Cross-sectional Analysis of Large International Engineering and Construction Firms

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Introduction

The construction industry generally plays a significant contribution to a country’s economy. Researches have shown that its output can represent as high as 15% of the gross domestic product (GDP) of a country (Mawhinney, 2001). With an estimated global market size of about $4 trillion in 2002, it stands as one of the largest industries in the world. However, unlike other large industries such as automobile and oil & gas, the construction industry remains very fragmented. This phenomenon accommodates various modes of survival and different configurations of competitive advantage. In the Engineering News Record’s “Top 225 International Contractors” ranking, among the most active engineering and firms are the European, the American, the Japanese and the Korean contractors – with the Chinese swiftly catching up with the trend in recent years. To date, limited research has been conducted comprehensively to analyze the performance of international engineering and construction (E&C) firms. Without some ground information that tracks the relative performance and competitiveness of these firms, other initiatives related to international management of E&C firms would be severely handicapped. As such, an objective assessment of the performance of E&C firms through fundamental and economic analyses is necessary. As a starting point, this article summarizes the pattern of growth of the global construction industry.

Firm sample

A total of 61 companies have been selected as the sample for this study. Among them, 25 of them are from Europe (UK, German, France, Spain, the Netherlands, Italy, Sweden and Norway), 17 from North America (US and Canada) and 19 from East Asia (Japan and South Korea). These companies are relatively large in terms of international revenue, as they are all listed in the Engineering News Record’s “Top 225 International Contractors” ranking in year 2003. Only publicly-listed companies are chosen from the ENR list due to two reasons: (1) abundant financial information is available from the annual reports of the firms and other public sources such as news coverage and reports; (2) these figures are considered reliable as they are objectively measured and have been audited by reputable accounting firms.

Methodology

Revenues from year 1999 to 2003 of the selected companies are extracted. The revenues in year 1999 are taken as the base year (with index value = 100), and revenues for the subsequent years are calculated with respect to the base year to arrive at the normalized index values. The normalization exercise is carried out as it helps to prevent unfair comparison among companies of different sizes and eliminates the need of standardizing a common currency unit for comparison across different countries. Graphs for companies from different regions – Europe, North America and East Asia, are plotted separately.

Results and discussion

The results show that companies from different region exhibit different trends and outlook. For instance, the North America group paints the best overall picture in terms of average revenue growth when compared to those from other regions (see Figure 1). 80% of the companies record consistent positive revenue growth during the study period. At the end of year 2003, the revenue is, on average, 62% higher than that in 1997 (the average figure excludes the Aecon Group and the Shaw Group, which have grown 356% and 569% respectively and thus are regarded as outliers). Even the contraction of revenue shown by the three companies in Figure 1 is not very significant: the reduction is less than 30%. Overall, the revenue growth in the region exhibits medium volatility.

For the European group, the outlook is also encouraging. Only 5% of the European sample was recording a negative revenue growth continuously for four years (refer to Figure 2). At the end of 2003, the revenue is, on average, 48% higher than that in 1999, slightly lower than that shown by the North American firms. However, the European firms show a more consistent growth trend as compared to their North American counterparts. The volatility of revenue growth is in fact the lowest among all three groups.

Figure 1. Revenue growth of North American companies
Conclusions

This preliminary study shows that a synchronized picture of global construction industry cannot be seen. Instead, each region exhibits different growth rates and different growth volatilities. This suggests that construction activities are still very much localized, and therefore domestic economic strength is expected to play an important role in determining the fate of revenue growth of the industry. In other words, unlike some have claimed, construction is yet to become a truly globalised industry. This is an important conclusion prior to structuring and designing a competitive strategy for a firm. Overall, the graphs also suggest that the industry is still very cyclical in nature. Peaks and troughs, though not synchronized within the same year, are observed in every region. However, in view of the limited study period, the entire length of the business cycle of the industry cannot be deduced from this preliminary study.

References

Case Analysis of Competitive Advantages of Large Chinese Construction Enterprises

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Introduction

Today, large construction companies in China are competing intensively in the domestic as well as overseas markets. Although the environment that they face is largely similar, some companies have successfully gained competitive advantages over the others. This phenomenon could be explained by the resource-based and core-competence theories, which analyse the internal mechanisms through which a company converts the influence of a challenging external environment into useful internal abilities (Haan et al, 2002). Another stream that could possibly explain the phenomenon is the “Classical” approach. This article combines these two streams to present a conceptual model and uses company cases to illustrate how competitive advantage could be achieved.

