17 %, which is relatively low. None of the researchers applied either the Experimental Studies (A) or the Observational Studies (B) methodology.

Due to the descriptive nature of a number of the papers in this category and the lack of quantitative data, 45.83 % of the papers employed unclear validation process. Surveys are a good approach for converting qualitative data into quantitative data, which explains why the Surveys methodology is associated with the highest usage percentage of all of the methodologies. The studies in which the Functional Demonstration methodology was applied all focus on models, tools, and simulations. Because the research data for this category is not easy to collect, only three of 22 papers reported the collection of data from real projects or the validation of the hypothesis through statistical analysis although it accounts for the second ranking percentage associated with the Empirical Studies methodology. Both the Experimental Studies and the Observational Studies methodologies are unsuitable for this category because of the difficulty of obtaining quantitative data.

5.2.2.5 Knowledge Management Category

The percentages that represent the usage of the validation methodologies reported in the 28 Knowledge Management papers were plotted as a histogram, as shown in Figure 5-5.

As shown in Figure 5-5, half of the papers in this category didn't report clear validation methodologies. Of all the validation methodologies mentioned, Case Studies (D) was used most often: 23.33 %. The second highest percentage, 13.33 %, represents the Functional Demonstration (F) methodology. The Empirical Studies (C) and Surveys (E) methodologies both show relatively low usage. None of the studies included the Experimental Studies (A), Observational Studies (B), or Archival Data Analysis (G) methodologies.

The reasons for 46.67 % of the papers not reporting any validation methodology are similar to the ones previously mentioned for the other categories. The characteristics of research in the Knowledge Management category make it suitable for validation through case studies since researchers can conduct intensive analysis of a particular matter using that methodology. The Functional Demonstration methodology is appropriate for the validation of models, simulations, and algorithms, and because a few authors focused on models and systems of knowledge management, in 13.33 % of the studies, the results were validated using this methodology. Experimental studies, observational studies, and archival data analysis cannot be easily applied in this category because quantitative data are difficult to obtain.

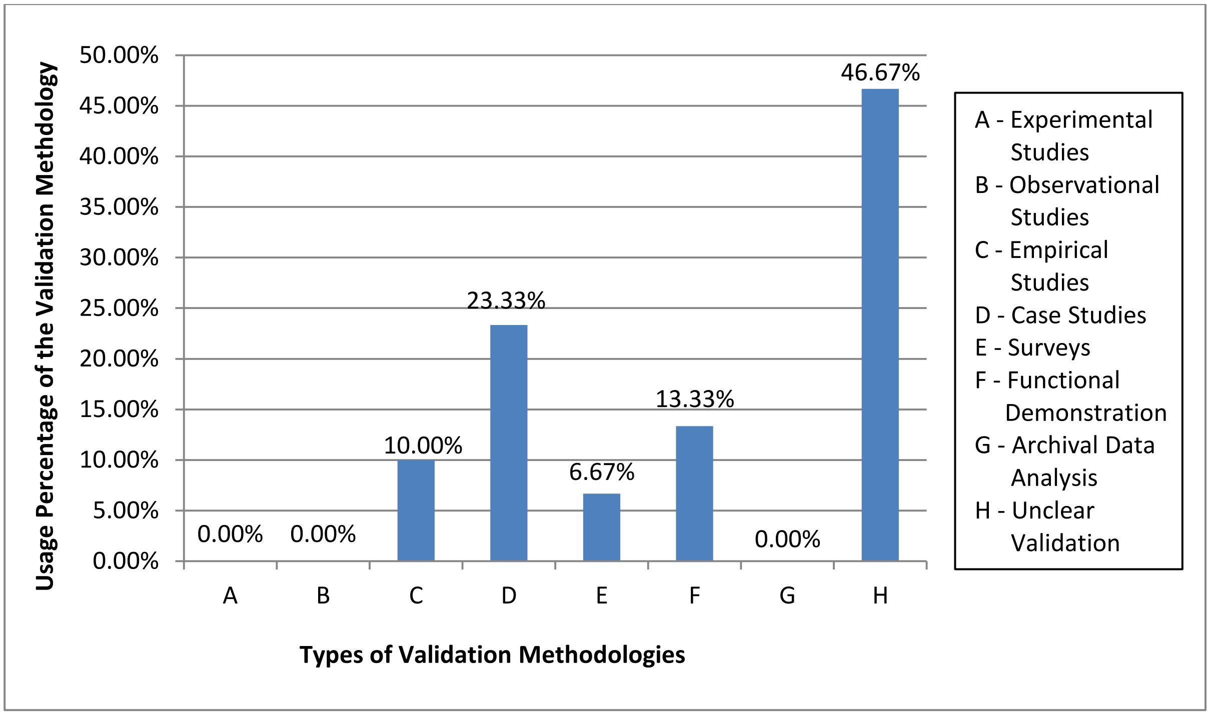

Figure 5-5 Distribution of Validation Methodologies Used in the Knowledge Management Category

5.2.2.6 Risk Management Category

The percentages that represent the usage of the validation methodologies described in the 29 Risk Management papers were plotted as a histogram, as shown in Figure 5-6.

As is evident from Figure 5-6, the Functional Demonstration (F) methodology has the highest usage percentage: 54.84 %. With respect to the other validation methodologies, 6.45 % papers described the application of the Surveys (E) methodology, and only a few researchers applied the Empirical Studies (C) methodology. None of the papers reported the Experimental Studies (A), Observational Studies (B), Case Studies (D), or Archival Data Analysis (G) methodologies. In 35.48 % of the papers, validation methodology that was unclear was mentioned.

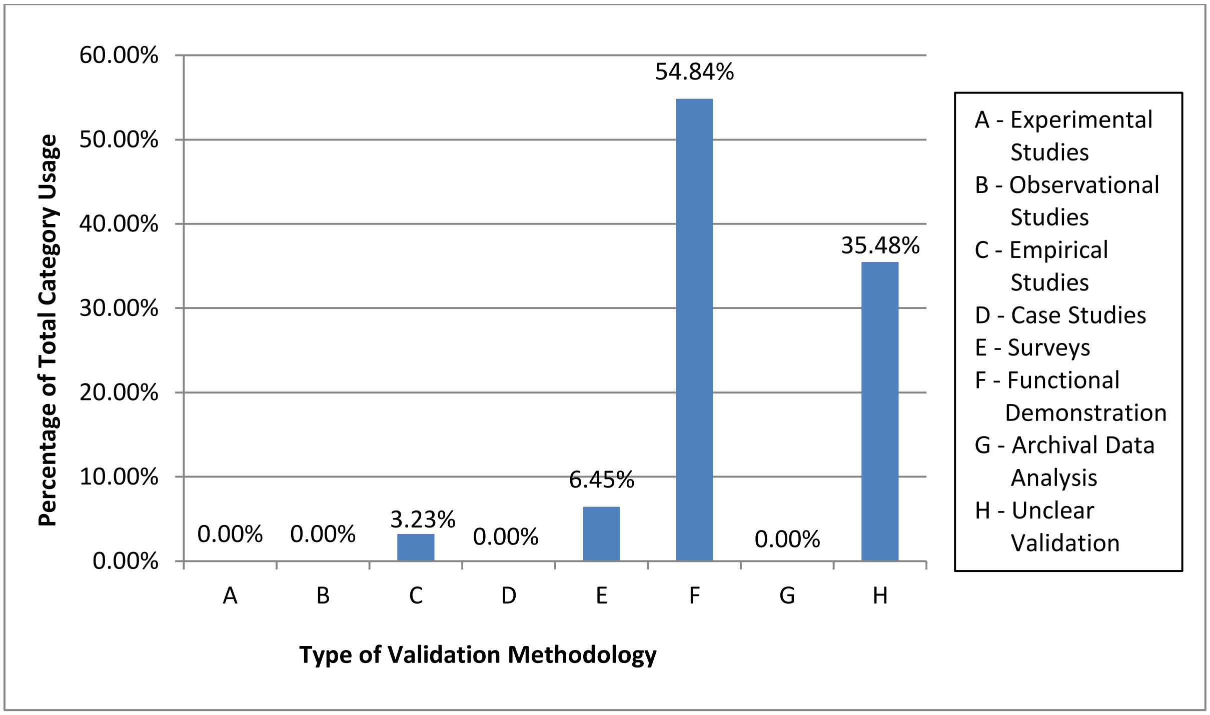

Figure 5-6 Distribution of Validation Methodologies Used in the Risk Management Category

A number of the papers in this category focus on models, programs, and approaches for assessing and managing risk, which make functional demonstration a good methodology for validating the research results. Surveys are also suitable for validating the results produced by systems, and they were applied along with functional demonstration by the authors of two papers: RM-16, in which the authors reported interviews with a number of experts who were asked to evaluate the model, and RM-4, in which interviews with 25 industry practitioners from 18 different construction companies were described. For the same reasons mentioned previously, unclear validation methodologies were employed in 35.48 % of the studies.

5.2.2.7 Contract and Project Delivery Category

The percentages that represent the usage of the validation methodologies reported in the 40 Contract and Project Delivery papers were plotted as a histogram, as shown in Figure 5-7.

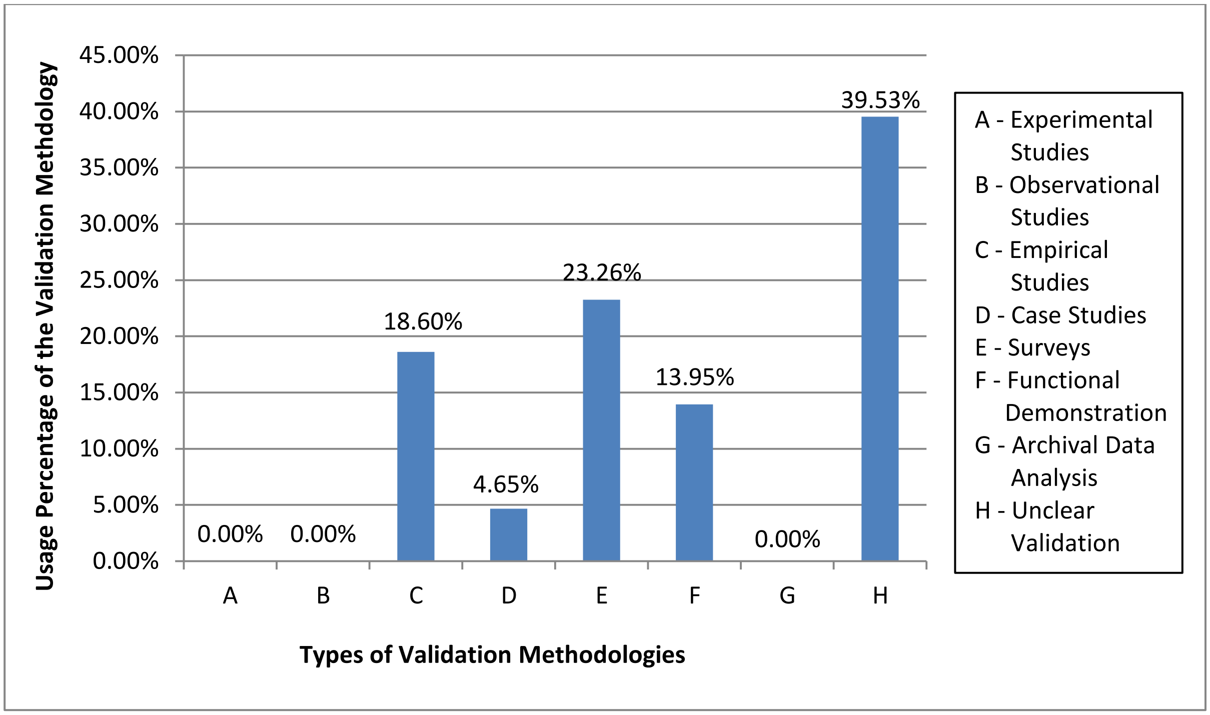

Figure 5-7 Distribution of Validation Methodologies Used in the Contract and Project Delivery Category

As shown in Figure 5-7, in 39.53% of the papers in this category validation methodology that was unclear was reported. The methodology most frequently used was Surveys (E), at 23.26 %. The Empirical Studies (C) methodology accounts for the second highest percentage: 18.60 %. The rates for the Functional Demonstration (F) and Case Studies (D) methodologies are relatively low, and none of the papers mentioned the Experimental Studies (A), Observational Studies (B), or Archival Data Analysis (G) methodologies.

