ANALYSIS OF COST ESCALATION AND RISK ASSESSMENT OF INFRASTRUCTURE PROJECTS: AN APPLICATION IN JAPANESE CIVIL ENGINEERING PROJECTS

N. Dawood[1], T.Yasuhara[2], Y.Usuda[2], C.Matsuda[2], and A.Sawada[2]

[1] *School of Science and Technology, University of Teesside, Middlesbrough TS1 3BA, UK*
[2] *Public Works Research Institute, Ministry of Land, Infrastructure and Transportation 1 Asahi, Tsukuba, Ibaraki 305 –0804, Japan*

Cost escalation of construction projects can be defined as the departure of final project costs (after construction) from the initial budget estimates. This can be caused by a number of factors ranging from design changes to high cost of materials, machinery and labour (i.e. more than initially anticipated). As cost escalates, all budgetary and fiscal plans can be thrown in to chaos, causing the construction market to suffer for the lack of predictability. There is an increasing interest by the Japanese Ministry of Land, Infrastructure and Transportation to establish accurate costs estimates and risk assessment for construction (in particular infrastructure) projects to reduce cost escalation at all stages of the construction process. Current practices in the industry suggest that there is a lack of structured methodologies to assess risk and cost escalation of construction projects. In this context, the objective of this research project is to identify cost escalation drivers through the analysis of previous projects and develop a methodology for assessing risk factors and improve cost estimates. A total of sixteen historical case studies (construction projects of bridges in Japan) has been collected and analysed.

Several investigation methodologies have been used in this papers, these were: literature review, analysis of historical case studies, Delphi methods for judgmental analysis, interviews and brain storming sessions with project mangers.

Keywords: case study, cost escalation, civil engineering, Japan, risk management

INTRODUCTION

The Japanese domestic construction market is worth approximately £400bn/annum. In real terms, this is a per capita spend 1.6 times that of the UK, at a time when Japanese contractors consider themselves to be in recession.

High costs compounded the Japanese construction industry problems. Though falling, average out-turn costs are reckoned to be twice in the UK (it self no shining example of construction efficiency). Japan ranks as the world's most expensive country in the world (NCE, March, 2001).

Japanese contractors produce work on time and to a high standard, but there is huge inefficiency in project planning, co-ordination, cost control and procurement. It is not uncommon for work to be sublet up to seven times on public works projects and each subcontractor will cream off a 'management fee' of up to 10% project cost.

Dawood, N N, Yasuhara, T, Usuda, Y, Matsuda, C and Sawada, A (2001) Analysis of cost escalation and risk assessment of infrastructure projects: an application in Japanese civil engineering projects. *In:* Akintoye, A (Ed.), *17th Annual ARCOM Conference*, 5-7 September 2001, University of Salford. Association of Researchers in Construction Management, Vol. 1, 835-44.

It is estimated that as much as 99% of construction work is done on a lump sum basis, with clients honour-bound to cover cost and time overruns. Adversarial relationships are not practised in Japan.

The infrastructure civil engineering projects are major contributors to the well being of the Japanese society and civilization and generally involve a high level of investment by the Government.

There is an increasing interest by the Japanese Ministry of Land, Infrastructure and Transportation to establish accurate cost estimates and risk assessment for projects and reduce cost escalations at the outset and execution stages of the construction processes. Cost escalation, in this context, is defined as the percentage increase of the final cost (out-turn) from the initial base. Current practices in the industry have suggested that there is a lack of structured methodologies and systematic cost escalation approach to achieve an appropriate cost analysis at the outset of projects and throughout the construction processes. In this context the prime objective of this research work is to analyse cost escalation of infrastructure projects and identify risk factors that contribute to such cost escalation. The ultimate objective is to develop a structured risk management approach that can be utilized by project managers to predict cost of construction projects.