Quality management

In this article, case analysis related to quality management (one of the iRCs) is chosen to demonstrate the intricate relationship between S&O and iRC variables. The case analysis is derived from the contexts of successful large construction firms in China. In summary, the main features of quality management identified in the analysis include: customer focus, management leadership, quality process control, quality culture, and implementation of external standards. These features will be briefly described in turn.

Customer focus

Many researchers had suggested that customer focus is a main feature of quality management (for example, Douglas and Judge, 2001). In the case of HQCEC, which is one of the largest construction firms in China, the company has set up customer-related management system consisting of four parts, as shown in Figure 2. Certain departments are designated to be responsible and accountable for the implementation of these four parts. The four parts form a closed loop and the entire procedure is standardized and formalized.

Management Leadership

The ability of top management to create a vision and promote change is at the heart of quality management. In the case of HQCEC, the role of the top leaders include: (1) creating a vision of quality management; (2) taking the initiative to implement; (3) assigning obligations to the subordinates; (4) examining, rewarding and punishing managers who have underachieved with respect to the quality objectives established previously; (5) organising and harmonising quality activities; (6) enhancing supervision and data feedback; (7) assessing the status of quality system frequently; (8) taking corrective action for problems surfaced and (9) recommending prevention procedures for the future.
Quality control process

The quality control process is primarily concerned with defects detection. Deming’s plan-do-check-act (PDCA) cycle may be instrumental in analyzing construction process problems and determining ‘root causes’ for removal of obsolete practices to establish new standards (Scherkenbach, 1991). The implementation of such a process needs to be formulated using a “customized” quality approach. In this manner, any deviations from the established plan may be addressed specifically through the PDCA problem-solving process. Relevant findings from HQCEC, CHEC-TPCC, CRCCG, SINOHYDRO, and SEI can be summarized as follows: (1) all companies adopt the continuous PDCA cycle to improve quality and customer’s satisfaction; (2) based on regulations, standards, internal documents of quality management and working procedures of quality improvement, product quality is closely associated with the performance of individual staff; (3) the rules of reward and punishment are based on the quality achieved; (4) correction and prevention activities are conducted together with internal quality audit systems to ensure that improvements have indeed taken place; (5) constant revision of standards to maintain levels of performance, which consequently create incremental improvements in the process of the construction system. It is concluded from this exercise that an S&O variable – HR Strategy, plays an important role in shaping quality management. This is because the quality control process is constantly linked to compensation and reward systems, which falls under the regime of HR Strategy.

Quality culture

Some researchers have proposed that the real purpose of quality management is to change the attitudes and skills of an organization so that the culture of the organization becomes one of preventing failure. Organizations need to adopt a quality culture, not just a quality process or a set of quality techniques. Such quality culture is reflected in the basic values, the general orientation towards work, some taken-for-granted assumptions and expectations, and the ideology of the organization. In the case of HQCEC, the relevant features include: (1) developing education and training of quality at multiple levels; (2) enhancing employees’ quality ideas according to their behavioral criteria; (3) encouraging employees to set up participation and competition in ideas concerning customer satisfaction; (4) imparting a mindset of “everyone is responsible for the highest quality”; and (5) building HQCEC’s brand around the concept of quality.

Implementing external standards

A successful implementation of external standards, such as the ISO 9000, can create several advantages for a company. These include improvements in quality, productivity and organizational competitiveness. In this case, companies including HQCEC, CHEC-TPCC, CRCCG, SINOHYDRO and SEI have all adopted the ISO standards. The ISO standards are formalized rules and procedures. Hence, it clearly supports the notion that organizational structure (another S&O variable) would in fact affect quality management. Besides, successful implementation of the ISO standards helps to improve customer-supplier relationships, therefore quality management indirectly strengthens “Guanxi” resources with customers and suppliers.

Conclusion

Based on the collective findings from the case analyses of ten large Chinese construction enterprises, the key features that promote quality management and the relevant S&O variables that support their development can be summarized in Figure 3.

References


Introduction

Economic feasibility of a project is often analyzed using the discounted cash flow methodology. Though generally recognized as sufficient to evaluate a project under certainty, investment opportunities abounded with uncertainties are often undervalued by simple Net Present Value. This leads to myopic decisions, underinvestment and eventual loss of competitive position because important strategic considerations are either ignored or improperly valued. Real option (RO) modeling currently emerges as a more superior evaluation method that improves strategic analysis by conceptualizing and quantifying the flexibilities embedded in capital investment opportunities.

By definition, an option is a right, but not an obligation, to exercise a certain action in the face of uncertainty. Different types of managerial flexibilities are often found in complex infrastructure projects, which include expansion option, contraction option, abandonment option, switching option, deferment option and learning option. Though not initially apparent, some guarantees and concessions can be interpreted in terms of options.