The highest percentage represents studies in which unclear validation methodology was applied because the descriptive nature of a number of the studies in this category makes it difficult to employ a validation methodology. Since the topics focus on methods of delivering a contract and project, it is easier to conduct surveys about the delivery methods than to implement functional demonstration, which requires the input of data and comparisons with the results of real projects. Surveys, on the other hand, entail only carefully designed questionnaires or interviews, which explains why the percentage associated with the Surveys methodology is higher than that linked to the Functional Demonstration methodology. Empirical studies are suitable for research that involves a hypothesis or a model, and 18.60 % of the papers describe the development of models of or a hypothesis about the delivery of a contract and project. Experimental studies, observational studies, and archival data analysis are difficult to apply in this category because quantitative data are not easy to acquire.

5.2.2.8 Craft Training Category

The percentages that represent the usage of the validation methodologies reported in the 17 Craft Training papers were plotted as a histogram, as shown in Figure 5-8.

Figure 5-8 reveals that the Surveys (E) methodology has the highest usage percentage: 33.33 %. The second highest is the Empirical Studies (C) methodology, at28.57 %. The Case Studies (D) and Functional Demonstration (F) methodologies are associated with a relatively low percentage: 4.76 % each. No rigorous validation process was reported in 28.57 % of the papers, and none of the studies applied the Experimental Studies (A), Observational Studies (B), or Archival Data Analysis (G) methodologies.

The reasons why validation methodology that was unclear was reported in 28.57 % of the papers are as the same as for the categories previously discussed. Researchers apply surveys to confirm their results in this category because of the easily achievable twofold requirements of this methodology: the careful design of the interview or questionnaire and the invitation of the appropriate people to participate. In the papers that describe the use of the Empirical Studies methodology, for the statistical validation of their results, the authors obtained access to data from industry sources. Only a few topics in this category are related to modeling and simulation, which explains why the Functional Demonstration percentage is relatively low. The difficulty of obtaining quantitative data in this category makes the use of experimental studies, observational studies, and archival data analysis challenging.

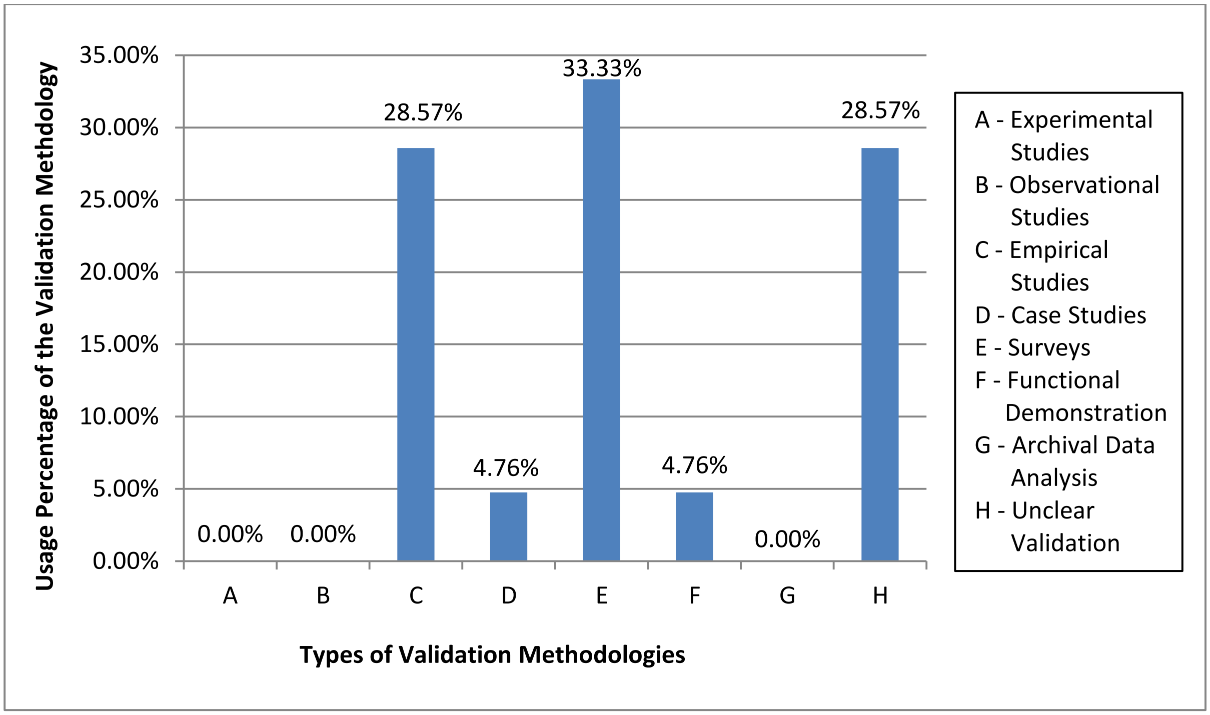

Figure 5-8 Distribution of Validation Methodologies Used in the Craft Training Category

5.2.2.9 Site Layout Category

The percentages that represent the usage of the validation methodologies employed in the 37 Site Layout papers were plotted as a histogram, as shown in Figure 5-9.

Functional Demonstration (F) is clearly the only validation methodology applied in this category, and only 18.92 % of the papers didn't report any rigorous validation methodology, for the reasons previously mentioned. Most of the papers in this category are about modeling and simulation, algorithms, and optimization methods, which are topics that typically lend themselves to validation through functional demonstration.

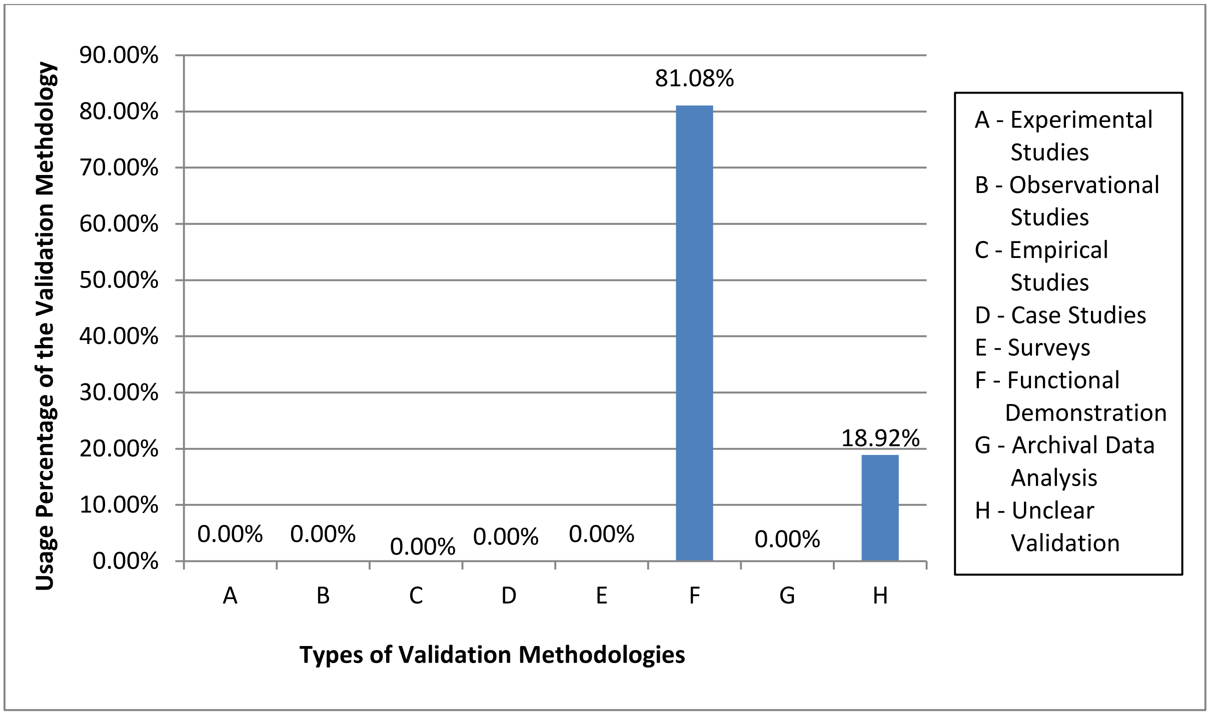

Figure 5-9 Distribution of Validation Methodologies Used in the Site Layout Category

5.2.2.10 Short-Term Scheduling Category

The percentages that represent the usage of the validation methodologies reported in the three Short-Term Scheduling papers were plotted as a histogram, as shown in Figure 5-10.

As shown in Figure 5-10, the Functional Demonstration (F) methodology accounts for the highest usage percentage: 66.67 %. The technique used in 33.33 % of the papers was the Surveys (E) methodology.

The investigations related to systems and programming were validated through functional demonstration. However, the sample size of this category is too small for a confident conclusion because only a very limited number of papers could be found, and further research is therefore needed.

5.2.2.11 Factors Category

The percentages that represent usage of the validation methodologies reported in the 40 Factors papers were plotted as a histogram, as shown in Figure 5-11.

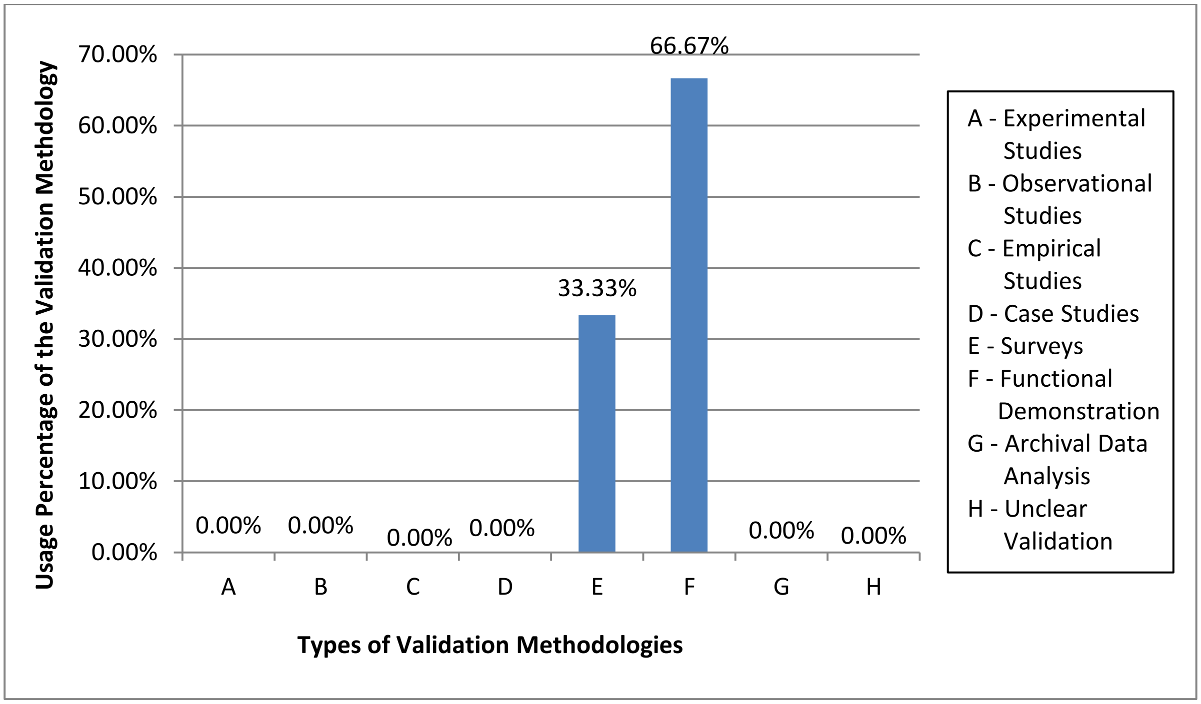

Figure 5-10 Distribution of Validation Methodologies Used in the Short-Term Scheduling Category

