METAGAME ANALYSIS FOR DETERMINING CONSTRUCTION METHODS

Metagame analysis for assessing construction methods

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Abstract

This paper deals with the use of metagame analysis to help resolve conflicting factors affecting the choice of a reinforced concrete structural system. The most suitable construction method in a project varies in accordance with several factors, but may be limited to: overall construction cost, construction duration, quality of construction and effect of environmental issues. A computer program was developed as a tool to analyse the decision making process using an Analytical Hierarchy Process and is used to decipher different preferences based on prioritised objectives. The specific focus in this paper is resolving to choose pre-cast concrete in comparison to cast-in-place technology in a project operated by a firm including an owner, an architect and a construction manager. The results derived from the metagame analysis shows that the priority afforded to the various factors affecting a particular choice of building system is dependent upon the preference given to these factors and this necessarily will have an effect the manner in which the conflicting objectives are resolved.

Keywords: Building construction, construction method, decision-making, design build, metagame analysis, pre-cast concrete

1 Introduction

Pre-cast concrete technology was introduced into building construction in the 1960's and ultimately brought about significant changes to Japan's construction industry. However, its adoption did not advance smoothly and the many advantages that the use of pre-cast concrete potentially offers have not been realised in Japan. Indeed, the adoption of pre-cast concrete construction within the industry was hindered by a number of problems such as the lack of skilled and the age of labourers, the requirement to insure quality construction, the need to minimise the duration of construction and the use of material resources to name but a few of the evident contributing factors. One of the factors inhibiting its implementation was that firms, or those individuals involved in the construction process such as the owner, architect and contractor, did not always collaborate to adopt pre-cast concrete. This is because the individual "players" in the construction "game" often sought to capture an advantageous strategy for themselves, by which they would minimise their perceived risk. For example in a given project where pre-cast concrete might be considered as a potential option, a project architect may have insisted on flexibility of design whereas the construction managers' priority was to minimise the duration of construction. In such a case, the architect avoids pre-cast concrete though the construction manager suggests it. Hence, there exists a conflict problem that often in the past has been resolved simply by resorting to construction solutions that minimise the risk to the owner or the owners representative, i.e. the architect. This typically is what has occurred to hinder the adoption of pre-cast in the Japanese construction industry that is, as are many other such industries around the globe, essentially risk avers.

The purpose of this paper is to analyse such types of conflict using the metagame decision support method specifically to help clarify the adoption of pre-cast concrete. The decision support system metagame was first developed in the 1970s and has since been applied to resolve conflicts in many different kinds of engineering fields. However in the Japanese building construction industry its use as a project management tool is not well known. The conflict problem that required solving is the preference for cast-in-place concrete in relation to pre-cast concrete given their respective construction costs. The authors assessed the preference using quantitative methods offered in metagame; a computer program of the metagame analysis was developed to help resolve this problem.

2 Conflict problem

2.1 Overview

If one compares the pre-cast and cast-in-place concrete industries, one might suggest that comparison could be made on the basis of overall construction costs, duration of construction, quality of work offered by the finished product and effect on environment issues. In general, the cost of pre-cast concrete is reasonably stable as a typical manufacture of pre-cast concrete regularly produces multiple units of high quality concrete assemblies. In regards to transportation of pre-cast units, this usually tends to be left to a specific trader of which few changes in cost can be expected.

To the Japanese pre-cast concrete is suggestive of shabby, uniform and uninspired architecture. An owner's interest is focused not on the construction method but indeed, on the design, as well as the construction duration and cost. It is generally agreed in Japan that architect-designers believe the use of pre-cast concrete construction offers little planning flexibility. Furthermore, such designers often wish to adhere to quality in the design and therefore, they do not always encourage adoption of pre-cast concrete. However, it is noted that pre-cast concrete is used not only for structural members but also for non-structural members such as balconies. In such instances, the flexibility of the design can be guaranteed.