The methodology deployed in this study is as follow:

- Collection of historical information and case studies of sixteen bridges that were recently built in Japan. The construction of each bridge was split into five sub-products (earth works and foundation, girder fabrication and assembly work, floor slab work, supplementary structure work and temporary work). Cost escalation information was collected for all sub-products and presented in a percentage terms from the initial cost (ceiling price). This information has been collated and analysed using spreadsheet models.
- In order to identify risk factors that contribute to the cost escalation, a comprehensive risk list was developed and sent to project managers for their evaluation. The list was developed through brain storming sessions with project managers.
- The feedback from the project managers was analysed (using the Delphi technique) and compared with the cost escalation figures identified in 1 above.

The following section deals with the current theories of risk management and cost escalation.

RISK MANAGEMENT AND COST ESCALATION: LITERATURE REVIEW

In this research it was hypothesized that cost escalation is mainly caused by risk factors. The objective of this section is to set the scene for risk management theories and review previous research activities in this subject. Risk management tends to vary from the extremely simplistic checklist approach (Toakley 1995) to the extremely complex probabilistic analysis (Russell and Ranasinghe 1992). The following explains three stages of risk management process which involves the identification of risk, the analysis of risk and response.

Risk identification

Risk and uncertainty are inheritance to all construction projects no matter where, when and how are being built (Thompson and Perry 1995). There are numerous sources of risk that could include financial, act of God, and type of project, procurement strategy, location, and familiarity and of course politics. In order to identify and categorize risk factors and their contribution to the out turn cost in the heavy civil engineering industry; objective statistical analysis, interviews, workshops, brain-storming sessions are being used by previous researchers.

Table 1 introduces the risk factors identified in the workshop and brainstorming sessions that were conducted with industrial personnel in Japan and previous literature (Bates and Dawood 1998)

Table 1: Selection Of Risks In The Heavy Engineering Industry

POLITICS	ACTS OF GOD	CONSTRUCTION PROBLEMS	DESIGN PROBLEMS
Choice Of Contractor	Flood	Duration	Project Complexity
Exchange Rates	Earthquake	Structural Damage	Design Variations
Strike, Productivity	Landslide	Equipment Damage	“Brief” Detail
Client Control	Bad Weather	Labour Injuries	Innovation / Research
Client Bureaucracy	Fire	Equipment Failure	
Site Supervision	Wind	Theft	
Environmental Impact		Site Conditions	
		Unforeseen Circumstances	
		Location	

Risk Analysis

Risk analysis is the process of quantifying risks factors and identifying the influence of each factor on the out-turn cost. Analysing risk normally involves more sophisticated techniques requiring the power of a computer. In many ways this is seen as the most difficult phase of the risk management process. The normal requirements for quantifying risk factors are:

- Estimates of uncertainty such as percentile values describing a distribution of probability for each risk (Russell and Ranasinghe 1992, Dawood 1998) or fuzzy numbers (Tah 1997), and
- A probabilistic combination of each of the uncertainties. (Russell and Ranasinghe 1992, Dawood 1998) or fuzzy set combinations (Tah 1997).

Knowledge elicitation techniques are used to quantify risk factors, and the techniques below are used to derive the influence of risk factors on the out-turn cost. The three most common techniques utilized within a Risk Analysis Procedure are:

Sensitivity Analysis, and

- Probability Analysis (Russell and Ranasinghe 1992) .The accuracy of the results depends on assumptions made, the experience of the risk analyst and the accuracy of the input data (Thompson and Perry 1995).
- The Delphi Method (Smith 1999). Analysis of risk factors is achieved by eliciting consensus form experts.

All of the above techniques, provide an addition to the estimate in terms of cost, however, the increase in cost may be caused by time overruns (Dawood 1998).

Risk response / contingency allocation
This is the most important phase of the risk management process. Without responding to the risk factors, risk identification and analysis will have no value. There are several ways of dealing or responding to risk when it arises. Risk response can involve:

- Identifying preventive measures to avoid a risk or calm its affect
- Improving control through step by step stage movement,
- Risk transfer,
- Setting and managing risk allowances in estimates, or
- Establishing contingency plans.