This article illustrates the application of the RO methodology to value one of the options identified in the Dabhol Power Project in India.

Brief background of the Dabhol Power Project

India maintained as a self-sufficient economy since independence in 1947 until the early 1990s. In 1991, to reduce the gap between India and other countries and to enhance the economic condition, the Indian government decided to launch several reform measures in conjunction with IMF’s assistance. Infrastructure projects are often the key to economic development in developing countries. India’s industrial growth was (and still is) highly dependent on adequate and reliable supply of electrical power. Nonetheless, it was estimated that many of India’s industries were only able to operate at half their capacity due to a lack of supply of electricity. To alleviate the difficult situation, the central government subsequently amended the Electricity Act in October 1991 and early 1992 to permit foreign investments to take part in the construction of India’s infrastructures (Mehta, 2000). In May 1992, a delegation of Indian central government visited the United States in order to seek investments from interested parties. After a few months, Enron signed a Memorandum of Understanding with the Maharashtra State Electricity Board (MSEB) and a new company – the Dabhol Power Company (DPC), was formed.

After a complex negotiation process, MSEB finally signed a power purchase agreement (PPA) with DPC in December 1993 on a Build-Own-Operate basis for a period of 20 years. The project was broken into two phases and the initially planned total capacity was 2015 MW (subsequently increased to 2184 MW). The cost was then estimated at US$920 million for Phase I and US$1,920 million for Phase II. DPC was responsible for financing of the project, which was scheduled to start construction in 1993 and operation in 1996. However, due to changes in political landscape in India after construction of Phase I had commenced, the project was reviewed, delayed and cancelled in 1995. After renegotiation between Enron and its Indian counterparts, the PPA was amended, leading to an increased capacity, a reduced “levelised” tariff, and a change in source of fuel for Phase I. Construction was soon resumed and Phase I was commissioned in May 1999. In December 1999, however, the state of Maharashtra was facing a power deficit. It then failed to make payments to DPC since December 2001. Meanwhile, Enron was also declared bankrupt in New York in December 2001.

Example of an option inherent in the project

According to the PPA, MSEB has the option to either extend the PPA for another 5 or 10 years or buy the plant from DPC. This is a type of call option maturing after 20 years at the expiration of the PPA. The cost of purchase is the strike price of this option if MSEB chooses to buy the plant. If savings from operating the plant itself surpass the cost of extending the PPA (effectively the cost of power according to the terms of the PPA), MSEB will buy the plant; otherwise, MSEB will let DPC continue operating the plant.

Evaluation of project value using the conventional NPV approach

To obtain a complete picture, net present values for both phases of the project – before and after renegotiation, are
calculated. Table 1 presents the results. \( S \) is the present value of net cash flows beyond construction and \( K \) represents the present value of capital expenditure. In real option’s parlance, \( S \) can be considered as the value of underlying asset while \( K \) represents the exercise price of the option to secure the underlying.

**RO evaluation of the option to extend PPA/buy plant at the end of concession period**

Prior to detailed analysis, cash flows must be constructed from the viewpoint of MSEB. In the original PPA before renegotiation, MSEB did not hold any equity stakes in DPC, so the value of the plant to MSEB is technically zero. This equally holds if MSEB chose to extend the PPA for another 5 or 10 years. On the other hand, if MSEB subsequently chose to buy the plant, the value to MSEB would then become the value of the plant (i.e. value of cash flows for the extended period) minus the cost of purchase (i.e. half of salvage value). The present value of cash flows for the extended period is hereby denoted by “\( NPV_e \)”.

In the case of the amended PPA after renegotiation, the model in Figure 1 needs to be modified slightly since MSEB now carries 30% stake of DPC. During the initial concession period, MSEB would be entitled to 30% of the project cash flows, the present value of which will be denoted by “\( NPV_i \)”. If the PPA is extended thereafter, MSEB would continue to get 30% of the extended cash flows (value being 30% of \( NPV_i \)). If, however, MSEB decides to buy the plant at the end of the initial concession period, it would secure 100% of cash flows from the extended period, minus the cost of half the salvage value. The model for this option is represented in Figure 2:

Based on the above models, the results of analysis are summarized in Table 2:

**Table 2. Value of extending or buying the plant**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Before Renegotiation</th>
<th>After Renegotiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>( NPV_e ) (in 1993)</td>
<td>43.14</td>
</tr>
<tr>
<td></td>
<td>( NPV_i ) (in 1993)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>( V_{opt} )</td>
<td>38.41</td>
</tr>
<tr>
<td></td>
<td>Value of option</td>
<td>38.41</td>
</tr>
<tr>
<td>II</td>
<td>( NPV_e ) (in 1996)</td>
<td>95.74</td>
</tr>
<tr>
<td></td>
<td>( NPV_i ) (in 1996)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>( V_{opt} )</td>
<td>85.95</td>
</tr>
<tr>
<td></td>
<td>Value of option</td>
<td>85.95</td>
</tr>
</tbody>
</table>

**Implications of evaluation results**

Other options such as expansion option, put option of selling the plant, etc, are also evaluated using the real option approach. The results show that the total values of these options can be substantial. Apparently, the true value of the project to each party would be grossly undervalued if these options are not taken into consideration.

Infrastructure projects are abounded with flexibility and embedded options. Properly capturing these values during the evaluation stage would lead to a more equitable contractual and risk-sharing arrangement. The issue is particularly important for developing countries that rely substantially on private and foreign sector investments. This article demonstrates that the real option approach is more superior to the simple DCF/NPV approach in valuing flexibility, although the traditional method still has a role to play in estimating the underlying asset value and exercise price in the real option model.

**References**


Reliability Sensitivity by Efficient Simulation

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Introduction

A probabilistic approach provides a rational and consistent framework for treating uncertainties and plausible reasoning in a quantifiable manner. The reliability of a system reflects the plausibility of the occurrence of system failure. During a reliability-based design process, the reliability performance of a system, or specifically, the failure probability, is evaluated for a number of potential design configurations to attain acceptably low failure probabilities, in addition to satisfying other design constraints and performance criteria.

Let \( \Phi = [\phi_1, \ldots, \phi_n] \) be the set of design parameters and let \( \Theta = [\Theta_1, \ldots, \Theta_m] \) be the set of uncertain parameters with joint probability density function (PDF) \( p(\Theta | \phi) \) that can possibly depend on \( \phi \). Reliability sensitivity analysis is concerned with how the set of design parameters \( \Phi \) affects the failure probability of the system, given by

\[
P(F | \phi) = \int P(F | \Theta, \phi) p(\Theta | \phi) d\Theta
\]

(1)

A simple approach for studying the dependence of \( P(F | \phi) \) on \( \phi \) involves computing the value of \( P(F | \phi) \) for different values of \( \phi \). This approach is direct but often tedious because evaluating \( P(F | \phi) \) for each \( \phi \) involves one reliability analysis, which is already a computationally demanding task. For complex problems encountered in applications, it is fair to say that Monte Carlo-based simulation procedures are the only methods that are generally applicable for computing the reliability. In this case, it becomes inevitable to perform repeated simulation runs for evaluating \( P(F | \phi) \) in order to conclude the information required for reliability-based design or optimization. The computational effort, in terms of the number of system analyses, is given by \( N_{\text{run}} \times N_f \), where \( N_{\text{run}} \) is the number of simulation runs and \( N_f \) is the number of system analyses required in each simulation run to evaluate the failure probability to a required accuracy. This article presents an approach for reliability sensitivity analysis, where the required number of system analyses is much less than \( N_{\text{run}} \times N_f \), although it may still be greater than \( N_f \), depending on the desired accuracy and resolution of results.

Augmented reliability problem

Consider an ‘augmented reliability problem’ where the set of design parameters are artificially considered as uncertain with specified probability density function \( p(\phi) \). This property of \( \phi \) in the augmented problem is referred as ‘robustness’ rather than ‘uncertainty’. Using Bayes’ Theorem, \( P(F | \phi) \) can be expressed as

\[
P(F | \phi) = \frac{p(\phi | F) P(F)}{p(\phi)}
\]

(2)

where \( p(\phi | F) \) is the conditional PDF of \( \phi \) given that failure has occurred. This equation indicates that information about \( P(F | \phi) \) as a function of \( \phi \) can be obtained when \( P(F) \) and \( p(\phi | F) \) are known. This in fact can be viewed as a probabilistic failure analysis [1] of the augmented system, where the influence of \( \phi \) on the failure probability is studied via \( P(F | \phi) \). The conditional PDF \( p(\phi | F) \) can be estimated through a simulation-based failure analysis, where conditional samples of \( p(\phi | F) \) are generated and used for estimating the conditional PDF. The efficient simulation of conditional samples is a highly nontrivial task, but it is solved by Subset Simulation [2].