In the Japanese construction industry, cast-in-place concrete is easier to complete than pre-cast concrete structures. For the contractor, it is important to know how to build and to control the cost of construction. Therefore, pre-cast concrete systems do not tend to be adopted by contractors since wide spread knowledge of this technology does not exist. However, certain projects have been completed using this technique in instances where the quality of construction, durability and reduced construction schedules were important factors. The duration of construction of pre-cast concrete structures can be reduced, since the unit assemblies are first fabricated in a factory environment permitting strict control over fabrication schedules and the finished goods are thereafter transferred to the site in appropriate sequence thus minimise delays or scheduling problems. In general, the quality of pre-cast concrete material is essentially the same in comparison with cast-in-place concrete. However, pre-cast concrete assemblies are produced under precise production controls that assure high quality in concrete materials and highly accurate dimensions. Hence they are the preferred system in instances where these attributes are of importance.

Pre-cast concrete has obvious advantage in regards to environmental issues since its use minimises the use of tropical wood in the construction process (for formwork) and construction waste is likewise reduced using pre-cast thus mitigating the disposal problem.

2.2 Problem defined

The adoption of pre-cast concrete is the conflict problem being investigated. The conceptual model developed to study this problem is based on the following assumptions. An integrated construction company is to execute a turnkey building project using a reinforced concrete (RC) structural system; the company itself is an owner of the project. The conflict problem is whether to adopt pre-cast or cast-in-place concrete for the project. It is assumed here that the company has sufficient knowledge of pre-cast technology that this is not a hindrance to its being selected. Each department of the company is considered is a person involved in the problem.

3 Outline of metagame

3.1 Using metagame

When certain persons or firms are faced with conflict problems, the solution is often not easy to derive. Because an individual person or firm will act in their best interest it is not then always possible to reach the best agreement for others involved in the conflict. Metagame analysis is a process introduced to help resolve conflict problems in which the main focus is that of finding a stable state common to all persons or firms involved in the conflict (Okada; 1988).

3.2 Components of metagame

The main components of metagame consist of: players, options, scenarios, order of preference and stability analysis, each of which is briefly described below.

Players:	The persons or firms involved in a conflict problem.
Options:	Players act in this conflict problem through a process called an option. One or several options exist for each player.
Scenarios:	Each option is not mutually exclusive. The player can take some of those options at the same time. The combination of options of each player describes a specific plan. When an option is selected, the number '1' is assigned to the option. When an option is not selected, '0' is assigned. A scenario is defined as a row of values consisting of '1' or '0' for each option. It is necessary to select the scenarios that can exist and actually be executed (i.e. executable scenarios).
Order of preference:	Each player defines the order of preference among executable scenarios. It is an order of scenarios sorted by the preference that the player assesses among all executable scenarios.
Stability analysis:	Stability analysis is the process of searching for a solution. The state in which stability exists for all the players is the solution of the conflict problem.

3.3 Procedure for stability analysis

There are four steps in the stability analysis (Okada *et al.* 1988), each of which is described below:

Step 1	Preparation of the scenarios	All the executable scenarios may be the solution. Therefore, it is necessary to pick up all possible scenarios.
Step 2	Finding unilateral improvement	When a player intends to change their plan, the action that is in the direction where the order of the preference goes up by changing their option is called unilateral improvement (UI). In UI, only one player changes the option whereas other players do not change their options.
Step 3	Finding detrimental processes	Assume that player *A* moves to scenario *p* by UI from scenario *q*. If another player *B* moves to other scenario where the order of preference for player *A* falls, player *B* is regarded as being detrimental to player *A*.
Step 4	Finding stable scenario(s)	There are three results in the stability analysis: (1) Reasonable (r); (2) Sequentially stable (s); (3) Unreasonable (u) When there are no scenarios that become UI from a scenario, the scenario is regarded as reasonable. Not unreasonable scenario, (r) and (s), for all players are the solution of conflict problem.

4 Application

Definition of players in the project

The player who takes the part as:

- an owner – is the development department (OW);
- an architect – is the design department (AR);
- a contractor – is the construction department (GC).

Definition of options

The options are based on the strategy of each of the players as shown in Table1.

Definition of scenarios

If all the options are executed independently, the number of total scenarios is 2^5=32. There exist within this set of possible scenarios a number of scenarios that cannot be executed. For example, two options of the AR are contradictory; hence in this case, the number of scenarios should be reduced to 16 as shown in Table 1.