The aim of a risk response procedure is not to remove all risk factors but to manage them efficiently. The recent partnering schemes (CRINE and ACTIVE in the heavy engineering industry) (Grice 1998) are aiding the risk management process as the affects of them can be shared and incentives used to provide further profit if certain risks have minimal consequences. Risk response helps other areas of the project progression, not only time and cost constraints. It can:

- Enable decision making to be more systematic,
- Allow comparison of robustness of projects to specific uncertainties,
- Make the relative importance of each risk immediately apparent,
- Give an improved understanding of the project,
- Demonstrate company responsibility to customers, or
- Improve corporate experience and communication.

RESEARCH METHOD: DATA COLLECTION

The objective of this research is to investigate and study the cost escalation in the heavy civil engineering projects and in particular bridges. Sixteen case studies (presenting 16 bridges from several prefectures in Japan) were selected and studied in greater depth. Information about initial and out-turn costs for the sixteen project were collated and presented. A summary of the cost information of the sixteen cases is presented in Table 2. In order to identify the risk factors contributing to the cost escalation of the above cases, a comprehensive list of risk factors was developed and sent to project managers of the above sixteen case studies. This was followed by brain storming sessions between the research team and representative of the above projects. The objective was to ascertain the risk factors and further the development of a risk management and cost escalation methodology to be used by project managers to accurately predict cost and identify risk factors of projects. The risk factors list is discussed in the coming sections of this paper.

RESULTS ANALYSIS

Statistical analysis of cost escalation
Detailed cost escalation was established for all cases through calculating the deviation from out-turn cost for 'level 2 standard items' from the initial estimate 'ceiling prices'. Table 3 shows detailed analysis for positive cost.

It can been seen from Table 3 that almost all projects have positive cost escalation with an average of 12% and standard deviation of 20%. For public works projects, any cost escalation will be undesirable as all projects are operating under a very tight fiscal budget. From the tables, it is apparent that the cost escalation has no standard pattern, reinforcing the believe that all work items are subject to cost escalation (foundation or super structure). Projects 4, 6,10,13 and 16 have a very high cost escalation with about 30% to 40% above the ceiling price.

Figure 1 shows the total costs escalation in 'Japanese Yen' for all works items for the sixteen projects. It can be concluded that almost all items are vulnerable to cost escalation except fence, channel reconstruction, roadwork, earth work and girder erection work.

From the data analysis, it can be concluded that, girder fabrication and assembly work, pier and culvert are exposed to cost escalation. This suggests that there should be thorough investigations of these items at the detailed design and execution stages. The question posses itself as to why such escalation is occurring and what are the risk factors that influence such escalations? In order to answer this question and generate knowledge about previous cases, a thorough investigation (survey, interviews and brain storming sessions) has been conducted as introduced in the next section.

Analysis of risk factors

The Delphi method was used to obtain consensus estimates of the impact of risk factors on the overall cost escalation from experts (project managers). The general procedure for this technique is that an estimate of the impact of risk is obtained from each of the experts (project managers). These estimates are related to the probability of occurrence and influence of the of the risk factors. The experts are then informed of all estimates and asked to provide a revised estimate. This process continues until consensus estimate is produced. Although the Delphi methods rely heavily on judgmental opinion, the research team has combined the statistical analysis with this method in order to reach satisfactory results.

A comprehensive list of risk factors (see Table 5) have been sent to sixteen project managers (these managers have been involved in some of the sixteen cases outlined above). Managers were asked to identify the impact and occurrence (high, medium or low) of risk factors to both cost escalation and time overrun. In order to establish a measure of the severity of risk factors a scoring system has been establish and presented in Table 4. As can be seen, if a manger indicates 'high influence' and 'high frequency' for a risk factor, the score will be 9 and so on. The justifications for establishing a scoring system was to be able to rank the risk factors according to their combined influence and frequency. The outcome of the analysis was used to establish the necessary addition for each risk factor (cost and time) to the overall ceiling price and duration of project.