Illustrative applications

Figure 1 shows the conditional histograms of inter-storey drift ratios of a 6-storey-3-bay moment resisting steel frame subjected to stochastic earthquake excitation modelled as a point source according to the work of Atkinson and Silva [3]. In addition to the white noise that generates the stochastic excitation, uncertainty in the regional seismicity in terms of the moment magnitude and the epicentral distance is also addressed. The moment magnitude is assumed to follow a truncated exponential distribution according to the Gutenberg-Richter relationship, and the epicentral distance follows a triangular distribution that roughly corresponds to spatially uniform likelihood of occurrence. The results in Figure 1 are obtained by Subset Simulation that requires 1,850 nonlinear dynamic analyses, compared to 10,000 if direct Monte Carlo were used.

The conditional events in Figure 1(a)-(c) correspond to violation of the performance levels in terms of peak drift level \( \delta \) suggested in FEMA-273: (a) \( \delta > 0.2\% \) (Fully Operational), (b) \( \delta > 0.5\% \) (Operational), and (c) \( \delta > 1.5\% \) (Life-Safety). It is seen that at low drift failure levels, the higher stories have a significantly lower drift than the lower stories. This is thought to be due to ‘isolation effects’ resulting from softening of lower stories at this damage level, where the structure has experienced substantial plastic deformation that are initiated at the lower stories. This hypothesis has been verified by considering a linear structure under the same conditions, which did not exhibit this phenomenon.

Figure 2 shows the sensitivity of the reliability to the equivalent damping ratio of a viscous damper system that is
to be installed to the building. The results are obtained with 3,700 nonlinear dynamic analyses using the proposed approach, which would have required more than a million of nonlinear dynamic analyses if direct Monte Carlo were used.

The failure probability limits at the three levels calculated based on FEMA-273 are (a) $2.3 \times 10^{-2}$, (b) $1.4 \times 10^{-2}$ and (c) $2.1 \times 10^{-3}$. The results in Figure 2 indicate that the reliability performance criteria at the Life-Safety level can be satisfied by choosing $\zeta_D > 5\%$ and that of the Operational level can be satisfied by choosing $\zeta_D > 20\%$. As is often the case, the reliability criteria at the Fully Operational level is the most demanding and critical one, which cannot be satisfied even when $\zeta_D > 30\%$.

**Conclusion**

The proposed approach is developed based on two fundamental principles of probability: Bayes’ Theorem and the Theorem of Total Probability. The theory indicates that by properly utilizing the information from conditional samples, it is possible to solve problems that involve repeated evaluations of reliability using a single simulation run. This once again demonstrates the potential versatility and strength of simulation methods.

**References**


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**Competitive Analysis of Construction SMEs in China**

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**Introduction**

In the Chinese construction industry, construction small and medium-sized enterprises (SMEs) have enjoyed rapid development since the adoption of the policy of reform and opening-up. The SMEs have grown to be an important force in promoting the development of the Chinese construction. With China’s WTO accession in 2001, the Chinese government is committed to open up the construction market to foreign companies, which brings forth opportunities and challenges to the development of construction SMEs. As the SMEs are a relatively new entrant to the Chinese construction industry, this research will examine the theories concerning the SMEs’ strategy management, analyze their development, and investigate their capabilities and competitive strategy to strengthen the competitive advantage.

**Approaches to the study of competitive advantage**

Since the 1960s, strategic management research has operated within the “SWOT” framework (strengths-weaknesses and opportunities-threats), as summarized in Figure 1 (Barney, 1991). The framework suggests that firms obtain sustained competitive advantages by implementing strategies that exploit their internal strengths, through responding to environmental opportunities, while neutralizing external threats and avoiding internal weaknesses. Two perspectives of competitive advantage, including industry-based approach and resource-based approach, are further developed as the most vital approaches for studying factors that underlie superior performance.

![Figure 1. The strategic management research framework](image-url)
In the industry-based approach, Porter (1985) advocates that the industry structure determines the market equilibrium by matching the products offered by competing firms with different market needs. The primary resources of competitive advantage are product/service and market factors, and an organization can position itself on these factors industry via its strategy to achieve competitive advantage. The resource-based approach shifts the focus from industry characteristics to resources developed by firms, and it postulates that the resources of firm are the primary determinant of competitive advantage. Resources in a firm can be classified into financial, physical, human, and technological resources (Barney, 1991). However, resources themselves cannot become competitive advantage unless they are organized into capabilities. Sustainable competitive advantage is resulted from the possession of relevant capability differentials, which are further linked to intangible resources. Therefore, core capability within firms represents the potential dimension of competitiveness from the firm’s performance. Table 1 summarizes the characteristics of the two approaches.