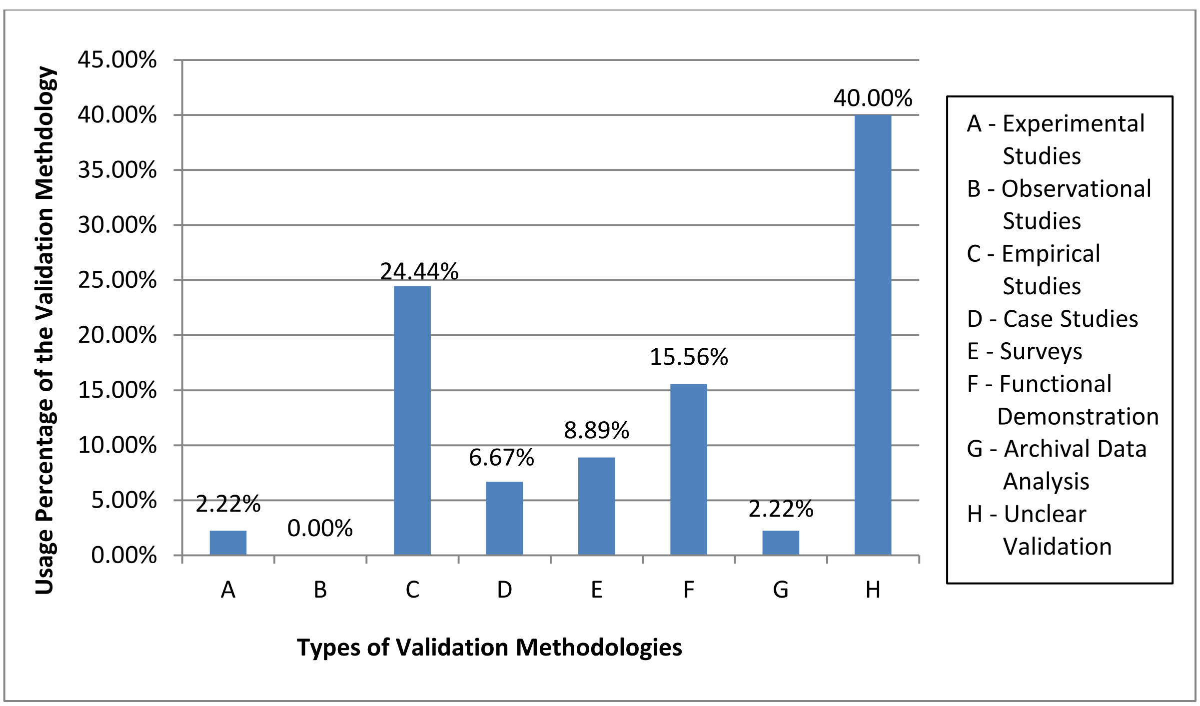

Figure 5-11 Distribution of Validation Methodologies Used in the Factors Category

As shown in Figure 5-11, 40.00 % of the papers in this category didn't describe a clear validation methodology. Of the validation methodologies employed, Empirical Studies (C) accounts for 24.44 % of the usage, and Functional Demonstration accounts for 15.56 % of the usage, which are relatively higher rates than those associated with the other validation methodologies. The Case Studies (D) and Surveys (E) methodologies represent 6.67 % and 8.89 % of the usage, respectively, and the Experimental Studies (A) and Archival Data Analysis (G) methodologies each constitute 2.22 %. The only type of validation methodology not encountered in this category is Observational Studies (B).

The absence of any mention of a validation methodology in 40.00 % of the papers can be attributed to the same reasons explained previously. A number of the studies in this category investigated the relationship between the factors and labour productivity as well as the modeling and simulation of the impact of the factors. Empirical studies help researchers validate their results with the use of empirical data. Functional demonstration provides a means of validating a model through a demonstration of the validity of the simulation or systems. For these reasons, the Empirical Studies and Functional Demonstration methodologies are used relatively more frequently than the other methods. The work presented in the paper that described the application of the Experimental Studies and Surveys methodologies was validated through interviews with the members of the treated and control groups, thus enabling the authors to conduct statistical analysis of the data. Since the effects of scheduled overtime on labour productivity had been previously studied by numerous researchers, the authors of paper FC-34 were able to validate their results with the use of the Archival Data Analysis methodology.

5.2.2.12 Technologies Category

The percentages that represent the usage of the validation methodologies reported in the 42 Technologies papers were plotted as a histogram, as shown in Figure 5-12.

Figure 5-12 shows that the Functional Demonstration (F) methodology is associated with the highest usage percentage: 45.45 %. The Empirical Studies (C) methodology ranks second, at 11.36 %, followed by the Experimental Studies (A) methodology, at 6.82 %. The Observational Studies (B), Surveys (E), and Archival Data Analysis (G) methodologies all represent relatively low percentages. None of the papers reported the use of the Case Studies (D) methodology. For the same reasons mentioned previously, in 27.27 % of the studies, the results were not rigorously validated.

The papers in this category focus on advanced technologies, such as automation and BIM, so researchers are easily able to apply functional demonstration as a means of validating their results. A few are able to acquire access to data from industry sources, enabling them to validate their models and hypothesis through empirical studies. Paper TC-24 describes the use of a surveillance camera to help validate the results.

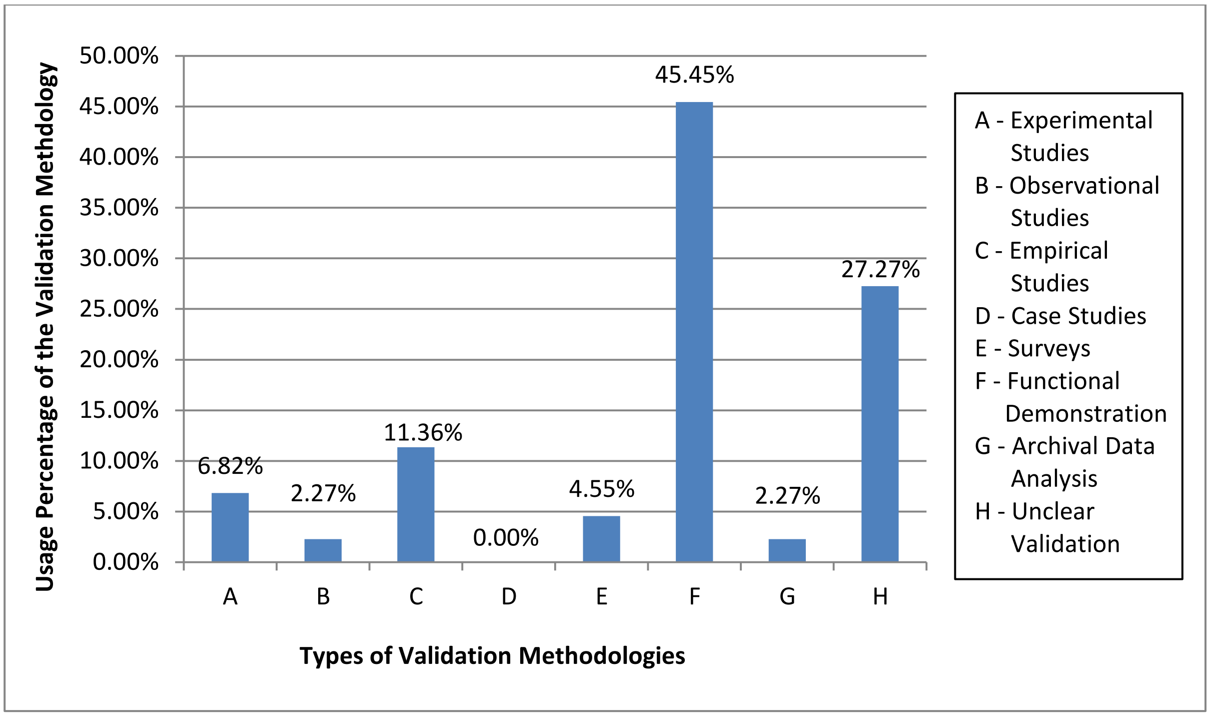

Figure 5-12 Distribution of Validation Methodologies Used in the Technologies Category

5.2.3 Summary

Section 5.2 has presented the analysis and discussion of the distribution of the validation methodologies in each source category. Some of the papers report application of a validation methodology that was unclear for two main reasons: first, some authors are unaware of the importance of the validation process; second, some papers are too descriptive to support the application of any validation methodology. As shown in the figures included in this section, each source category involved the use of specific, commonly applied validation methodologies. Researchers who are investigating topics in these categories may therefore want to consider these frequently used methodologies so that they can select the most appropriate technique when attempting to validate the results of their studies. Based the highest usage percentages, Table 5-2 summarizes the validation methodologies recommended for each source category.

Table 5-2 Top Validation Methodologies in Each Source Category

Source Category	Top Validation Methodologies
Constructability	Case Studies
Zero Accident Techniques	Case Studies and Surveys
Resource Leveling	Functional Demonstration
Alignment	Surveys
Knowledge Management	Case Studies
Risk Management	Functional Demonstration
Contract and Project Delivery	Surveys
Craft Training	Empirical Studies and Surveys
Site Layout	Functional Demonstration
Short-Term Scheduling	Functional Demonstration
Factors	Empirical Studies and Functional Demonstration
Technologies	Functional Demonstration

5.3 Distribution of Source Categories for Each Type of Validation Methodology

5.3.1 Summary of Distribution Results

5.3.1.1 Introduction

The distribution of the source categories for which each validation methodology is reported is shown in Table 5-3. The percentage of each source category for which a specific validation methodology x was used is calculated as follows:

$$\boldsymbol{q_{xi}} = \frac{\frac{\boldsymbol{n_{xi}}}{\boldsymbol{N_i}}}{\sum_{\boldsymbol{i=CN}}^{\boldsymbol{TC}}\left(\frac{\boldsymbol{n_{xi}}}{\boldsymbol{N_i}}\right)} * \mathbf{100}\% \qquad \textbf{(5.2)}$$

where q_{xi} indicates the percentage of the papers in source category i that reported validation methodology x, n_{xi} represents the number of occurrences of validation methodology x in source category i, and N_i means the total number of articles in category i.

5.3.1.2 Illustrations of Equation 5-2

The percentage q_{xi} can only be obtained by Equation 5-2 instead of being obtained by equation $\boldsymbol{p_{xi}} = \frac{\boldsymbol{m_{xi}}}{\boldsymbol{M_i}} * \mathbf{100}\%$, where m_{xi} represents the number of articles that reported validation methodology x in category i and M_i means the total number of examined articles that reported validation methodology x.

The reasons are follows. The total numbers of examined papers, $\mathrm{N}_{i,}$ in each category are not equal. Therefore, the value of m_{xi} can be affected by the value of N_i in category i. Let's take Archival Data Analysis methodology as an example. There are 5 papers repoting this validation methodology, one in Constructability category, one in Zero Accident Technique category, one in Alignment category, one in Factors category and one in Technology category. According to equation $\boldsymbol{p_{xi}} = \frac{\boldsymbol{m_{xi}}}{\boldsymbol{M_i}} * \mathbf{100}\%$, the percentage of the papers in each source category mentioned above is 20%, which means the five categories domain this validation methodology equally. However, if we double the total number of examined papers in Constructability category, the number of papers reporting Archival Data Analysis in Constructability category will be changed into 2. Consequently, the most dominant category for this validation methodology will be changed into Constructability category.

To solve this problem, the number of papers that reported each validation methodology in category i needs to be converted into percentage which is calculated as $\frac{\boldsymbol{n_{xi}}}{\boldsymbol{N_i}} * \mathbf{100}\%$. The percentage of papers that reported validation methodology x in category i are not affected by the total number of examined papers in category i. Also, the total number of examined papers in each category can be regarded as the same as 100%. Therefore, we have the equation of calculating the percentage of the papers in source category i that reported validation methodology x: $q_{xi} = \frac{\frac{n_{xi}}{N_i}}{\sum_{i=CN}^{TC}\left(\frac{n_{xi}}{N_i}\right)} * 100\%$.