Table 5 gives the responses from project managers and Table 6 gives the overall ranking of risk factors for all respondents with respect to the scoring system outlined in Table 4. As can be seen the score ranges from 31 to 0. High design variations and additional work risk factors have shown a high score compared to other risk factors, 31 and 20 receptively. Nine of the managers (60% of respondents) have indicated that high design variations have attributed to cost escalation of projects.

Table 2: Summary of cost information (in Japanese Yen) of the sixteen cases

Project ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Regional Bureau	Hokkaido	Hokkaido	Tohoku	Tohoku	Kanto	Kanto	Hokuriku	Hokuriku	Kinki	Kinki	Tyugoku	Tyugoku	Shikoku	Shikoku
Initial Cost	51,581,517	192,174,625	15,992,428	148,229,306	136,106,252	36,567,744	14,959,541	71,048,850	83,386,982	79,858,167	172,409,238	89,062,939	36,128,967	7,808,919
Final Cost	51,479,577	192,174,625	16,367,754	212,670,199	139,616,404	40,238,664	15,847,521	56,703,867	88,802,039	113,100,140	184,635,217	92,311,133	41,866,435	7,808,919
Overall Escalation	-101,940	0	375,326	64,440,893	3,510,152	3,670,920	887,980	-14,344,983	5,415,057	33,241,973	12,225,979	3,248,194	5,737,468	0
Start Date	6-Nov-98	25-Mar-99	8-Jul-98	25-Jul-98	19-Nov-98	29-Sep-98	30-Sep-98	8-Aug-98	2-Oct-98	25-Aug-98	10-Aug-98	27-Jul-98	17-Sep-98	11-Aug-98
Finish Date (Planned)	25-Mar-99	10-Mar-00	20-Nov-98	15-Mar-99	6-Jun-99	31-Mar-99	30-Jun-99	14-Feb-99	28-Jul-99	15-Mar-99	28-Feb-99	31-Mar-99	20-Mar-99	10-Mar-99
Finish Date (Actual)	25-Mar-99		28-Dec-98	30-Mar-99	6-Jun-99	31-Mar-99	30-Jun-99	14-Feb-99	28-Jul-99	30-Jun-99	28-Feb-99	31-Mar-99	30-Jun-99	25-Mar-99

Table 3: Positive cost escalation for 16 cases

Item	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	Project 9	Project 10	Project 11	Project 12	Project 13	Project 14	Project 15	Project 16
girder fabrication and assembly work	0.00%	0.00%	0.00%	37.48%	0.26%	0.00%	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
girder purchasing	0.00%	0.00%	2.01%	0.00%	0.00%	0.00%	0.00%	2.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
girder erection work	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
floor slab work	0.00%	0.00%	0.00%	0.63%	0.00%	0.00%	0.00%	0.00%	0.31%	0.00%	0.00%	0.00%	0.26%	0.00%	0.32%	0.00%
bearing work	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.43%	0.00%	1.49%	0.00%	0.00%	0.00%	0.00%	0.00%
supplementary structure work	0.03%	0.00%	1.42%	5.29%	0.23%	0.00%	0.00%	0.00%	0.00%	0.00%	5.60%	0.00%	1.01%	0.00%	1.53%	0.00%
temporary work (Superstructure)	0.00%	0.00%	0.00%	0.39%	0.00%	0.00%	7.88%	0.00%	0.18%	0.00%	0.15%	0.00%	0.00%	0.00%	0.00%	0.00%
abut	0.16%	0.00%	0.00%	0.00%	0.59%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.16%	0.00%	0.00%	0.00%
pier	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.13%	0.00%	0.00%	0.00%	41.87%
temporary work(Foundation)	0.09%	0.00%	0.00%	0.00%	1.50%	0.00%	0.00%	0.00%	3.32%	0.06%	0.00%	5.13%	0.00%	0.00%	0.00%	0.00%
earth work	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
road work	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
structure removal	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.52%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
fence	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
channel reconstruction	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
revetment	0.00%	0.00%	0.00%	0.00%	0.00%	16.46%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	4.47%	0.00%	0.00%	0.00%
curvert	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	41.57%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
others	0.00%	0.00%	0.00%	0.00%	0.00%	2.34%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total	0.38%	0.00%	3.43%	43.81%	2.58%	18.80%	7.88%	2.18%	6.76%	41.63%	7.24%	6.26%	15.90%	0.00%	1.84%	41.87%