4.1 Defining the order of preference using the analytical hierarchy process

The strategy of each player depends on their respective viewpoint regarding overall costs, construction duration, and quality of construction and environmental issues. The order of preference differs according to criteria the players use to assess the respective significance of each factor. For example, the criteria for the OW (owner-development department) are cost, duration, quality and environment as shown in Table 2(a). Likewise, the criteria for the AR (architect-design department) are cost, duration, and quality, as shown in Table 2(b). Finally, The criteria established for GC (contractor-construction department) are cost, duration, and environment, as shown in Table 2(c).

Three cases (a, b, c), representative of combined criteria of the three players acting in concert, are the basis for analysis using the metagame method; these combinations are provided in Table 3. Case (a) shows the requirement for cost reduction. Case (b) is an often-expressed pattern in construction projects, i.e.; it is the situation where the AR (architect-design department) gives priority to quality. Case (c) is the typical situation in which the OW (owner-development department) and the GC (contractor-construction department) focus on an effective sales strategy and hence may be intent on minimising the construction duration.

The Analytical Hierarchy Process (AHP) is used for defining the order of preference by calculating an integrated degree of worth of the various options. In AHP, the criteria are compared in pairs and the evaluation of superiority or inferiority of each set is given subjectively in five stages. The qualitative relations among the criteria can be obtained by calculating the geometric average. The correspondence of the evaluation is assessed according to a consistency index (CI). Here it is assumed that if CI is 0.1 or less, it is appropriate to use the model.

Table 1: Scenarios of the conflict problem

Scenario Number	OW	AR		GC	
	Permitting Cost increase	Using cast-in-place Concrete	Using PCa	Hiring more staffs	Using more materials And equipments
1	1	1	0	1	1
2	1	1	0	1	0
3	1	1	0	0	1
4	1	1	0	0	0
5	1	0	1	1	1
6	1	0	1	1	0
7	1	0	1	0	1
8	1	0	1	0	0
9	1	1	0	1	1
10	1	1	0	1	0
11	1	1	0	0	1
12	1	1	0	0	0
13	1	0	1	1	1
14	1	0	1	1	0
15	1	0	1	0	1
16	1	0	1	0	0

In AHP, the sum of the respective degrees of worth is 1.0. In this case, as there are 5 options, their average is 0.2. It is assumed that an undesirable option for a player is one for which the degree of worth falls below 0.2 (i.e. below the average). Values above 0.2 are subtracted from original degree of worth are shown in Table 2. For example, in Table 2(a), for OW, the value of "duration" is as follows: "permitting cost increase":-0.054; "using cast-in-place concrete": -0.09; "using pre-cast concrete"; 0.310; "hiring more staffs"; -0.058; and, "using more materials and equipment":-0.117.

The score for each scenario is determined in the following manner: assume the degree of worth of each option is given by (*A, B, C, D, E*); selection of each option (1 or 0) is given by (*a, b, c, d, e*); and, the point of scenario *j* is *P(j)*. Then *P(j)* is:

$$P(j) = Aa + Bb + Cc + Dd + Ee \quad \textbf{(1)}$$

All the scenarios are sorted by the order of preference as shown in Table 4.

4.2 Stability analysis

The results of metagame analysis are shown in Table 5. Case (a) is explained in detail below. Scenario 1 for the OW (owner-development department) is the initial item discussed. The OW moves to scenario 9 as a one-sided improvement from scenario 1. On the other hand, there is no one-sided improvement of the AR (architect-design department). The one-sided improvement of the GC (contractor-construction department) is found in scenarios 10, 11 and 12. Here, the order of preference of scenarios 10, 11 and 12 is higher than that of scenario 1 for the OW. Hence this scenario is not detrimental to the OW. Therefore, scenario 1 becomes unreasonable (u) for the OW. Likewise, scenarios 2 to 8 are also unreasonable for the OW.

Next, the stability of scenario 9 of the OW is analysed. A review of scenario 9 shows that the OW does not have a one-sided improvement therefore, scenario 9 is reasonable (r) for the OW. In the same way, scenarios 10 to 16 are also reasonable (r) for the OW.