Table 5-3 Source Category Distribution Results for Each Validation Methodology

Validation Methodologies	Source Category	CN	ZA	RL	AL	KM	RM	CP	CT	SL	SS	FC	TC
	Experimental Studies	11.42 %	24.52 %	18.62 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	11.17 %	34.27 %
	Observational Studies	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	100.00 %
	Empirical Studies	7.19 %	3.86 %	2.93 %	9.89 %	7.91 %	2.55 %	22.61 %	22.61 %	0.00 %	0.00 %	19.34 %	8.99 %
	Case Studies	17.12 %	31.50 %	0.00 %	8.97 %	25.11 %	0.00 %	5.01 %	5.12 %	0.00 %	0.00 %	7.17 %	0.00 %
	Surveys	5.71 %	10.72 %	0.00 %	10.46 %	4.18 %	4.05 %	14.60 %	20.92 %	0.00 %	20.92 %	5.58 %	2.85 %
	Functional Demonstration	2.29 %	1.23 %	18.70 %	3.16 %	3.37 %	13.84 %	3.52 %	1.20 %	20.47 %	16.83 %	3.93 %	11.47 %
	Archival Data Analysis	16.99 %	18.24 %	0.00 %	31.16 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	16.62 %	16.99 %
	Unclear Validation	13.42 %	9.39 %	4.75 %	11.76 %	11.98 %	9.11 %	10.15 %	7.33 %	4.86 %	0.00 %	10.27 %	7.00 %

Legend:

Name of Category	Abbreviation	Name of Category	Abbreviation
Constructability	CN	Contract and Project Delivery	CP
Zero Accident Technique	ZA	Craft Training	CT
Resource Leveling	RL	Site Layout	SL
Alignment	AL	Short-Term Scheduling	SS
Knowledge Management	KM	Factors	FC
Risk Management	RM	Technologies	TC

5.3.2 Analysis and Discussion of Distribution Results

The detailed analysis and discussion of the results related to each validation methodology are presented in this section. A number of figures display the distribution results for each validation methodology. The vertical axis shows the percentage of the total number of papers in each source category that reported the use of that validation methodology. The horizontal axis represents each source category. For readability purposes, the name of each source category is indicated by two capital letters, as listed in Table 3-1.

5.3.2.1 Experimental Studies

As shown in Figure 5-12, the Experimental Studies methodology was applied most often in the Technologies category (TC): 34.72 %. The second most dominant category for this validation methodology is the Zero Accident Techniques (ZA) category, at 24.52 %. Resource Leveling (RL) accounts for 18.62 % of the papers, and the Constructability (CN) and Factors (FC) categories have relatively low representation. This methodology was not employed for the other categories.

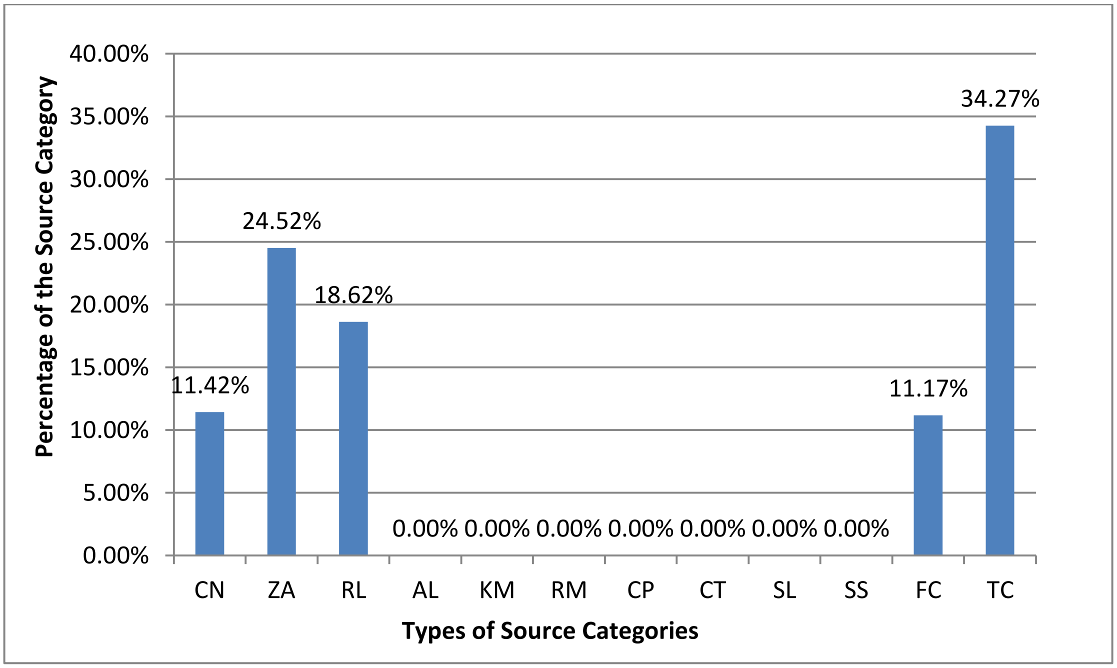

Figure 5-13 Distribution of the Use of Experimental Studies

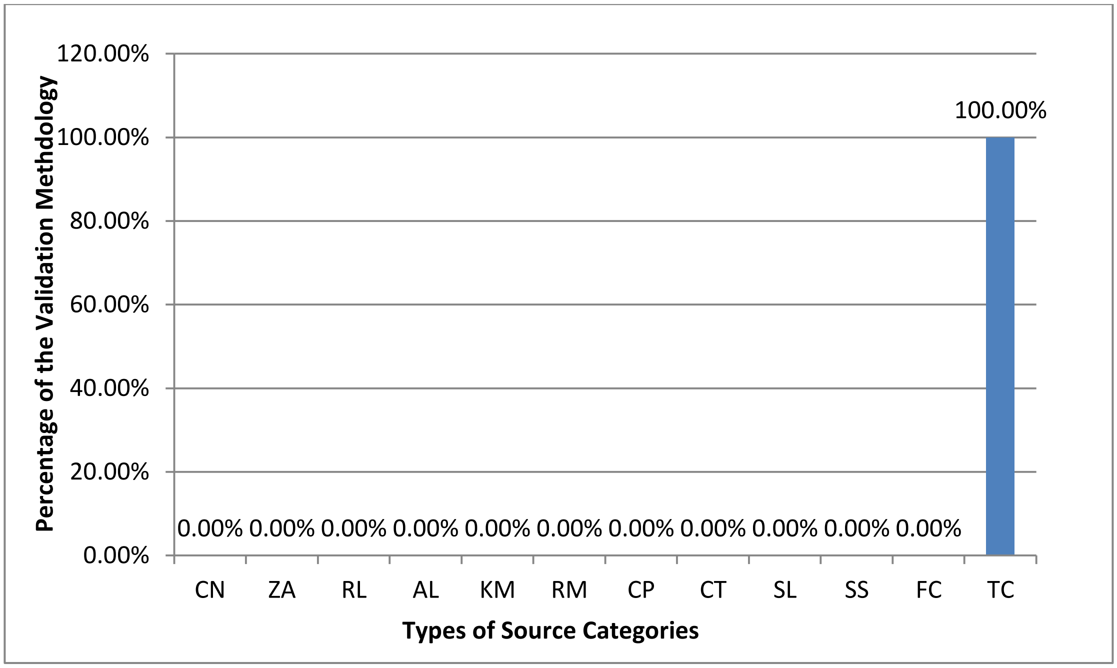

Figure 5-14 Distribution of the Use of Observational Studies

5.3.2.2 Observational Studies

As Figure 5-14 clearly shows, the Technology category (TC) is the only one in which observational studies were applied, primarily because researchers seldom use cameras or microphones in order to validate their research results.

5.3.2.3 Empirical Studies

As shown in Figure 5-15, Craft Training (CT) is the category for which the Empirical Studies methodology was most often employed, followed by the Factors (FC) category, which accounts for 19.34 % of the use of this methodology. The Contract and Project Delivery category (CP) is next, at 14.72 %. The Alignment (AL), Technologies (TC), Constructability (CN) and Knowledge Management (KM) categories did not entail very great use of the Empirical Studies methodology, and percentages for these categories range from 5 % to 10 %. The rates of use in the Zero Accident (ZA), Resource Leveling (RL) and Risk Management (RM) categories each are lower than for any of the above categories. None of the papers in the Site Layout (SL) or Short-Term Scheduling (SS) categories reported the use of this methodology.

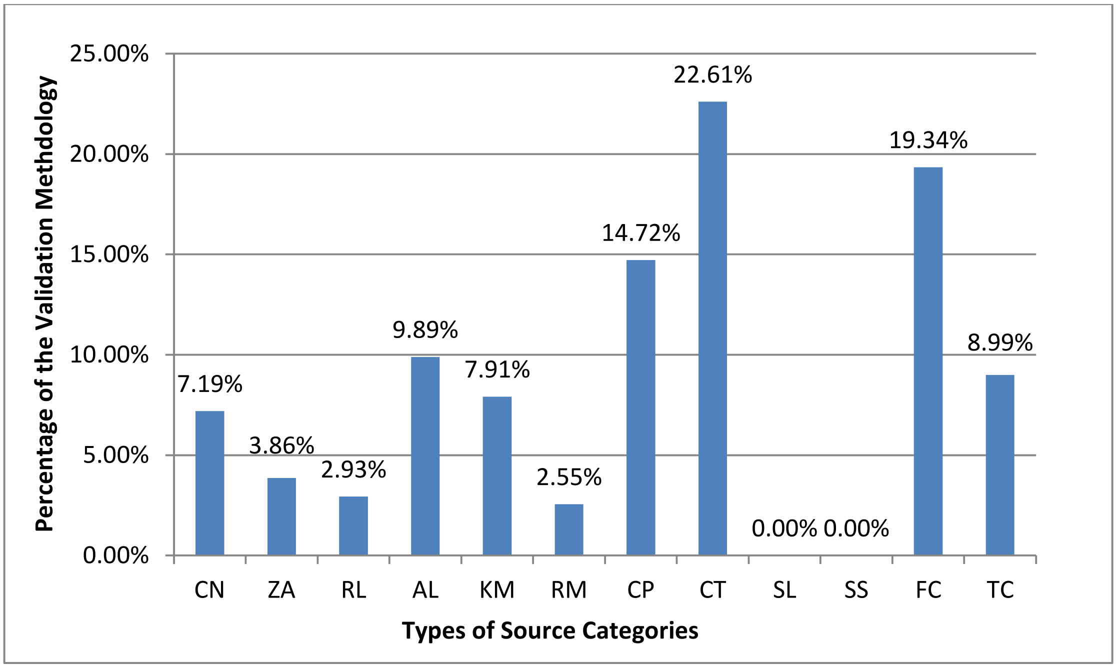

Figure 5-15 Distribution of the Use of Empirical Studies

5.3.2.4 Case Studies

As shown in Figure 5-16, the Zero Accident Techniques (ZA) category represents the most dominant use of the Case Studies methodology, accounting for 31.50 %. The percentage for the Knowledge Management (KM) category is also high, at 25.11 %, and the Constructability (CN) category constitutes 17.12 % of the use of this methodology. The percentages for the Alignment (AL), Contract and Project Delivery (CP), Craft Training (CT), and Factors (FC) categories are relatively low. None of the studies in the Resource Leveling (RL), Risk Management (RM), Site Layout (SL), Short-Term Scheduling (SS), or Technologies (TC) categories made use of the Case Studies methodology.

5.3.2.5 Surveys

As shown in Figure 5-17, with the exception of the Resource Leveling (RL) and Site Layout (SL) categories, every source category involved the application of the Surveys methodology. The highest percentage, 20.92 %, is associated with both the Craft Training (CT) and Short-Term Scheduling (SS) categories. The Contract and Project Delivery (CP), Alignment (AL), and Zero Accident Techniques (ZA) categories follow. The percentages for the Constructability (CN), Knowledge Management

(KM), Risk Management (RM), Factors (FC), and Technologies (TC) categories are all relatively low.