Average (all projects) 12.53%

SD (all projects) 20%

Table 4: Scoring system for the severity of risk factors

Risk factors		Influe.		
		Hi	Me	Lo
	Score	3	2	1
Freq.				
Hi	3	9[1]	6[1]	3[1]
Me	2	6[1]	4[1]	2[1]
Lo	1	3[1]	2[1]	1[1]

[1] Influence * Frequency

In fact all risk factors related to 'Design and Politics' risk factors have scored higher than 'Act of God' and 'Construction' risk factors. The results indicated that more evaluation of the design options should definitely lead to a more predictable and accurate cost estimate.

SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

The prime objective of this research project was to identify cost escalation drivers for public works infrastructure projects and develop a risk management methodology for the public works projects. A total of sixteen construction projects of bridges in Japan were studied and analysed using historical statistical data and knowledge elicitation from project managers. It was concluded that design changes and development, additional works and public claims have substantial impact on cost escalation of projects. A risk management methodology has been developed during the course of the research project and presented in this report.

The authors recommend the following activities to further and extend the research project, these are:

Collection of more information about current and past projects (hard and soft data).

Extension of the investigation to include other types of infrastructure projects (tunnels, roads, dams, etc).

Comparison of the results of different infrastructure categories.

Development and encapsulation of the judgmental risk factors (% addition to the total cost for each risk factor) in a computer-based system to be used by the developed risk management methodology.

Research to be carried out on the methods and ways to reduce the influence of the risk factors on construction projects and hence the incorporation of Value Management within the developed Risk Management methodology. The methods of integrating value management with risk management need more research and investigation.

ACKNOWLEDGEMENT

The author would like to thank the following for their contribution to this research:

Japan Science and Technology Corporation for awarding the STA Fellows.

Ministry of Construction and Public Works Research Institute for providing all means for tackling the research project.

Table 5: Responses from project managers

Risk Factor Level 2	Cost																																																		
	1			2			3			4			5			6			7			8			9			10			11			12			13			14			15			16			17			
	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	I	Fr	Sc	ota
High Design Variations(DESIGN)	2	2	4	1	1	1	2	2	4				1	1	1	3	2	6	3	1	3										3	2	6	1	2	2							2	2	4							31
additonal works(POLITICS)	2	2	4													1	1	1	2	2	4	2	1	2							2	2	4							2	2	4	1	1	1							20
Contract with preliminary							1	2	2							2	2	4	1	2	2	1	1	1							2	2	4																			13
New Design/Innovation(DESIGN)				1	2	2													2	2	4										1	1	1				2	2	4										1	1	1	12
public claim(POLITICS)																																		3	3	9																9
Contract with representative																1	1	1	1	2	2	2	1	2							2	2	4																			9
further survey(POLITICS)	1	1	1										1	1	1	1	1	1				1	1	1																			2	2	4							8
change scope(POLITICS)	1	1	1																																														3	2	6	7
Bad Site																1	2	2	2	1	2	1	1	1																			1	2	2							7
another works(POLITICS)	1	1	1										2	1	2				2	1	2																															5
Bad																																		2	2	4																4
land acquisition(POLITICS)													2	1	2				1	1	1																															3
Landslide(ACT OF GOD)																			1	3	3																															3
Unforeseen Ground													1	1	1				1	1	1	1	1	1																												3
																															3	1	3																			3
Environmental Impact(POLITICS)																			1	1	1													1	1	1																2
external indication(POLITICS)																						2	1	2																												2
poor client																			2	1	2																															2
Public Involvement(POLITICS)																																		1	1	1																1
Flood(ACT OF GOD)																			1	1	1																															1
Structural																						1	1	1																												1
High Project																						1	1	1																												1
Inflation(POLITICS)																																																				0
Earthquake(ACT OF GOD)																																																				0
Bad Weather(ACT OF GOD)																																																				0
Wind(ACT OF GOD)																																																				0
Tight Schedule																																																				0
Total			11			3			6						7			15			28			12									22			17			4			4			11						7	
% cost escalation			0			0			3			44			3			19			8			2			7			42			7			6			16			0			2			41				