<table>
<thead>
<tr>
<th>View of competitive advantage</th>
<th>Focus</th>
<th>Assumptions</th>
<th>Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry-based approach</td>
<td>Industry characteristics</td>
<td>Firms are homogeneous</td>
<td>Firm’s strategy</td>
</tr>
<tr>
<td>Resource-based approach</td>
<td>Firm’s characteristics</td>
<td>Firms are heterogeneous</td>
<td>Firm-specific resources and capabilities</td>
</tr>
</tbody>
</table>

### Research methodology

The researchers will adopt in-depth interviews, review of documents, multiple sources of evidence and questionnaire survey for the purposes of data collection for the present study. These multiple sources of evidence also facilitate the development of a converging line of inquiry through the process of triangulation. Based on the analysis of core capability and competitive strategy within Chinese construction SMEs, questionnaires will be designed to gather data, and documents are primarily used in an effort to strengthen and corroborate the finding of the interviews and questionnaire survey. Questionnaire surveys and interviews would be carried out with founders, managers and engineers of construction and related enterprises in China. The survey result will subsequently be analyzed to provide specific information for construction SMEs.

### Integrating a conceptual model for strategic analysis

The conceptual model presented here integrates these two dominant perspectives, and it proposes four constructs of industry structure, core capability, competitive strategy and firm performance (see Figure 2). It is necessary to emphasise that it is the whole model, including industry structure, core capability, competitive strategy and the firm performance, which together represent the concept of competitiveness, rather than a particular construct only. The relationships between industry structure, core capability and competitive strategy are the central focus of the theoretical model of this research.

Analyzing these linkages provides an opportunity to explain a firm’s success by its resources and strategy. When studying linkages between the concepts of the framework, two issues should be considered. First, a deep understanding of competitive environment, which is one of the common elements of successful strategies, is needed. The structure of an industry has a direct impact on the nature of competition and the competitive strategies available to a company in this industry. Second, certain strategies require specific core capabilities and key internal conditions. The resource-based approach focuses on the conditions in a firm, and supports the core capability that is demanded. Effective patterns of firm strategies, core capabilities and resources vary with market dynamism. These two aspects will be discussed in more details based on empirical analysis.

![Figure 2. Proposed conceptual model of competitive advantage](image)

### Conclusion

As an important participant in China’s construction market, SMEs are confronted with the tasks of keeping themselves competitive, which concern their survival and future growth. To analyze the competitiveness of Chinese construction SMEs, a theoretical framework is proposed to study the core capability, competitive strategy and performance within construction SMEs. The framework can be used to examine how the core capability and competitive strategy can be managed and turned into competitive advantage. Analyzing empirical data based on this framework will help to understand which capabilities and strategies are most associated with a firm’s favorable position in the market and its success.

### References

Internationalization Strategies of Chinese Construction Firms

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Introduction

The current external environment is very favourable to Chinese construction firms (CCFs) because of the increase in China’s domestic infrastructure investment and the WTO entry, in the midst of conducive political, economic and legislative environments. Besides securing sufficient contracts in the domestic market, a large number of CCFs are going abroad and have performed well. Currently CCFs are actively involved in international construction projects in more than 190 countries or regions. Based on the experiences accumulated, CCFs are set to play a greater role in the international market. Concurrently, foreign contractors are also presented with tremendous opportunities to participate in construction activities in China. Hitherto CCFs are still relatively weak compared to other international competitors. Hence, improving their international competitiveness becomes a top priority and challenge. However, the amount of extant literature about CCFs’ internationalization strategies is quite limited. Addressing these important issues and bridging the literature gap become the focus and objective of this research.

In order to tailor suitable overall strategies for CCFs’ international development, their international performance will first be reviewed, with their strengths and weaknesses being analyzed. The literature about generic competitive strategies will also be reviewed. A framework for CCFs’ overall competitive strategy will be conceptualized, which will be validated through on-going survey and case studies.

International performance review

CCFs have made significant achievements in international construction. Their international performance is reviewed from the perspectives of market share distribution, longitudinal comparison, and horizontal comparison.

Market share distribution

Table 1 shows the CCFs’ market share (construction and related values) by regions and countries respectively. It can be seen that most of the business of CCFs were centralized in Asian countries especially in Hong Kong, which is now part of China. Their international market share in Asia was 54.4 percent of the total in 2002, as against 14.1 percent in Africa, 7.7 percent in Europe, 5 percent in North America, and 18.8 percent for the rest of the regions. CCFs were unable to compete with local contractors in Europe and North America, where they failed to gain enough market shares to survive and develop. CCFs have conspicuous advantages in Hong Kong because of the easy supply of low cost resources from mainland China and low overhead. Many CCFs are also successful in Singapore due to similar cultural environment, open construction industry and flexible immigration rules for labour and management staff recruitment.