Results from the analysis show that scenarios 1 to 4 and scenario 9 to 12 of the AR (architect-design department) do not have a one-sided improvement hence, they are reasonable (r). Scenario 5 of the AR moves to scenario 1 by a one-sided improvement. On the other hand, the OW moves to scenario 9 by a one-sided improvement. As for scenario 9, the order of the preference is lower for the AR than that of scenario 5. Therefore, scenario 5 is stable (s) for the AR. Scenarios 6 to 8 are similarly stable for the AR. The AR moves from scenario 13 to scenario 9 by a one-sided improvement. On the other hand, the OW has no one-sided improvement, and the GC moves to scenarios 10, 11 and 12 by a one-sided improvement. There is no one-sided improvement from there for the OW either. The order of the preference of scenarios 10, 11 and 12 is higher for the AR than that of scenario 13. Therefore, scenario 13 is unreasonable (u) for the AR. Scenarios 14 to 16 are similarly unreasonable for the AR. So the balanced solution is scenario 12, "Conventional industrial method design" in Case (a).

Table 2: Degree of worth of each option

Criteria	Permitting Cost increase	Using cast-in-place Concrete	Using PCa	Hiring more staffs	Using more materials And equipments
(a) Development department (OW)					
Cost	-0.105	0.216	0.032	-0.013	-0.139
Duration	-0.054	-0.090	0.310	-0.058	-0.117
Quality	-0.016	-0.106	0.313	-0.077	-0.123
Environment	0.039	-0.078	0.226	-0.064	-0.127
(b) Design department					
Cost	0.077	0.050	-0.014	-0.048	-0.064
Duration	-0.036	-0.107	0.185	0.005	-0.047
Quality	-0.025	-0.076	0.130	-0.020	-0.003
(c) Construction department					
Cost	0.261	0.003	-0.095	-0.049	-0.127
Duration	0.135	-0.129	0.083	0.004	-0.094
Environment	0.215	-0.129	0.063	-0.036	-0.114

Table 3: Criteria each player gives priority

Case Name	Criterion of each player		
	OW	AR	GC
(a)	Cost	Cost	Cost
(b)	Cost	Quality	Cost
(c)	Duration	Cost	Duration

Table 4: Scenarios sorted by the order of preference

Order of	OW				AR			GC		
Preference	Cost	Duration	Quality	Environment	Cost	Duration	Quality	Cost	Duration	Environment
1	12	16	16	8	4	14	16	4	8	6
2	10	8	8	16	2	16	15	2	6	8
3	4	14	14	6	8	13	14	8	7	5
4	2	6	6	14	3	15	13	3	5	7
5	11	15	15	7	12	6	8	6	4	14
6	9	7	7	15	6	8	7	1	16	16
7	16	13	13	5	1	5	6	7	2	2
8	14	5	5	13	10	7	5	12	14	4
9	3	12	12	4	7	10	12	5	3	13
10	1	4	4	12	16	12	11	10	15	15
11	8	10	10	2	11	9	10	16	1	1
12	6	2	2	10	5	11	9	11	13	3
13	15	11	11	3	14	2	4	14	12	10
14	13	3	3	11	9	4	3	9	10	12
15	7	9	9	1	15	1	2	15	11	9
16	5	1	1	9	13	3	1	13	9	11

Table 5: Result of stability analysis

Scenario	Case (a)			Case (b)			Case (c)		
Number	OW	AR	GC	OW	AR	GC	OW	AR	GC
1	u	r	s	s	u	s	u	r	s
2	u	r	s	s	u	s	u	r	s
3	u	r	s	s	u	s	u	r	s
4	u	r	r	s	u	r	u	r	r
5	u	s	s	u	r	s	s	s	s
6	u	s	s	u	r	s	s	s	s
7	u	s	s	u	r	s	s	s	s
8	u	s	r	u	r	r	s	s	r
9	r	r	u	r	u	s	r	r	u
10	r	r	u	r	u	s	r	r	u
11	r	r	u	r	u	s	r	r	u
12	r	r	r	r	u	r	r	r	r
13	r	u	u	r	r	u	r	u	s
14	r	u	u	r	r	u	r	u	s
15	r	u	u	r	r	u	r	u	s
16	r	u	r	r	r	r	r	u	r