I: Impact, Fr: Frequency, Sc: Score

Table 6: Importance of risk factors

Risk Factor Level 2	Experience	
	Importance Score	Cost Escalation MAX
High Design Variations(DESIGN)	31.00	4.02%
additonal works(POLITICS)	20.00	1.29%
Contract with preliminary design(DESIGN)	13.00	2.68%
Poor Quality Design(DESIGN)	11.00	15.88%
public claim(POLITICS)	9.00	1.93%
Contract with representative section design(DESIGN)	9.00	1.29%
further survey(POLITICS)	8.00	0.67%
Bad Site Conditions(CONSTRUCTION)	7.00	1.34%
another works(POLITICS)	5.00	0.74%
Bad Foundation(CONSTRUCTION)	4.00	0.86%
Structural Damage(CONSTRUCTION)	4.00	0.97%
land acquisition(POLITICS)	3.00	0.74%
Landslide(ACT OF GOD)	3.00	0.64%
New Design/Innovation(DESIGN)	3.00	0.37%
Environmental Impact(POLITICS)	2.00	0.21%
external indication(POLITICS)	2.00	0.00%
poor client management(POLITICS)	2.00	0.42%
change scope(POLITICS)	1.00	0.01%
Public Involvement(POLITICS)	1.00	0.21%
Flood(ACT OF GOD)	1.00	0.21%
High Project Complexity(DESIGN)	1.00	0.00%
Inflation(POLITICS)	0.00	0.00%
Earthquake(ACT OF GOD)	0.00	0.00%
Bad Weather(ACT OF GOD)	0.00	0.00%
Wind(ACT OF GOD)	0.00	0.00%
Tight Schedule	0.00	0.00%

