THE IDENTIFICATION OF UNCERTAINTY AND RISK ASSOCIATED WITH INADEQUATE SITE INVESTIGATION PROCEDURES RELATIVE TO PROJECT COMPLEXITY

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This paper is part of a global research aimed at developing a system that could be used in practice to objectively measure the level of risk associated with an inadequate site investigation. The work described in this paper has developed a Project and Site Investigation Information Evaluation Program (PSIIEP), designed to evaluate and place an index of relative importance upon both project complexity and risk associated with inadequate site investigation information. Despite the wealth of knowledge available from leading 'expert' sources that provide guidelines for site investigation procedure, this research indicates that over 56% of construction contracts reported major difficulties when carrying out sub-structure works, solely as a result of inadequate site investigation (SI) information. This research has identified the factors that brought about discrepancies that led to project uncertainty and risk in SI survey data. The developed PSIIEP utilises these findings to evaluate project and site data and deliver a concise appraisal of risk associated with uncertain site investigative information. The research has been based on data and information collected using 1,000 questionnaires sent to construction practitioners. The work used logic through a grounded theory methodology supported by 36 case studies from a selection of construction projects in the UK.

Keywords: project complexity, risk management, site investigation procedure.

INTRODUCTION

This work subscribes to the adage 'you pay for a site investigation whether you have one or not' (Tomlinson, M.J. and Meigh 1971), yet, it acknowledges the answer is not simply to throw more money at unplanned site investigative work. The will to spend appropriate funds to achieve adequate results has been lacking historically. This research considered the technical sophistication of current methods and the availability of such techniques not to be the problem. The problem seems to hinge on lack of reliable information and until clients are made aware of the economic risk that uncertain ground conditions pose, they will remain unwilling to commit adequate funds at the appropriate time for this vital work.

The focus of this paper therefore is to develop a Project and Site Investigation Information Evaluation Program (PSIIEP). This program has been designed to afford information to enable effective decision making on whether or not to procure further Site Investigation (SI) work, in order to reduce risk associated with uncertain site conditions. The work employed a combination of research approaches, including a literature search targeting the reports of site investigative related problems, an extensive postal questionnaire and the statistical analysis of the data from the review of over 36 case studies. A postal questionnaire was considered appropriate to achieve

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the extensive coverage desired. Grounded theory allowed new issues to emerge from case studies in relation to site investigative procedures. Existing theories were compared with the new observations and the variants considered and used to establish a new theoretical understanding. The holistic advantage afforded by case studies is compatible with the ideas of Glaser and Strauss (1967) regarding the continual restatement of the theory upon which the data was gathered.

BRIEF LITERATURE REVIEW

Researchers such as White and Fortune (2002) have indicated that current risk analysis techniques are not being effectively used in practice. An empirical study of current project management practices identified that from a sample group of 236 project management organisations, 65% reported having not used any form of risk assessment tools, methods or techniques. Other researches have identified weaknesses within current methods and techniques for risk analysis, highlighting their inability to make no allowance for 'fuzzy parameters' or 'incomplete knowledge'. Incomplete knowledge requires the inclusion of 'possible' or 'could happen' to the range of outcomes; deterministic or probabilistic techniques, designed for the gaming tables, struggle to address these possibilities. Having critically reviewed the traditional acceptance and assumptions used within risk management and the management of risk, Pender (2001) recently drew attention to limitation of probability analysis. Jaafari (2001) has indicated that risk management will only be plausible when the probability of occurrence and magnitude of impact can be estimated with a reasonable degree of accuracy. Peacock and Whyte (1992) focuses on risk associated with site investigation. Their work concludes, "the client financing the works may not be aware of the economic risk associated with uncertain ground conditions – nor the benefits of carrying out risk management techniques".

Despite the availability of advanced risk analysis programs to assist clients in identifying risk and uncertainty in construction works, there seems to be a poor application and commitment by construction practitioners to use such resources. Previous work has attempted to improve the SI process through the development of complex computer programs. Willmer (1988) has suggested that a most significant progression in SI risk management was the emergence of a Computer Aided Simulation for Project Appraisal and Review program (CASPAR). Another is that of Weltman and Head's (1983: 14) ground investigation model. Despite all these works, Berkeley (et. al. 1991) has still called for further research for appropriate techniques that could assist project managers assess and pre-empt potential sources of risk.