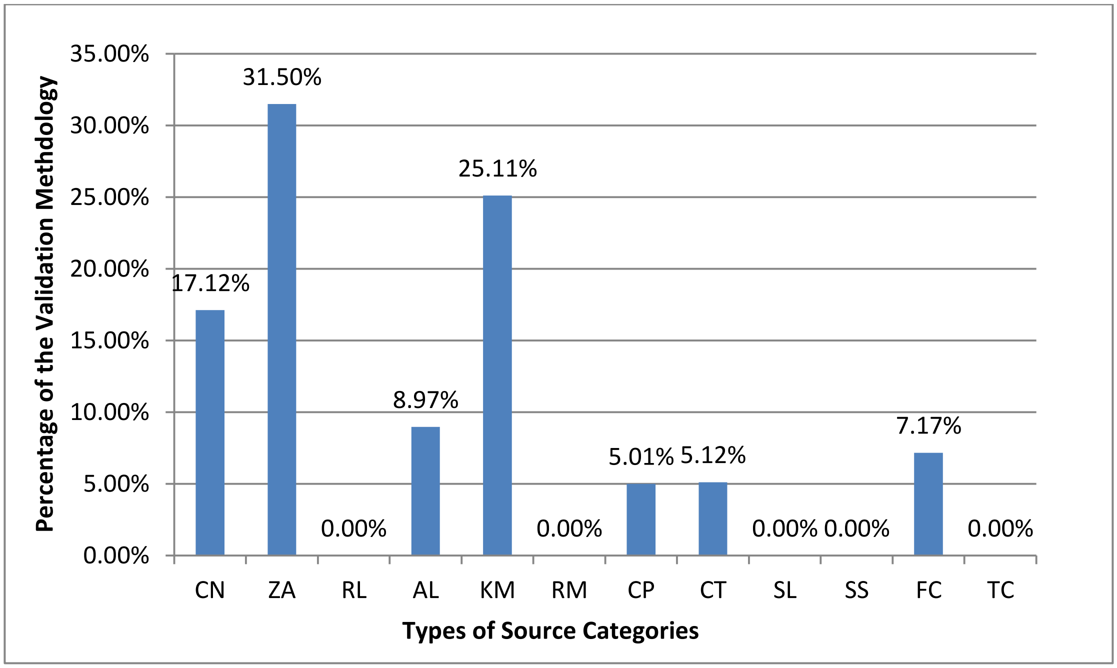

Figure 5-16 Distribution of the Use of Case Studies

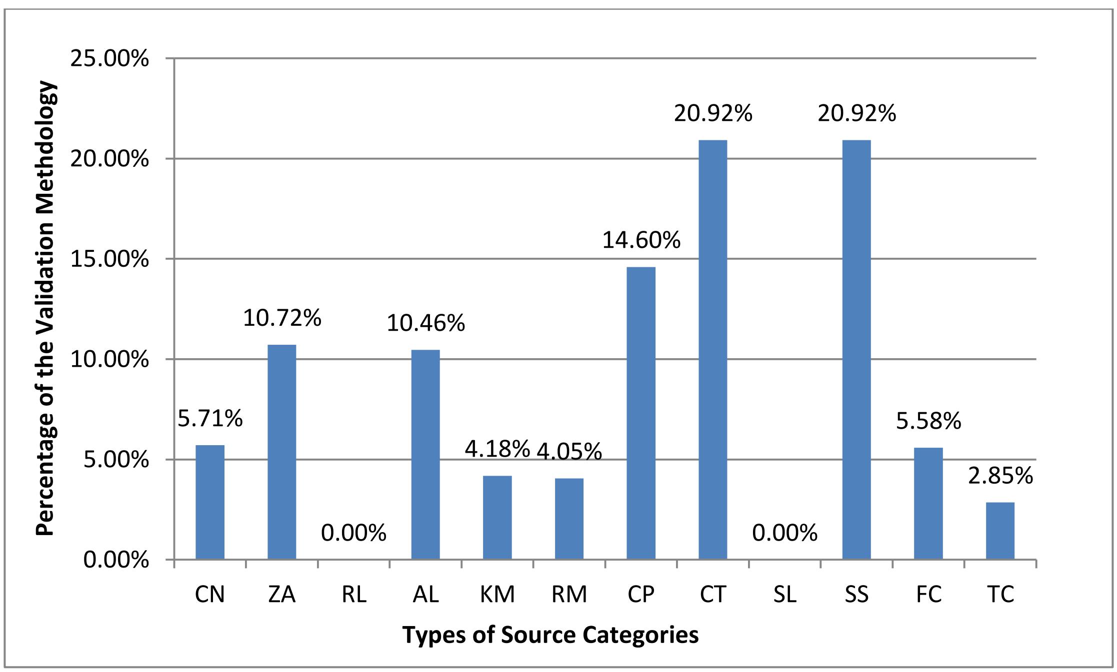

Figure 5-17 Distribution of the Use of Surveys

5.3.2.6 Functional Demonstration

As can be seen in Figure 5-18, every source category includes the application of the Functional Demonstration methodology. The greatest number of applications was in the Site Layout (SL) category, which accounts for 20.47 %. The next most frequent use appears in the Resource Leveling (RL) and Short-Term Scheduling (SS) categories, at 18.70 % and 16.83 %, respectively. The percentages for Risk Management (RM) and Technologies (TC) categories are 13.84 % and 11.47 %, respectively. The remainder of the categories account for relatively low percentages: less than 5 % each.

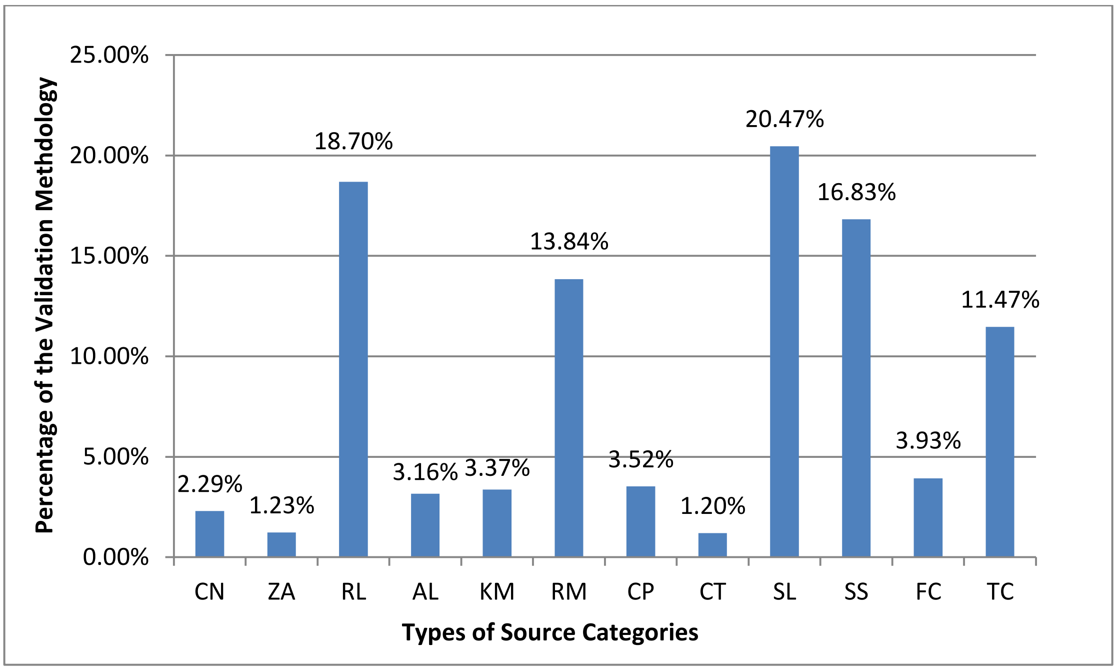

Figure 5-18 Distribution of the Use of Functional Demonstration

5.3.2.7 Archival Data Analysis

As shown in Figure 5-19, the Alignment (AL) category accounts for the highest use of the Archival Data Analysis methodology: 31.16 %. The second highest percentage, 18.24 %, is associated with the Zero Accident Techniques (ZA) category. The percentages for the Constructability (CN), Factors (FC), and Technologies (TC) categories are almost identical: about 16.80 %. The other categories did not include studies in which the Archival Data Analysis methodology was employed.

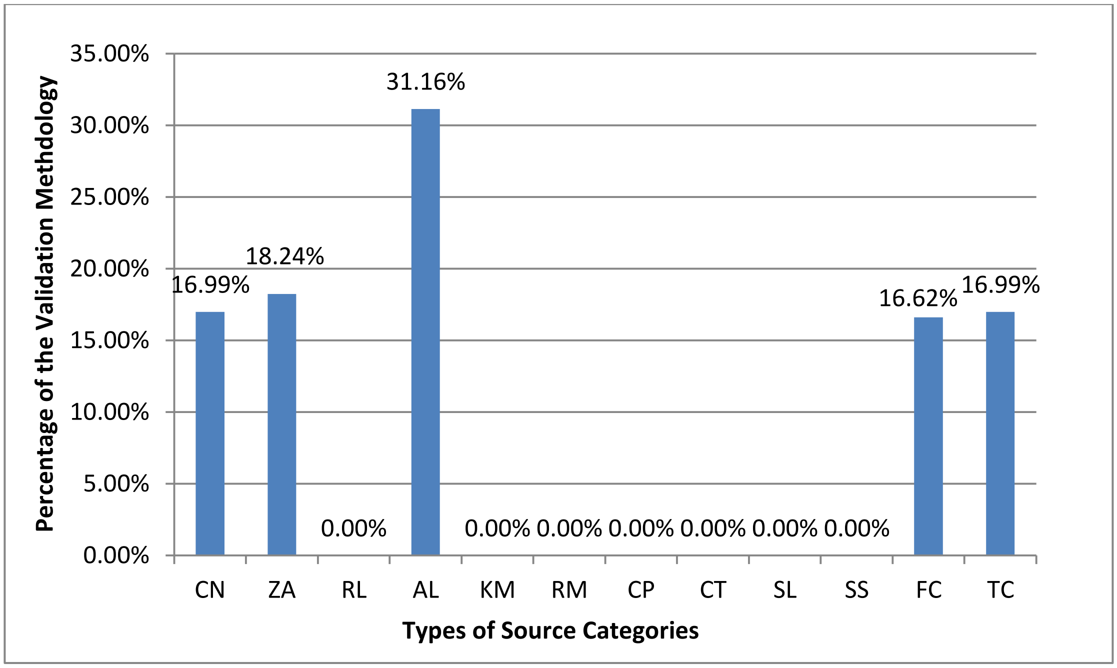

Figure 5-19 Distribution of the Use of Archival Data Analysis

5.3.2.8 Distribution of Studies with Unclear Validation

As shown in Figure 5-20, except for Short-Term Scheduling (SS), every category contains papers that did not describe any validation methodologies. The Constructability (CN) category is associated with the highest percentage of papers that didn't describe a rigorous validation methodology. The second highest percentage is 11.98 %, for Knowledge Management (KM) category, followed by Alignment Category (AL). At 10.27 % and 10.15 %, respectively, the Factors (FC) and Contract and Project Delivery (CP) categories also include a relatively high percentage of studies in which unclear validation methodology was applied. The categories that exhibit the lowest percentage of unclear-validation papers are Resource Leveling (RL) and Site Layout (SL). The Short-Term Scheduling category was not included in the consideration because the sample size of that category is too small to support a conclusion that this category is associated with the lowest percentage.