1:Low 2:Mid 3:High

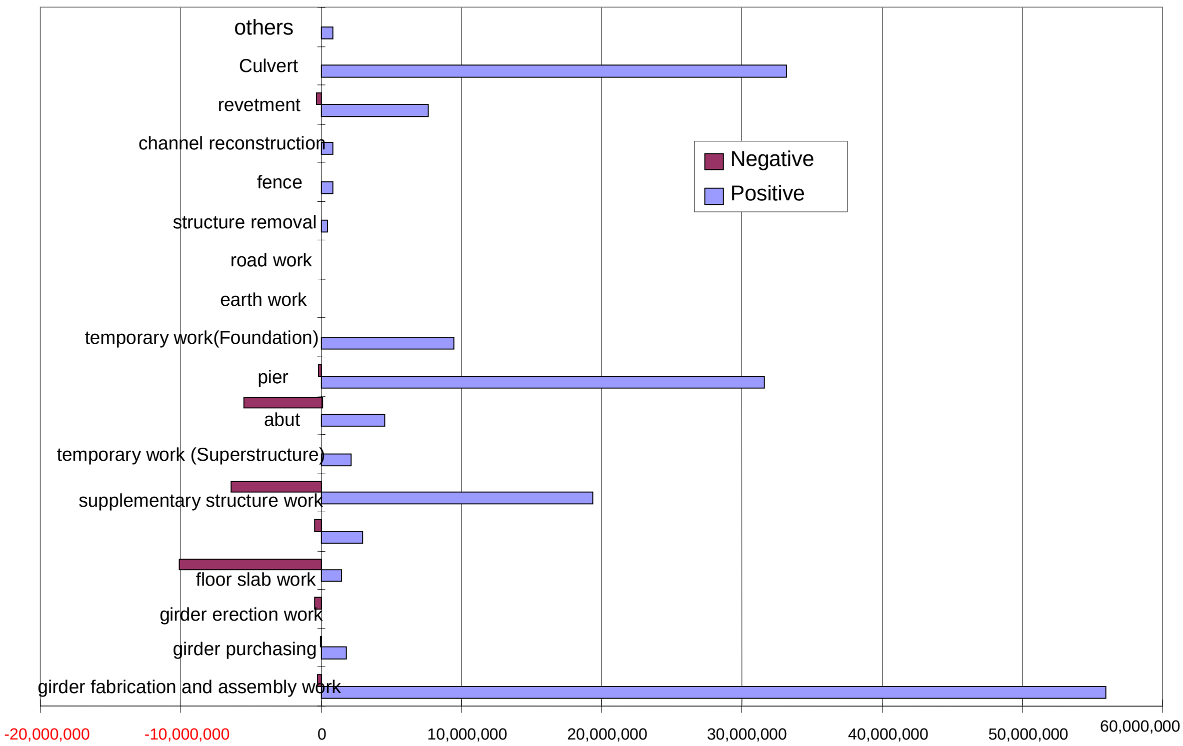

Figure 1: Total cost deviation in Yen for the sixteen case studies

REFERENCES

Bates, W. A. (1998) *Strategy For The Prediction Of Out-turn Cost In The Heavy Engineering Industry*. Submitted Thesis In Partial Fulfilment Of The Requirements For PhD, University of Teesside, Middlesbrough.

Bates, W., and Dawood, N.N. (1998) Development of a risk allocation strategy for construction in the process industry. *In:* Hughes, W.P. (ed) *Procs 14th Annual ARCOM Conference, University of Reading, September 1999*. Reading: ARCOM.

Dawood, N. N. (1998) Development of a risk management approach for allowing dependency and uncertainty between activities' duration. *Construction Management and Economics*. **16**: 41-48.

Dawood, N. N. and Bates, W. A. (2000) Decision Support System Specification for Out-turn Cost and Cost Escalation in the Heavy Civil Industry. *Engineering, Construction and Architectural Management* (Sept).

Grice, D. R. (1998) Potential Project Cost Savings Using Principles Similar to Those Recommended By CRINE and ACTIVE. *The Cost Engineer.* **36**(2, Mar): 5-10.

Russell, A. D. and Ranasinghe, M. (1992) Analytical Approach for Economic Risk quantification of Large Engineering Projects, *Construction Management And Economics.* **10:** 277-301.

New Civil Engineer (NCE), March, 2001.

Sparkes, J. R. and McHugh, A. K. (1984) Awareness And Use Of Forecasting Techniques In British Industry. *Journal Of Forecasting*. **3:** 37-42.

Smith, N. (1999) *Managing Risks in Construction Projects*. Blackwell Science.

Tah, J. M. H. (1997) Towards a Qualitative Risk Assessment Framework for Construction Projects. *Managing Risks in Projects*. 265-274.

Thompson, P. and Perry, J. (1995) Engineering Construction Risks. London: Thomas Telford Services.

Toakley, A. R. (1995) Risk Analysis Techniques. *Australian IOB Papers*. **6:** 69-75