The developed Project and Site Investigation Information Evaluation Program (PSIIEP) has moved away from the typical use of probabilistic interpretation as the sole means by which to measure a projects' exposure to risk or as an evaluation mechanism. In the absence of such certainty, PSIIEP provides a proactive system to reduce the uncertainty, thus reducing incomplete knowledge. Although it is beyond the scope of this work to quantify the cost of problems associated with inadequate and uncertain site conditions, the ability to provide economic certainty for construction projects has been recognised as vitally important to achieving project success.

DATA GATHERING

In order to identify the factors that bring about discrepancies in current SI information and the problems that result from inadequate SI procedures, 1000 postal questionnaires were sent to construction organisations and achieved a response rate of about 47.4%. The literature review, the analysis of the questionnaire and a further robust examination of 36 case studies enabled the identification of 49 key issues or prime causes of dissatisfaction with current site and ground investigative procedures. Again, the questionnaire survey and case studies enabled the research to establish the factors that led to project uncertainty as a result of inadequate site investigative procedures.

In accordance with grounded theory methodology, the research observed actual events and compared these scenarios with known theory and theoretical systems. Within this methodology case studies are able to influence and enhance existing theory, practice and procedures.

The 49 key issues and the factors of project uncertainty are listed in Table 1.1 and were used as the basis from which to design the PSIIEP. Using the case studies these factors were grouped into twelve elements as shown in Table 1.1. Each time a case study incident corresponded with one of the twelve elements, a dot is indicated in the table as shown. This enabled a total number of recorded events as a percentage of occurrences to be established from the 36 case studies and a weighted value from the total number of experiences observed.

DEVELOPMENT OF THE PSIIEP

The Project and Site Investigation Information Evaluation Program (PSIIEP) has been designed to facilitate and assist decision making on whether or not to procure further site investigation work at any stage throughout the design and construction process. Uniquely, this research has embraced the difficulties construction practitioners face during the early phases of construction and has used these observations to remodel the process and procedures of site investigative work.

The task of delivering a concise appraisal of an organisation's exposure to risk associated with uncertain site conditions remains the most important aim of this work. Having acknowledged that simplicity in the design of a 'tool boxes' technique for the PSIIEP should remain of paramount importance, a 'Yes/No' format was used where possible to obtained the data from the questions. Due to its ease of use and being commonly available, Microsoft ExcelTM computer spreadsheet was used as the medium through which construction practitioners input raw project data in order to initiate the evaluation process. The user of the PSIIEP has been guided through a series of questions, the answers of which provide an index of project complexity and a measure of the availability of SI information.

The PSIIEP has been divided into two sections; the first section enables the user to input raw data specific to project and contract details. This information typically includes: the criticality of the project duration, financial constraints, whether a site investigation had been carried out with knowledge of the foundation layout and any other relevant practical and economic considerations. Ultimately, this section of the program was designed to establish a Project Complexity Index (PCI) relative to the proposed development.

The second section of the PSIIEP processes and assesses the available site investigation information. This research identified and categorised survey tasks and data into elements. This process has enabled a measure of relative importance to be established and assigned to the data, thereby delivering a Site Investigation Information Index (SIII).