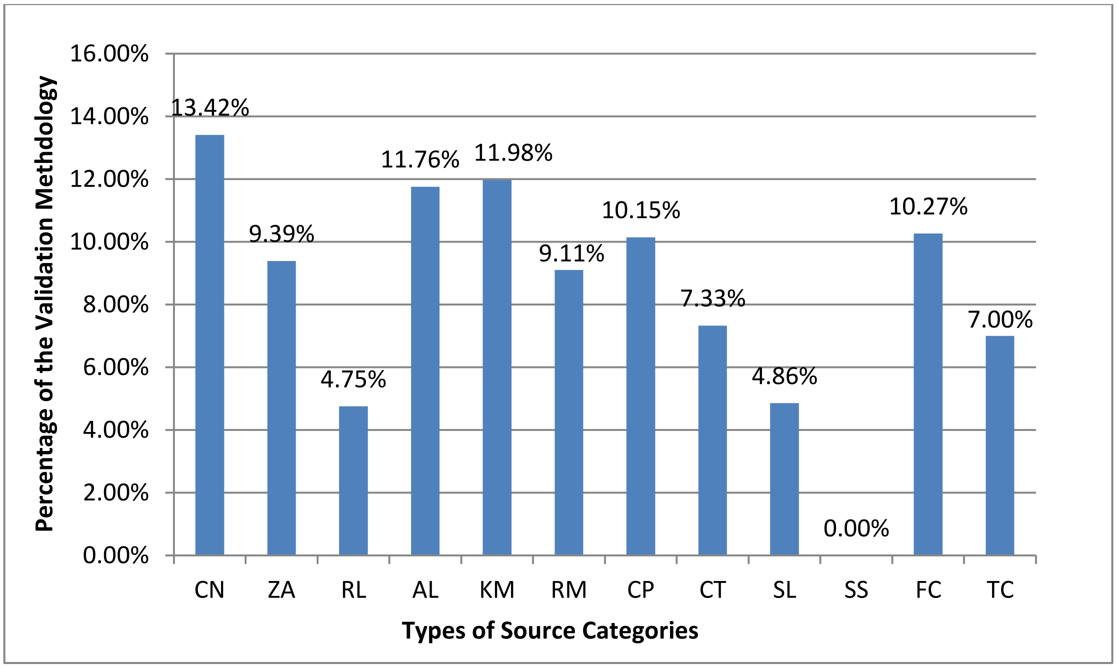

Figure 5-20 Distribution of Unclear-Validation Papers

5.3.3 Discussion

This subsection includes a discussion of the results related to each validation methodology.

5.3.3.1 Comments about the Distribution

The Experimental Studies methodology requires researchers to collect sets of data and then conduct statistical analysis in order to compare the control group with the treated group. Researchers who study topics that fall into the Technology category find it easier to compare the results obtained from groups who are given advanced technology with the results from non-treatment groups than do researchers who investigate topics in the other categories.

With respect to the Observational Studies methodology, the Technologies category is the only one that includes studies in which this methodology was applied, primarily because these papers were focused on vision-based crane tracking, which involves the use of cameras.

The authors of the published articles included in the Craft Training and Factors categories usually had access to data from industry sources that they could use to validate their models or hypothesis, so these two categories thus contain the highest percentage of studies in which the Empirical Studies methodology was applied.

The Case Studies methodology is the dominant technique employed in the studies reported in the Zero Accident Techniques and Knowledge Management source categories because validation through intensive analysis that is based on other similar cases is more appropriate for these two categories than for the other categories, and with respect to this method, these two categories rank higher than the other categories. Perhaps the complex and behavioral nature of these practices is also a fact in their prevalence of case studies.

The distribution of categories for the Surveys methodology is relatively less variable because surveys are easier to conduct than other validation methodologies. Therefore, in almost every category, surveys have been applied as a means of validating results; the only exceptions are the Resource Leveling and Site Layout categories. Interestingly, because they contain more papers related to modeling, simulation, and algorithms than the other categories, these two categories also display the highest percentages of studies in which the Functional Demonstration methodology has been employed. In fact, every category contains papers that report the use of the Functional Demonstration methodology for the simple reason that it offers the most easily implemented method of validating the proposed approaches, systems, and algorithms. On the other hand, only five categories contain papers that describe the use of the more challenging Archival Data Analysis methodology, which requires a range of documented data related to a specific topic as well as access to the data source.

5.3.3.2 Case Studies and Functional Demonstration Methodologies

As shown in Table 2-1, the Case Studies methodology is popularly applied in the humanities, medical science, biology, physics, and psychology but is not as common in construction engineering and management (CEM). However, almost every author who applied the Functional Demonstration methodology claimed to have validated their results through case studies.

As reviewed in section 2.3, the Case Studies validation methodology focuses on the intensive analysis of a particular matter so that the subject of the case studies is in fact the “case” itself. However, researchers who claimed to have applied the Case Studies methodology in their research usually focused on the input and output of modeling and simulation, algorithms, or systems, etc., rather than on an intensive analysis of the case. If it is a case, it is more in the sense that the scope or range of variability of the inputs and outputs is usually quite restricted to the conditions of the “case” itself. Their validation of results involved inputting the data to the systems or algorithms followed by either a comparison of the output with actual industry results or an evaluation of the results according to specific principles. According to the definition of Functional Demonstration used in this thesis, which is a process or evidence that demonstrates the valid functioning of the algorithm/model through the input of data and comparisons of the output, those authors actually validated their research results with the use of the Functional Demonstration methodology.

5.4 Trends in the Use of Validation Methodologies over the Past 33 Years

5.4.1 The Trend Results

This section discusses trends in each validation methodology. The research presented in this thesis involved the examination of 365 papers that were sorted in chronological order from 1980 to 2013. For an analysis of the trends over the past 34 years, the papers were divided into four periods: 1980 to 1989, 1990 to 1999, 2000 to 2009, and 2010 to the present. The percentage of each validation methodology that was reported in each period is shown in Table 5-4.

Table 5-4 Percentages of Validation Methodology Use over Four Time Spans

Period		1980-1989	1990-1999	2000-2009	2010-2013
Validation Methodology	Experimental Studies	0.00 %	5.41 %	1.79 %	2.99 %
	Observational studies	0.00 %	0.00 %	0.00 %	0.60 %
	Empirical Studies	31.25 %	13.51 %	15.48 %	5.39 %
	Case Studies	0.00 %	8.11 %	10.71 %	11.38 %
	Surveys	12.50 %	2.70 %	8.93 %	13.17 %
	Functional Demonstration	0.00 %	27.03 %	30.95 %	31.14 %
	Archival Data Analysis	0.00 %	2.70 %	1.19 %	1.20 %
	Unclear Validation	56.25 %	40.54 %	30.95 %	34.13 %

A comparison of all of the validation methodologies, including “Unclear Validation,” reveals an obvious increasing trend in the use of the Functional Demonstration methodology and a decreasing trend in the number of papers that didn’t report any rigorous validation methodology. These trends are mainly the result of the advantages of the Functional Demonstration methodology: simple to conduct and inexpensive. Usually a personal computer suffices. An increasing awareness of the importance of validation processes has contributed to the decreasing trend in the use of unclear validation.

5.4.2 Validation of the Trend Results

Considering the inconsistent sample sizes for each period, the decision was to validate the trends revealed with respect to the Functional Demonstration methodology and the studies with unclear validation, called Unclear-Validation, by conducting an empirical study. The data were all obtained from the examination of the 365 papers.

The groups of papers were designated as follows: those published from 1980 to 1989 are named Group I; those from 1990 to 1999, Group II; those from 2000 to 2009, Group III; and those from 2010 to 2013, Group IV. While grouping into decades rather than four equal length sub-periods of the period studied may seem arbitrary, it was done with the intent that the study might be replicated more easily in the future this way. Groups II and III each represent 10 data points; the number was smaller in Group I because of the lack of papers from 1981 to 1984, and in Group IV because the papers were published only from 2010 to the present. For the calculation of the parameters, such as the mean and variance, for each data set, a total of 30 data points were used, with each data point representing the usage percentage of either the Functional Demonstration methodology or the Unclear-Validation methodology. The analysis of variance (ANOVA) and least significant difference (LSD) could thus be determined for the data sets.

5.4.2.1 Validation of the Functional Demonstration Trend

5.4.2.1.1 ANOVA

The percentages of the occurrence of the Functional Demonstration methodology in each group are presented in Table 5-5. The ANOVA tables that were generated with the use of the Excel Analysis Tool Package are shown in Tables 5-6 and 5-7.

Table 5-5 Functional Demonstration Data Points in Each Group

Group No.	Group I	Group II	Group III	Group IV
Percentage of Functional Demonstration	0.00 %	0.00 %	0.00 %	24.07 %
	0.00 %	16.67 %	50.00 %	30.67 %
	0.00 %	33.33 %	33.33 %	35.29 %
	0.00 %	16.67 %	14.29 %	100.00 %
	0.00 %	16.67 %	18.18 %	
	0.00 %	33.33 %	29.41 %	
		50.00 %	38.46 %	
		50.00 %	29.41 %	
		40.00 %	38.46 %	
		0.00 %	33.33 %	

Table 5-6 Summary of Functional Demonstration Parameters in Each Group

Groups	*Count*	*Sum*	*Average*	*Variance*
Group I	6	0	0	0
Group II	10	2.57	0.26	0.03
Group III	10	2.85	0.28	0.02
Group IV	4	1.90	0.48	0.12

Table 5-7 ANOVA of Functional Demonstration (α = 5 %)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.59	3	0.20	5.91	0.003	2.98
Within Groups	0.86	26	0.03			
Total	1.45	29				

The goal was to determine whether the variation between group means is significantly larger than the variation that occurs within groups. The null hypothesis in this test is as follows:

H_0: There's no difference between groups. H_1: There exist differences between groups.

As shown in Table 5-7, we know that the F-value, which is 5.91, is larger than the F-critical value, which is 2.98. Therefore, the null hypothesis can be rejected, with the conclusion that significant differences exist between the groups at the 95 % confidence level.

5.4.2.1.2 LSD

The calculation of the LSD enables a determination of whether the difference between a specific pair of means is significant at the 95 % confidence level. The difference between a specific pair of means is significant at the 95 % confidence level if it exceeds the value of the LSD. The LSD equation is as follows:

$$\boldsymbol{LSD = t_{df,\alpha} * \sqrt{\frac{2s^2}{n}}} \quad \textbf{(5.3)}$$

where df means the total degree of freedom which, in this case, is 29; α indicates the significance level, which is 5 % here; n represents the average number of data points in each group, which is approximately 7; and s denotes the mean of the sources of variation within groups, which is MS = 0.033, based on Table 5-7. The LSD value is thus $LSD = 1.699 * 0.016 = 0.02725$. The results are shown in Table 5-8.

Table 5-8 Analysis of the LSD for Functional Demonstration (α = 5 %)

Pair of Groups	Difference	Larger than LSD?
I and II	0.26	Yes
II and III	0.03	Yes
III and IV	0.19	Yes

It can therefore be concluded that a significant increasing trend exists with respect to the use of the Functional Demonstration methodology over the past 34 years at the 95 % confidence level.

5.4.2.2 Validation of the Unclear-Validation Trend

5.4.2.2.1 ANOVA

The percentages of Unclear-Validation papers in each group are presented in Table 5-9. The ANOVA tables that were generated with the use of the Excel Analysis Tool Package are shown in Tables 5-10 and 5-11.

Table 5-9 Unclear-Validation Data Points in Each Group

Group No.	Group I	Group II	Group III	Group IV
Percentage of Unclear-Validation	0.00 %	100.00 %	100.00 %	40.74 %
	0.00 %	33.33 %	25.00 %	36.00 %
	66.67 %	33.33 %	33.33 %	23.53 %
	75.00 %	50.00 %	42.86 %	0.00 %
	75.00 %	33.33 %	59.09 %	
	50.00 %	33.33 %	29.41 %	
		00.00 %	7.69 %	
		50.00 %	35.29 %	
		40.00 %	23.08 %	
		0.00 %	25.49 %	

Table 5-10 Summary of Unclear-Validation Parameters in Each Group

Groups	*Count*	*Sum*	*Average*	*Variance*
Group I	6	2.67	0.44	0.13
Group II	10	3.73	0.37	0.08
Group III	10	3.81	0.38	0.07
Group IV	4	1.002	0.25	0.03

Table 5-11 ANOVA of Unclear-Validation (α = 5 %)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.09	3	0.03	0.39	0.76	2.98
Within Groups	2.03	26	0.08			
Total	2.12	29				

Again, the goal was to test whether the variation between group means is significantly greater than the variation that occurs within groups, based on the following null hypothesis:

H_0: There’s no difference between groups. H_1: There exist differences between groups.