The computer program was developed to automatically analyse the stability of the conflict problem for each player when the order of preference within a given scenario given. The GC (contractor-construction department) moves from scenario 1 to scenarios 2, 3 and 4 by a one-sided improvement. The AR has no one-sided improvement from them, and the OW moves to scenarios 10, 11 and 12 by a one-sided improvement. As the order of preference of those scenarios is lower than that of scenario 1 for an architectural department, scenario 1 is a stable (s) for the GC. Scenarios 2, 3, 5, 6 and 7 are similarly stable. The GC moves from scenario 9 to scenarios 10, 11 and 12 by a one-sided improvement. Because neither the OW nor the AR has a one-sided improvement from there, scenario 9 is unreasonable (u). Scenario 10 and 11 are also unreasonable. The GC moves from scenario 13 to scenarios 14, 15 and 16 by a one-sided improvement. Only the AR has a one-sided improvement from there to scenarios 10, 11 and 12. As for scenarios 10, 11 and 12, the order of preference is higher than that of scenario 13 for the GC. Therefore, scenario 13 is unreasonable (u) for the GC. Scenario 14 and 15 are also unreasonable. Because the GC does not have a one-sided improvement from scenarios 4, 8, 12 and 16, these scenarios are reasonable (r).

5 Discussion

The result of the analysis of the three cases shows the following features:

Case (a) — Where the players prioritise cost as the significant parameter, "conventional industrial design" offers the balanced solution. Hence in such situations, the adoption of the pre-cast concrete method is shown to be difficult. In this case, the conventional method is preferred where the cost reduction is the main criterion as it currently exists in the construction industry.

Case (b) — When the AR (architect-design department) gives priority to quality, the order of the preference of the scenarios changes towards adopting the pre-cast concrete method; indeed, the balanced solution moves to the "Pre-cast concrete method".

Case (c) — for this case, five balanced solutions exist. However, the balanced solution that is chosen as the preferred one is not obtained from metagame analysis. Here, the most preferred solution is obtained from multiple balanced solutions by the method described below.

The one scenario in which all players are most balanced in the state of stability should first be determined from which "harmony" score of the given scenario is thereafter calculated by applying AHP. The "harmony" score for the scenario is determined for each of the 3 players, and superiority or inferiority is evaluated depending on the degree of "harmony".

For example, the total score of the 3 players was calculated in Case (c). The harmony score level becomes scenario 8, i.e., "Full pre-cast concrete design by which the OW admitted an increase in the cost of construction", and continues with scenario 6, 7, 5, and finally, scenario 12. Even in the same balanced solution, the order can be determined by evaluating the sum of the scores for the 3 players.

The method differs according to the problem and depends on the judgement of the metagame analyst. The analysis using the above-mentioned method shows that:

- If the combination of elements to which each player gives priority changes, the balanced solution is also different.
- The intention of the AR (architect-design department) greatly influences in the range of the cases treated here.

6 Conclusions

The difference in preferences of individual players in regards to the pre-cast concrete method was modelled as a conflict problem among three players in an integrated construction firm: the owner (OW), the AR (architect-design department) and the GC (general contractor). The metagame decision making method was used to analyse these preferences and provide a means to examine the outcomes of the decision making process.

The order of preference of the respective players in regards to overall construction cost, duration of construction, quality of work and environmental issues was assigned and their respective priorities determined. The player who had the most significant influence on the decision process based on the chosen combinations, preferences and priorities was examined. Results show that a balanced solution to resolve the conflict problem varies in accordance with the factor to which the players gave priority. Although in this paper the number of players was restricted to three, there are likely to be a number of additional players in a real project; e.g., specialist contractors and pre-cast concrete material suppliers would, most likely, also take part. And it is also necessary to review in greater detail the pre-cast concrete option in regards to both the promotion and obstruction factors and in relation to actual conditions in the field. This should be taken into consideration in future work.

7 References

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