Case Study Ref:	(SI) Client Brief					Planning Restrictions			Serviceability / Access				Ordnance Survey Records				Local Authority Records				Local Memoirs			Aerial Photography				Geological Info. & Memoirs				Utilities Services				Mining & Mineral Deposits				Availability of Clients Site Info.				Project / Mgt. Inexperience / Client ~SI Brief						No	%
	True nature (stage) of SI required	Inadequate funds allocated for SI	Uneducated Client (Need for thorough SI)	Unclear SI brief (Statement of SI needs)	Unrealistic time schedule for thorough SI	Inadequate LA interpretation	Incompatible with Client brief	Inadequate cross-checking of design requirements and client brief	Width of Rd / plant access unchecked	Overhead power / elect. line obstruction	Inadequate temp. capacity / supply	Inadequate working area, plant & mat. del.	Unchecked OSR	Unavailable OSR	Inaccurate OSR & Information	Inaccurate OSR interpretation	Unchecked LAR	Unavailable LAR	Inaccurate LAR & Information	Inaccurate LAR interpretation	Unchecked LM	Unavailable LM	Inaccurate LM & Information	Unchecked AP	Unavailable AP	Inaccurate AP & Information	Inaccurate AP interpretation	Unchecked GI & M	Unavailable GI & M	Inaccurate GI & M & General Information	Inaccurate GI & M interpretation	Unchecked Utility Capacity	Data unavailable to check serv. capacity	Inaccurate Utility Information (Positions)	Inaccurate Utility interpretation of data	Unchecked M & M Deposits	Unavailable M & M Deposits	Inaccurate M & M Deposits	Inaccurate M & M Deposit interpretation	Unchecked client SI information	Unavailable SI information	Inaccurate SI information	Inaccurate SI information interpretation	Inexperience led to inaccurate SI spec.	Inexperience led to inaccurate Interpretation of SI report and Geo. data	Inappropriate mgt. of client and clients funds to ensure a thorough SI operation	Incorrect Mgt. Procedures	Reduce risk on design team org'n.	Arrogance ? Blind experience		
P1													●				●				●				●						●					●			●								●			8	22.2
P2													●				●				●								●		●					●				●										7	19.4
P3																				●	●							●			●	●							●									●		7	19.4
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P5	●			●			●	●	●				●			●	●			●	●			●					●	●							●			●				●						16	44.4
P6	●	●	●	●					●		●					●	●				●			●								●				●													●	14	38.9
P7				●													●																																	1	2.8
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P11				●						●		●	●			●					●											●																		7	19.4
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P15	●			●								●				●	●						●			●	●					●																		9	25.0
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P17		●				●							●				●				●							●				●																		7	19.4
P18				●				●					●								●								●				●																	6	16.7
P19	●			●													●							●										●												●				6	16.7
P20	●	●	●	●	●												●											●				●																	●	9	25.0
P21	●	●	●	●												●	●				●							●				●				●													●	11	30.6
P22	●			●				●						●		●	●							●				●				●															●			10	27.8
P23	●			●	●					●					●				●		●		●																								●			9	25.0
P24				●												●	●		●				●									●																		6	16.7
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P26		●	●													●	●				●							●																						6	16.7
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P28		●						●								●	●											●								●														6	16.7
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P30		●						●										●			●			●					●				●			●											●			9	25.0
P31															●		●				●		●						●							●								●						7	19.4
P32				●													●				●								●							●														5	13.9
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No	8	8	5	19	4	1	3	7	4	4	1	2	8	2	2	12	24	1	4	2	23	0	6	6	3	1	1	9	9	1	3	16	3	2	1	14	1	2	2	2	1	0	0	3	0	1	4	1	3	238	
%	22.2	22.2	13.9	52.8	11.1	2.8	8.3	19.4	11.1	11.1	2.8	5.6	22.2	5.6	5.6	33.3	66.7	2.8	11.1	5.6	63.9	0.0	16.7	16.7	8.3	2.8	2.8	25.0	25.0	2.8	8.3	44.4	8.3	5.6	2.8	38.9	2.8	5.6	5.6	5.6	2.8	0.0	0.0	8.3	0.0	2.8	11.1	2.8	8.3	% of 36 CS	
SIII	3.4	3.4	2.1	8.0	1.7	0.4	1.3	2.9	1.7	1.7	0.4	0.8	3.4	0.8	0.8	5.0	10.1	0.4	1.7	0.8	9.7	0.0	2.5	2.5	1.3	0.4	0.4	3.8	3.8	0.4	1.3	6.7	1.3	0.8	0.4	5.9	0.4	0.8	0.8	0.8	0.4	0.0	0.0	1.3	0.0	0.4	1.7	0.4	1.3	Index Wg.	

TABLE 1.1 Factors that lead to project complexity resulting from inadequate SI

The research considered that if the PSIIEP was to be used in professional practice, it must embrace the importance of being accessible and above all be able to provide a comprehensive appraisal of risk. Further, the identification of the risk should be based upon a robust analysis of SI and project information, thereby providing an improved body of information to those carrying out the design and construction process.

At this stage it is perhaps prudent to clarify the use and interpretation of the term 'risk' and 'uncertainty'. The former has been used to express the degree of probable loss or the known or calculable measure of negative effect or impact. 'Uncertainty' indicates that there may be more then one possible outcome in a chain of events or during an activity. Where uncertainty is present, a course of action has not been decided upon nor the outcome definitely known. Ultimately, this research has been designed to identify where uncertainty exists, thereby providing the opportunity for measurable risks to be calculated.

The Identification of a Project Complexity Index (PCI)

The aim of this section of the PSIIEP was to establish a numerical measure that can be used to categorize projects into levels of project complexity. This work significantly differed from other research designed to establish project complexity (Gidado 1993, William 1999) in that it specifically focussed upon the assignment and assessment of a project in relation to the adequacy of the site investigative information. Therefore, Project Complexity is considered in this research as the measure of the "influencing factors of a project design" which impact upon the site investigation. Using structured, semi-structured and informal interviews with construction practitioners that were involved in the 36 case studies this research has identified the "influencing factors". These were used to check and develop a *feel* for the issues surrounding project complexity from an industry perspective. The identified factors are: project duration, financial certainty, foundation proposal, category of land type, outline design, presence of water, relative experience of the project team, familiarity o methods and planning, and contaminated site/environment.