As shown in Table 5-11, the F-value, which is 0.39, is known to be smaller than the F-critical value, which is 2.98. The null hypothesis can therefore not be rejected at the 95 % confidence level.

5.4.2.2.2 LSD

The LSD for the Unclear-Validation papers was calculated according to Equation 5-3, where $df = 29, \alpha = 5\ \%, n = 7,$ and $s = 0.078$. Therefore, L$SD = 1.699 * 0.037 = 0.0708$. The results are shown in Table 5-12.

Table 5-12 Analysis of the LSD of Unclear-Validation (α = 5 %)

Pair of Groups	Difference	Larger than LSD?
I and II	-0.0711	Yes
II and III	-0.0081	No
III and IV	-0.1306	Yes
I and IV	-0.1938	Yes

The differences of the means between Group I and Group II on the one hand, and Group III and Group IV on the other are significant at the 95 % confidence level because they exceed the value of the LSD. However, we fail to reject hypothesis that there are no differences in the means between Group II and Group III. Therefore, it cannot be concluded that the trend in the occurrence of Unclear-Validation papers has been decreasing over the past 34 years. Nonetheless, the comparison of an additional pair, Group I and Group IV, revealed that the mean of Group IV is significantly smaller than that of Group I at the 95 % confidence level. A conclusion that can thus be drawn is that the occurrence of Unclear-Validation papers has improved when Group IV is compared to the groups representing other periods.

5.5 The Relationship between the Degree of Validation and the Number of Citations

5.5.1 Introduction

This section explores the question of whether the degree of validation relates to the number of citations. The comprehensive analysis of the data is twofold: the relationship in a specific category and the relationship in a specific year. Please note that the searches of examined papers are done with Scopus, ASCE, etc. while the citation study is done by using Google Scholar, because the information of citations from Scopus is all included in Google Scholar.

5.5.2 The Relationship in a Specific Category

5.5.2.1 Qualified Categories

The qualified categories must meet two requirements as follows:

- The category contains an adequate number of articles, i.e. around or more than 40 articles.
- The number of articles reporting validations and the number of articles reporting validations that were unclear are close. In other words, the percentage of unclear-validation papers is required to be close to 50%.

These two requirements aim to minimize the adverse impacts caused by problems of small sample size. For a study that has a sample size which is too small it is possible to turn out inconclusive results. Screened by the requirements, two qualified categories are Constructability and Factors. The Constructability category contains 43 papers and the percentage of unclear-validation papers is 52.27 %. The Factors category contains 40 papers and the percentage of unclear-validation papers is 40%.

5.5.2.2 Results

Table 5-13 presents the number of citations of each paper in the Constructability category. Table 5-14 presents the number of citations of each paper in the Factors category. Papers in Group I reported validations that were unclear and papers in Group II reported validation methodologies that were clear.

Table 5-13 Number of Citations in the Constructability Category

Group I			Group II		
Year	Code Name	Number of Citations	Year	Code Name	Number of Citations
2012	CN-3	2	2012	CN-1	1
2011	CN-4	5	2012	CN-2	1
2011	CN-8	9	2011	CN-5	0
2010	CN-11	36	2011	CN-6	0
2010	CN-12	16	2011	CN-7	0
2009	CN-13	7	2010	CN-9	0
2007	CN-16	27	2010	CN-10	0
2005	CN-19	17	2009	CN-14	26
2005	CN-21	21	2008	CN-15	3
2004	CN-22	7	2006	CN-17	14
2004	CN-23	1	2006	CN-18	24
2004	CN-24	5	2005	CN-20	38
2004	CN-26	4	2004	CN-25	17
1994	CN-31	18	2002	CN-27	61
1993	CN-33	15	2001	CN-28	71
1993	CN-34	1	1994	CN-29	19
1993	CN-36	24	1994	CN-30	28
1991	CN-38	19	1994	CN-32	33
1988	CN-39	55	1993	CN-35	12
1987	CN-40	70	1991	CN-37	55
1987	CN-41	8			
1986	CN-42	49			
1986	CN-43	23			

Table 5-14 Number of Citations in the Factors Category

Group I			Group II		
Year	Code Name	Number of Citations	Year	Code Name	Number of Citations
2012	FC-2	0	2013	FC-1	1
2011	FC-4	8	2012	FC-3	0
2011	FC-7	0	2011	FC-5	4
2010	FC-8	1	2011	FC-6	10
2010	FC-9	7	2009	FC-10	4
2009	FC-12	13	2009	FC-11	6
2009	FC-13	5	2009	FC-16	2
2009	FC-14	1	2008	FC-17	26
2009	FC-15	5	2007	FC-18	4
2006	FC-20	8	2007	FC-19	33
2005	FC-24	12	2005	FC-21	0
2004	FC-25	0	2005	FC-22	45
2004	FC-27	2	2005	FC-23	49
2002	FC-29	15	2004	FC-26	22
1998	FC-30	19	2003	FC-28	79
1990	FC-35	25	1996	FC-31	69
1987	FC-37	16	1995	FC-32	72
			1995	FC-33	102
			1992	FC-34	49
			1989	FC-36	89
			1986	FC-38	74
			1985	FC-39	66
			1980	FC-40	253

In order to explore the relationship between the degree of validation and the number of citations, scatter-charts are plotted in Figure 5-21 and 5-22.

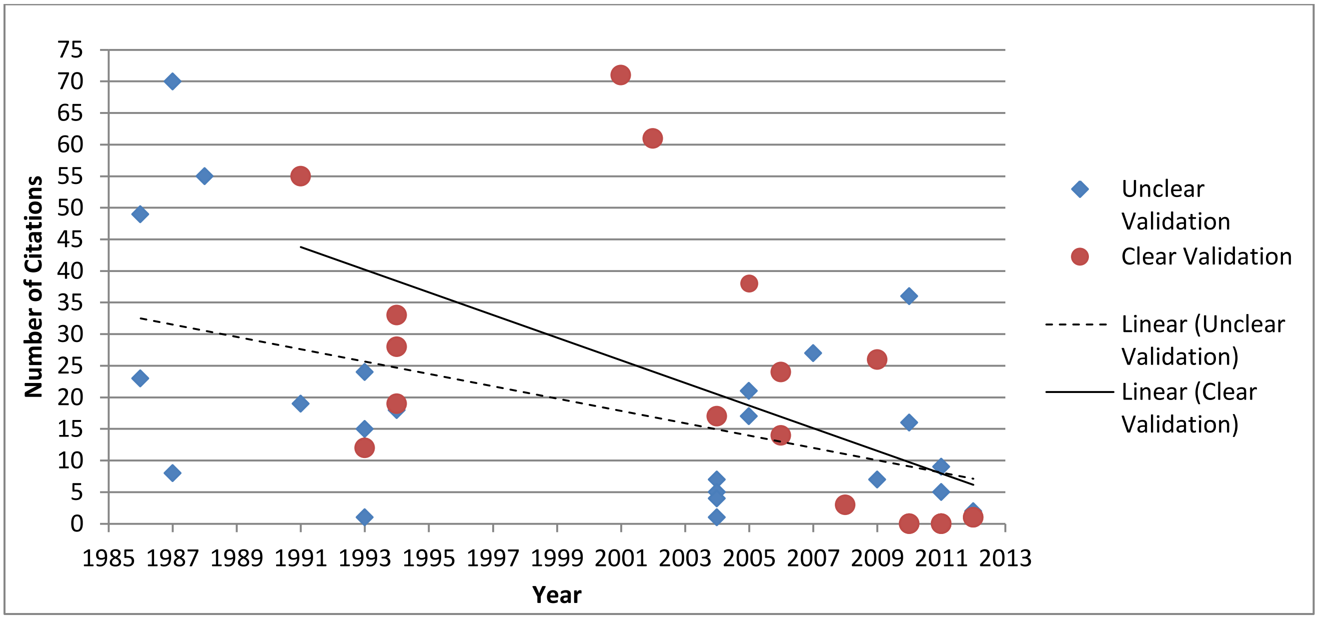

Figure 5-21 Number of Citations in the Constructability Category

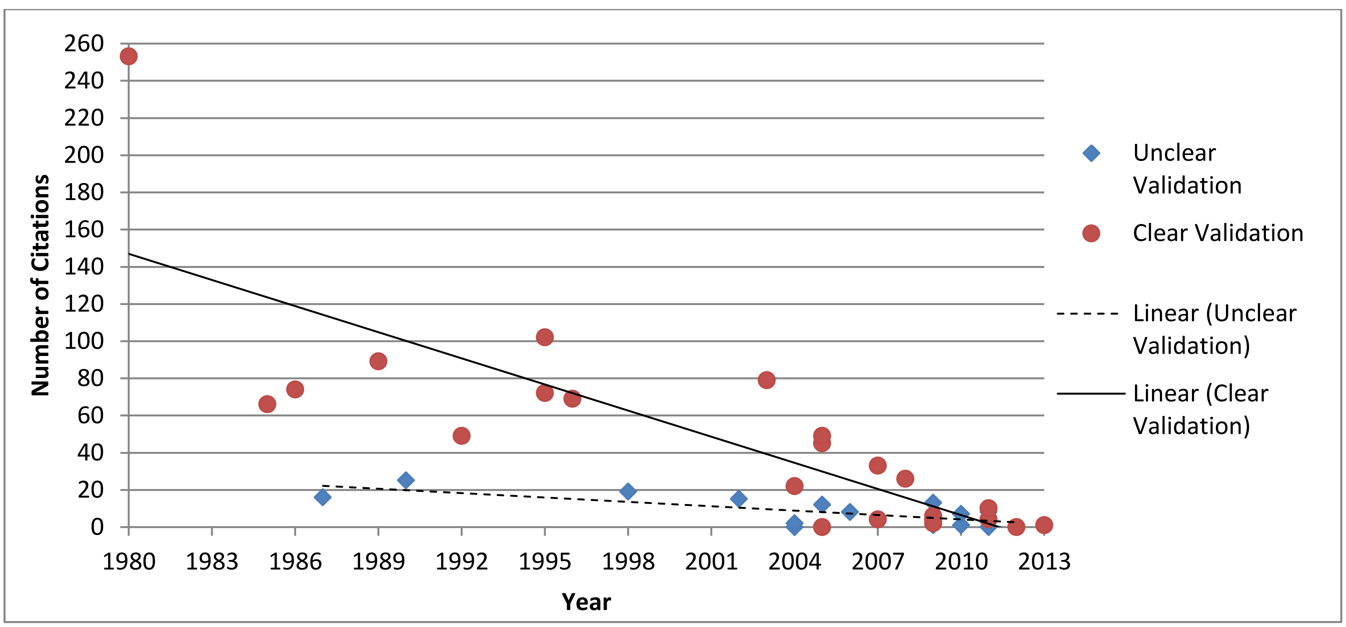

Figure 5-22 Number of Citations in the Factors Category

In both figures, the trend lines indicate that the number of citations is positively related to the degree of validations before the year 2010. After 2010, the relationship is negative, which is mainly because of the impacts of time. The articles after 2010 are too new to get enough number of citations.
In Figure 5-21, we find that a few articles before 90s reporting validations that were unclear have a very large number of citations. This is because those articles focused on concepts related to the topics of constructability and the authors of those articles have a relatively high reputation. From my perspective, authors like me, who begin to do research in areas of constructability, would like to cite their articles in order to get a comprehensive literature review. In sum, we can draw the conclusion that in a specific category, the stronger the validation is, the larger the number of citations is.

5.5.3 The Relationship in a Specific Year

5.5.3.1 Qualified Years

The qualified years must meet two requirements similar to the ones of categories:

- The number of articles in the specific year must be around or more than 40.
- The number of articles reporting validations and the number of articles reporting validations that were unclear are close. In other words, the percentage of unclear-validation papers is required to be close to 50%.