<table>
<thead>
<tr>
<th>Region</th>
<th>Market Share (Transacted Construction and Related Value) by Regions (US$ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>7807.0</td>
</tr>
<tr>
<td>Africa</td>
<td>2023.0</td>
</tr>
<tr>
<td>Europe</td>
<td>1107.4</td>
</tr>
<tr>
<td>North America</td>
<td>721.9</td>
</tr>
<tr>
<td>Latin America</td>
<td>409.5</td>
</tr>
<tr>
<td>Ocean &amp; Pacific</td>
<td>122.2</td>
</tr>
<tr>
<td>Others</td>
<td>2161.3</td>
</tr>
</tbody>
</table>

Top 10 Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Market Share (Transacted Construction and Related Value) by Regions (US$ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HK</td>
<td>2313.4</td>
</tr>
<tr>
<td>Singapore</td>
<td>1086.4</td>
</tr>
<tr>
<td>US</td>
<td>707.3</td>
</tr>
<tr>
<td>Japan</td>
<td>594.3</td>
</tr>
<tr>
<td>Sudan</td>
<td>440.3</td>
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Longitudinal comparison

Since late 1970s, China’s international construction business has been growing steadily, especially for the past few years, as shown in Figure 1. Total contracted and transacted value for overseas construction in 2003 was US$17.67 billion and US$13.84 billion respectively. Since 1994, more CCFs have become top international contractors. 45 CCFs made it to the list of ENR Top 225 according to 2003 international revenues (Figure 2).

Horizontal comparison

Among CCFs, there has been an unbalanced international development. CCFs must get international business licenses from the Chinese government before they venture abroad. A number of big CCFs went abroad in early days and have become multinational contractors. Some CCFs have no strong competitive position at home but have since gained substantial experience in international market because they managed to obtain licenses early. However, other big CCFs with strong competitive position in home market are still not familiar with international construction due to their late overseas foray. Even as they secure sufficiently high profit projects at home, their international performance is still lacklustre.

Compared to international competitors, CCFs’ international market share is relatively small. For example, Skanska secured...
US$14.14 billion of contracts and completed US$11.52 billion of international projects in 2002. Skanska’s international construction market share alone was almost the same as the total of all CCFs in 2002. CCFs’ strengths mainly lie in their low costs and strong government support. The abundant natural resources and low labour costs lead to lower construction costs. Construction tools, machinery and equipment made in China are also cheaper than imported ones. CCFs’ overhead could have been far lower than that of their international competitors if their organizational structures were optimized.

Conversely, their weaknesses are reflected in the following aspects: (1) a large number of equal-sized firms leading to fierce competition among CCFs; (2) most of big CCFs are either SOEs or shareholding enterprises among which the management is still not fully market-oriented; (3) overstaffing and over capacity; (4) heavy social responsibility burden; (5) low profits and tight cash flow; (6) small international revenues; and (7) low technology and management know-how.

A framework for overall competitive strategies of CCFs’ internationalization

Porter (1985) highlighted three types of competitive advantages that a firm may possess: cost leadership, differentiation and focus. Cost advantage means having lower cost arising from the firm’s ability to perform activities differently than rivals. Differentiation means that a firm differentiates itself from its competitors if it can be unique at its competency that is valuable to buyers. Focus strategy rests on the choice of a narrow competitive scope within an industry. Hoskisson et al (2003) identified five strategies which were adapted from Porter (1985): cost leadership, differentiation, focused cost leadership, focused differentiation and integrated cost leadership/differentiation. Firms can choose from among these five strategies to establish and defend their desired strategic position against rivals.

Based on the above literature review and coupled with the practical situation of CCFs, an overall competitive strategy framework is postulated, as shown in Figure 3. There are two approaches for CCFs to compete internationally. The first approach involves focused cost leadership as low labour cost and overhead is CCFs’ most obvious advantage. They should focus on specialized projects in a few target markets to minimize unforeseen risks. Gradually, cost leadership can be broadened to cover all fields of construction.

The second approach involves differentiation in a narrow segment where CCFs have competitive advantage in certain construction technology and construction equipment. However, differentiation in a broad range of segments can hardly be achieved by CCFs as they lag behind big Japanese and Western contractors in technology.

Ultimately, the two approaches will lead to integrated cost leadership/differentiation which is the ideal competitive advantage strategic approach. To what extent cost leadership can be broadened or differentiation can be achieved is firm-specific. For example, a specialist CCF may exert more differentiation advantage than a building CCF. On the contrary, cost leadership may be more advantageous for a building CCF than a specialist CCF. The balance between cost leadership and differentiation is determined by the firm’s business nature and decision makers’ management ability and style.