Initially, the 36 case studies were separated into three categories: low, medium and high complexity. Theoretical testing regarding the boundaries of these categories established plausible values for different elements within the questioning and assessment process. The relative degree and significance associated with project information and site investigative data was established by the magnitude of occurrence. These have been carried out in relation to the influencing factors of a project design and described as follows:

<u>Project Duration</u>: The criticality of the project duration had a 14% significance factor apportioned to the response, based upon the 36 cases analysed.

<u>Design or Planning Changes</u>: Design and/or the effect of planning changes carried a significance factor of 10%. Although this element of project complexity was not considered as critical as the ‘project duration’ element in the overall index system, the financial burden of design changes was established to be as severe as any other cost based penalty to a project. These estimates were based upon several exercises carried out to establish the financial consequence of SI related difficulties during construction.

<u>Financial Certainty</u>: Financial certainty was considered to be an element of equal importance to the project duration, subsequently, it too had a 14% significance factor. It is widely accepted that the greater the effort and resources invested to establish and understand a project’s environmental characteristics; the greater will be the ability to pre-plan and conceptualise different project variables, which will undoubtedly reduce the uncertainty of the project and afford the opportunity to estimate the project with a greater degree of certainty.

<u>Foundation Proposal</u>: Four categories of foundation system, namely; trench / strip, raft systems, piled; and a combination system have a total significance factor of 14%. This percentage was then divided between the various foundation systems according to their association, application and ability to deal with; loading patterns (use), the bearing capacity and the characteristics of the soil; and lastly, the respective founding depth/level. Each category carried an individual and increasingly greater factor relative to the complexity of the foundation system.

<u>Category of Land Type</u>: There was a simple choice between the land category being either *Green field* or a *Brown field* development site. The significance of this distinction, however, is slight, with a significance factor of just 7%. Many respondents believe that the immediate discovery or classification of a site being deemed a *Brown field* development places huge and spiralling costs onto the build cost. This research has shown that this may not necessarily be the situation. A case study revealed that the failure to identify deformation and subsidence, behaviour that

occurs naturally in soil and rock, over a wide expanse of land designated under the category of a *Green field* site, resulted in the demolition of several housing units. It may be argued that had the site been deemed a *Brown field* development, further SI would have been undertaken to determine and examine the soils and its characteristics, thus reducing the likelihood of the final solution.

Outline Design - 'footprint': The significance of obtaining and using the 'footprint' or the building planned layout in preparation for and during the SI process was ranked with just 3 ~ 7% within the project complexity index. The number of incidents relating to difficulties associated with the consequence of failing to identify the 'footprint' of the project during the SI warranted its inclusion when considering project complexity.

Presence of Water: With a factor of significance at 7% the existence of water was recognised as having an influence on many facets of the construction process, including the foundation proposal and the sequence and method of construction.

Relative Experience of the Project Team: The overall significance factor to represent the relative experience of the project team was 10% spread between five levels of competence and ability. A very experienced project management team scored in reverse 0.005 ~ 0.0001% factor of project complexity, whilst a relatively inexperienced project team scored 3, equivalent to10%. The higher the final PCI figure, the more complex the project is judged to be using these factors for project complexity in relation to SI information.

Familiarity of Project Methods and Planning: The significance of a project team's familiarity with the proposed construction methods and the project planning tools and techniques was judged to be as important, with 14%, as the project's duration and the ability to determine the financial certainty of the design and construction process.

Contaminated Site and/or Environment: Whether a project had been recognised as being contaminated / unknown or not, had a significance factor 8% or PCI 2.5 apportioned to the response. Contamination alone, as discussed earlier, does not necessarily equate to a significant increase in project complexity.

The Identification of a Site Investigation Information Index (SIII)

The layout of the categories under the section Site Investigation Information Index within the PSIIEP, closely follow the format established for the Site Investigation Procedural Framework Model (SIPFM) developed by Ashton and Gidado (2001a).

Over 36 case studies were used to identify and record the problems, as observed by this research and construction professionals, as a consequence of unforeseen site conditions. A further examination established the magnitude and occurrence of site investigative procedural failures, enabling a weighted factor to be calculated to represent the relative importance of each item within the PSIIEP. The research data provided evidence to validate a comprehensive table detailing the Factors of a Site Investigation that Led to Project Uncertainty.