These two requirements are for the same reasons as the ones for categories. Screened by the requirements, only the year 2010 is qualified. There are 45 papers in the year 2010 and the percentage of unclear-validation papers is 47.06 %.

5.5.3.2 Results

Table 5-15 presents the number of citations of each paper in the year 2010. Papers in Group I reported validations that were unclear and papers in Group II reported clear validation methodologies.

Table 5-15 Citation Numbers of Each Article in Year 2010

Group I		Group II	
Code Name	**Number of Citations**	**Code Name**	**Number of Citations**
CN-11	36	CN-9	0
CN-12	16	CN-10	0
ZA-18	3	ZA-16	4
ZA-21	0	ZA-17	5
ZA-22	0	ZA-19	5
ZA-24	4	ZA-20	0
RL-11	6	ZA-23	5
AL-9	6	RL-9	10
AL-10	27	RL-10	21
RM-17	7	RL-12	4
RM-19	4	AL-8	2
RM-20	2	KM-9	0
CP-14	4	KM-10	25
CP-15	4	RM-16	6
CP-19	3	RM-18	85
CP-20	1	RM-21	4
CP-21	1	CP-16	1
CP-22	7	CP-17	0
CP-26	20	CP-18	3
CP-28	4	CP-23	8
CT-2	1	CP-24	6
FC-8	1	CP-25	21
FC-9	7	CP-27	4
TC-25	35	SL-2	3
		SL-3	2
		TC-26	0
		TC-27	6

The ANOVA tables that were generated with the use of the Excel Analysis Tool Package are shown in Tables 5-16 and 5-17.

Table 5-16 Summary of the Number of Citations in Each Group

Groups	*Count*	*Sum*	*Average*	*Variance*
Group I	24	199	8.29	112.22
Group II	27	230	8.52	277.33

Table 5-17 ANOVA of the Number of Citations (α = 5 %)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.65	1	0.65	0.003	0.95	4.04
Within Groups	9791.70	49	199.83			
Total	9792.35	50				

The goal was to determine whether the variation between group means is significantly larger than the variation that occurs within groups. The null hypothesis in this test is as follows:

H_0: There's no difference between groups. H_1: There exist differences between groups.

As shown in Table 5-17, the F-value, which is 0.003, is known to be larger than the F-critical value, which is 4.0384. The null hypothesis can therefore not be rejected at the 95 % confidence level. We fail to conclude that significant differences exist between groups at the 95 % confidence level.

Chapter 6
Barriers to the Application of Meta-Analysis in CEM

6.1 Introduction

As mentioned in Section 2.7, meta-analysis is defined as the systematic statistical analysis of a number of individual results from studies of the same topic and for the same purpose. As shown in Table 2-1, meta-analysis has been used in numerous applications in education, human resources, medical science, physics, and psychology because more scientific and objective conclusions can be derived from meta-analysis than from traditional literature reviews. However, the examination of 365 papers for the research presented in this thesis revealed no examined papers that described the application of meta-analysis. Even in a broader search in CEM, the only known example of meta-analysis we can find, which is not a part in the sample, is the one written by Horman and Kenley (2005). These are clear indications of the existence of barriers to the application of meta-analysis in construction engineering and management (CEM). The following sections present a discussion of each of these barriers.

6.2 Coding Process

To create a suitable dataset for meta-analysis, researchers must code the studies. Systematic coding is an important preparation for measuring the effect size, which refers to the process of extracting the information from the literature included in the meta-analysis. A well-designed coding process helps researchers establish effective descriptions of the characteristics of the studies so that they can conduct a comprehensive comparison and synthesis of the articles. The coding process also enables readers to understand the detailed procedures used by the researchers, which makes the research replicable.

Coding the literature involves several steps: first, select suitable characteristics; second, develop a code book, which is similar to a dictionary, in which the details of each characteristic are recorded; third, conduct a few training sessions for at least two coders before the literature is coded. Coders must work on the coding process independently so that the second coder can check the calculations of the effect size.

Considering all the requirements the coding process entails, the second and third steps are not simple, and the writing of a code book and the training sessions are quite time-consuming. As well, because the coding process requires two or more coders, the author needs at least one extra person to help with the coding process.

6.3 Data Source

In contrast to conditions in fields such as education, human resources, medical science, etc., finding consistent data from past CEM research is difficult, given the wide range of detailed content that can be related to a topic. For example, a goal might be to study the impact of constructability on construction projects. Only 5 of the 43 papers in the Constructability category include data sets to which statistical analysis can be applied. In addition, the data-sets in each paper are focused on different aspects of constructability so that the data cannot be combined. In contrast, in medical science literature, it is easier to find consistent data related to a comparison of the effects within and without a specific aspect of medicine. Establishing control groups and treated groups for construction projects is also difficult in CEM because contractors are unwilling to take risks that might jeopardize their projects. For example, normally they will not try a new method of contract delivery unless it has already been proven successful.

6.4 Summary

In summary, the barriers to the application of meta-analysis in CEM are twofold: the difficulty involved in coding the studies and the challenge of finding suitable data-sets. To solve these two problems, adequate preparation is required at the very beginning of the research, for example, finding at least two or more researchers to participate in the study. The literature review must also be expanded so that an attempt is made to find additional papers related to the same topic.

Chapter 7
Conclusions and Recommendations for Future Research

7.1 Introduction

The primary goal of this research was to provide assistance for construction engineering and management (CEM) researchers as well as for students undertaking master's or doctoral studies in this area so that they can select appropriate methodologies for the validation of their results. A comprehensive literature review was conducted in order to help readers acquire an understanding of the background and importance of choosing appropriate validation methodologies. The review also illustrated the definitions, features, advantages, and disadvantages of each validation methodology. A total of 365 CEM papers were examined in order to analyze the distributions of both the validation methodologies and the source categories, to identify trends in the use of validation methodologies over the past 34 years and to explore the relationship between the degree of validations and the number of citations. This chapter summarizes the findings and conclusions and offers recommendations for future studies.

7.2 Findings and Conclusions

The following are the findings and conclusions of this research.

7.2.1 Findings Related to the Distribution of Validation Methodologies in Each Source Category

Every source category except Short-Term Scheduling contains papers that didn't report any rigorous validation methodology; the sample size of the Short-Term Scheduling category was not large enough to permit conclusions to be drawn. Studies in the Constructability category were most often validated with the use of the Case Studies methodology, as were studies in the Knowledge Management and Zero Accident Techniques categories. The Surveys methodology was also frequently used in the Zero Accident Techniques category. Papers in the Resource Leveling, Risk Management, Site Layout, Short-Term Scheduling, Factors, and Technologies categories most often reported validation through the Functional Demonstration methodology since a number of the papers in those categories were focused on the development of modeling and simulation, algorithms, and systems. The Surveys methodology accounts for the highest percentage in the Alignment category and is also commonly applied to studies in the Craft Training category. Another popular methodology in the Craft Training category is the Empirical Studies methodology, which is also prevalent in the Factors category.

7.2.2 Findings Related to the Distribution of Source Categories in Each Validation Methodology

Of all the source categories, the Technology category contains the highest percentage of papers that reported the application of Experimental Studies. With respect to Empirical Studies, the Craft Training and Factors categories represent the top two categories in which this methodology was applied. Only one study in the Technologies category applied the Observational Studies methodology. The Case Studies methodology is dominated by the Zero Accident Techniques and Knowledge Management source categories. Almost every category included the application of the Surveys methodology. The exceptions were the Resource Leveling and Site Layout categories, which represent the dominant areas in which the Functional Demonstration methodology was employed. With respect to the Archival Data Analysis methodology, the Alignment category contains the highest percentage of papers that reported this technique, with four other categories also including mention of its use: Constructability, Zero Accident Techniques, Factors, and Technologies. The Constructability category contains the highest percentage of studies in which unclear validation methodology was applied.

7.2.3 Findings Related to Trends in the Usage of Validation Methodologies over the Past 33 Years

Based on the data acquired from the examination of 365 papers, it can be concluded that the trend in the use of the Functional Demonstration methodology over the past 34 years has increased significantly at the 95 % confidence level. This result has been validated using ANOVA and LSD analysis. Compared to the period from 1980 to 2009, the incidence of Unclear-Validation papers decreased from 2010 to the present at the 95 % confidence level. However, a continuous decreasing trend in the number of papers that reported validation methodology that was unclear over the past 34 years cannot be demonstrated because no significant difference exists between the means of the period from 2000 to 2009 and the period from 1990 to 1999 at the 95 % confidence level.

7.2.4 Findings Related to the Relationship between the Degree of Validation and the Number of Citations

Based on the data acquired from the examination of articles in Constructability and Factors categories, it can be concluded that the number of citations is positively related to the degree of validations in a specific category. The result can be observed from the scatter-plotting. However, based on the data acquired from the examination of articles in the year 2010, we fail to conclude that significant differences of the number of citations exist between clear-validation group and unclear validation group at the 95 % confidence level.

7.3 Recommendations for Future Research

The research presented in this thesis has involved the examination of validation methodologies reported in papers that present CEM research. However, many aspects of the study still need improvement so that more comprehensive and reliable conclusions can be obtained. The following possible areas for future research are suggested:

- Additional papers should be examined. The research sample size was insufficient due to the limited time available. The American Society of Civil Engineers published a special journal issue devoted to CEM research methodologies (Taylor & Jaselskis, 2010). The issue described the examination of 1102 manuscripts in order to analyze trends in methodological utilization and rigour. Conclusions based such a large sample size would be more reliable.

- Gaps in the representation of time periods should be filled. In addition to enlarging the sample size, researchers also need to review papers published during periods for which no papers or an insufficient number of papers have been included. For this research, none of the papers collected was published between 1981 and 1984, and only one paper was published in 1980, one in 1985, two in 1989, and two in 1990. These gaps in the time span represented by the papers may have created bias that influenced the final results.

- CEM applications of meta-analysis need further exploration. The first step would be the detailed study of a specific topic and the acquisition of the most source data possible. The ideal research team would be comprised of two or more researchers.

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Appendix A
Source of Examined Articles

#	Name of Journals
1	Automation in Construction
2	Advanced Engineering Informatics
3	Advanced Materials Research
4	Annual ARCOM Conference
5	Applied Mechanics and Materials,
6	Architectural Science Review
7	Automation and Robotics in Construction
8	Building and Environment
9	Canadian Journal of Civil Engineering
10	Computer Modeling and New Technologies
11	Computing in Civil and Building Engineering
12	Construction and Building Materials
13	Construction Management & Economics
14	Construction Management and Economics
15	Construction Research Congress
16	Cost Engineering
17	Engineering Applications of Artificial Intelligence,
18	Journal of Architectural Engineering
19	Journal of Bridge Engineering
20	Journal of Civil Engineering and Management
21	Journal of Computing in Civil Engineering
22	Journal of Construction Engineering and Management
23	Journal of Energy Engineering
24	Journal of Engineering Design
25	Journal of Information Technology in Construction
26	Journal of Legal Affairs and Dispute Resolution in Engineering and Construction
27	Journal of Management in Engineering
28	Journal of Performance of Constructed Facilities
29	Journal of Professional Issues in Engineering
30	Journal of Urban Planning and Development
31	Journal of Water Resources Planning and Management

32	Leadership and Management in Engineering
33	Manufacturing Engineer
34	Natural Hazards Review
35	New Research on Knowledge Management
36	Ports 2010: Building on the Past, Respecting the Future
37	Practice Periodical on Structural Design and Construction
38	Scandinavian Journal of Work, Environment & Health
39	The Revay Report
40	Tinbergen Institute Discussion Paper
41	Tsinghua Science & Technology
42	Vulnerability, Uncertainty, and Risk

Appendix B
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AL-1: Elbarkouky, MMG, & Fayek, A. (2010a). Fuzzy similarity consensus model for early alignment of construction project teams on the extent of their roles and responsibilities. Journal of Construction Engineering and Management, (JUNE), 432–440. doi:10.1061/(ASCE)CO.1943-7862.0000310.

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