DISCUSSION OF RESULTS

Among the twelve elements shown in Table 1.1., six have been identified as the main factors that led to project uncertainty as a result of inadequate site investigative procedures. These six elements are:

Briefing Process - Unclear SI brief resulting from an inadequate statement of SI needs accounted for over half the number of case studies difficulties;

Ordinance Survey Records – Inaccurate interpretation of OS data was at the route cause of 12 incidents, resulting problems during the construction process;

Local Authority Records – 24 situations arose because this vital source of SI data had not been adequately checked;

Local Memoirs – The failure to seek out local knowledge or to have gathered information via a thorough review of local memoirs accounted for a further 23 instances of disruption during the construction process. When combined with the failure to glean data from LA records, the overall analysis indicated that 89% of the case's studied suffered some form of disruption to the project because of the inadequacy of SI checking procedures;

Utility Services – Accounted for 16 recorded problems. The disappointing fact behind this record was that these problems were as a consequence of having failed to request or to check the adequacy of the utility capacity for either; the temporary construction requirements, or permanent suppliers needed by the project end user, and;

Mining and Mineral Deposit (Data Collection) and Analysis – The most encouraging element, despite the 14 case studies that experienced difficulties due to inadequate situational analysis, was that the fundamental task of soils and rock sampling, testing and analysis could not be held accountable for the problems identified within the case study sample group. The warning, however, was that 40% of the case's studied suffered severe disruptions, sometimes resulting in a substantial re-design of founding elements of the building, and the severity of the problem in one case study resulted in the closure of the building organisation.

Despite the frenzy of research activity that followed Simon (1944), Banwell (1964), Latham (1994) and more recently Egan (1998) the failure to carry out rudimentary SI principles, established during the first International Conference of Soil Mechanics at Harvard University, Cambridge, Massachusetts in 1936, remains the primary reason for construction difficulties during substructure work.

Unlike the work of Alhalaby and Whyte (1994) this research has not attempted to assess the financial impact of risk upon an organisation; rather it has developed a program to assist with the identification of those factors that contribute to uncertainty associated with unforeseen site conditions.

The work of Odeyinka and Lowe (2000) on modelling cashflow and a subsequent study analysing the impact of risk and uncertainty on construction cash flow (Odeyinka and Lowe, 2001) have identified that the impact of *Problems with the foundations* was critical upon cash flow. Furthermore, whilst analysing different elements within the construction environment; size of firms, procurement methods, contract duration, project types, *Problems with the foundations* were ranked 9th under traditional procurement methods while 1st under design and build procurement systems. Researches, such as Ahston (1998) have shown that the use of Design-and-Build as a procurement system is rapidly increasing in the UK construction industry. Odeyinka and Lowe (2001) findings suggest that until SI improvements reduce uncertainty and problems during sub-structure work, the impact of risk and uncertainty on construction cash flow is set to rise.

CONCLUSION

The methodology used in this research has served as an appropriate means to collect the necessary data required to develop the Project and Site Investigation Information Evaluation Program. The research concludes that the validity of the PSIIEP has been tested in order to afford information to enable effective decision making on whether or not to procure further SI work, thereby reducing risk associated with uncertain site conditions.

This research provides evidence to support the need for adequate SI work to be undertaken. It further establishes the link between substructure related problems as a direct consequence of unforeseen ground conditions resulting from inadequate SI data. The importance of carrying out a thorough SI meet with absolute agreement, yet, this research has established that 57% of contractors used in this survey had experienced difficulties in the ground working phases on site, solely as a result of inadequate site investigative work. It is difficult to understand how the benefits of ‘concurrent engineering’, ‘lean thinking’, ‘best practice’ and the introduction of a ‘generic design and construction process protocol’ can be realised when fundamental errors still occur during the site investigative survey and analysis process.

The work has identified 49 factors or reasons why site investigations fail to deliver adequate survey data. These factors have been categorised into 12 elements, out of which 6 elements have been established to be the main factors that lead to project complexity as a result of inadequate site investigation. The developed PSIIEP is made user friendly by formating the interface with the user in a table using Excel spreadsheet. The model is able to produce a project complexity index and indicate a measure of availability of SI information. These two indexes would enable the practitioner to decide on whether to seek more information by further site investigation.

Grounded theory enables existing theory and procedural processes to be continually re-appraised, re-examined and ultimately changed to reflect new and proven logic. The aim of the global research programme has been to develop a system that can be used by construction practitioners to objectively establish the level of risk associated with an inadequate SI. This paper has delivered the second stage in the development of the system that may be used to supplement, compliment or replace the failing existing SI theory. The PSIIEP shown in the Appendix utilises existing project information data, PCI and SCII to evaluate the risk associated with available site investigation information.

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