Conclusion

Review on CCF’s international performance showed that they have made noticeable achievements in international construction. However, their international market share is still relatively small, focusing mainly on the Asian and African countries. A framework for CCFs’ overall competitive strategy was hypothesized, with two strategy-evolution approaches being suggested. The conceptualized framework and model, together with the other propositions for CCFs’ internationalization strategies made beyond this paper, will be validated through the on-going questionnaire survey, personal interviews and case studies.

References

Dynamic Path Finding Techniques in Highly Regular Networks Augmented by Interval Routing Scheme

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Introduction

In real time computation systems, completing the computation in a short time is a basis on which the systems can be applied to solve real world problems. The real world problem specifies the requirements on the computation speed, software and hardware limitations and the accuracy level for an algorithm. As this research is to develop fast algorithms in shortest route finding in a large indoor area and the algorithms would be deployed in an emergency evacuation system implemented on a virtual reality (VR) platform, it is required that the computation speed of the algorithms be fast enough in order to give real time information despite a large number of nodes and arcs of the input network.

In this research, a fast algorithm is developed to calculate the shortest path in networks with typical topologies, which appear in most building structures. When a network is augmented with the interval routing scheme, a fast routing technique used in computer networks, the numbers of nodes and arcs could be significantly reduced to shorten the computation time for the shortest path.

The classic shortest path finding algorithm is Dijkstra’s work [3], which has become a fundamental algorithm in a variety of fields such as computer networks, transportation operations, robot motion planning, etc. The new algorithm is supposed to be much faster than Dijkstra’s algorithm in dealing with most inside-building topologies.

Research objectives

The developed algorithm is to be used in an emergency rescue and evacuation system to search the shortest path between any two points in the system’s VR environment. As the computation effort needed for a VR environment requires intensive use of CPU and memory, reducing the computation complexity yet retaining an acceptable level of accuracy becomes a crucial issue in this research.

In addition, as users roaming in the VR environment may issue path finding requests to any new destination, the source and target for shortest path searching are dynamic. Therefore, the new algorithm should be able to deal with a large network efficiently with dynamically assigned source and target locations.

Optimal path finding

Through analysis on common building indoor geometries, the complexity of Voronoi diagram of indoor space is suitable as the input network for the algorithms. After simplification and minor modification, the Voronoi diagram-like graph of common building indoor geometries could handle some regular topologies, like 2-D grids, 3-D cuboid grids, rings or trees, which are called element classes in this research. In most cases, a building structure could be converted to a number of element classes. All element classes, i.e., rings, trees or grids, are highly regular structures which can facilitate a fast routing technique called Interval Routing Scheme.

Interval Routing Scheme (IRS)

A routing scheme is a strategy that assigns to every source-target pair the path that a message from the source to the target should take. The concept of routing scheme was originally developed for computer networks. For example, one possible routing scheme is to store a complete routing table in each of the vertices of the network, specifying for each target the next edge in some shortest path over which the message must be forwarded. But with the increase of the number of nodes, the size of the routing table stored at each node would increase as well. Another way of implementing routing is called interval routing, which has been discussed in a number of research articles and is summarized in [4]. In this method, each node is assigned a distinct label from the set \{1, 2, ..., n\}. Arcs are bi-directional and labeled with one or several subintervals of the interval \([1, n]\) so that for any node \(v\) the intervals associated with outgoing edges from \(v\) are pair wise disjoint and their union covers \([1, n]\). When a message to be sent to \(v\) arrives at node \(u\), the message is forwarded along the unique outgoing edge labeled with an interval containing \(v\). In most cases, \([1, n]\) is a cyclic interval, i.e., all subintervals are understood to wrap around. Such a scheme is called a circular interval routing scheme (IRS). Variants of the scheme include linear interval routing schemes (LIRS), in which \([1, n]\) is viewed as a linear interval; \(k\)-interval routing schemes, in which edges can be labeled with at most \(k\)-intervals (\(k\)-IRS or \(k\)-LIRS). An interval routing scheme for which all messages are routed along shortest paths is called an optimal scheme.

Some highly regular networks, such as 2D grids (alias meshes) or 3D grids, admit optimal 1-LIRS [2]. Trees and rings admit optimal 1-IRS [5]. The efficiency of an optimal interval routing scheme is measured in terms of its compactness – the maximum number of intervals constituting the label of an edge. As element classes are 2D or 3D grids, rings or trees, within each element class, IRS of low compactness (thus of high efficiency), like 1-LIRS or 1-IRS, can be used to help raise the calculating speed of optimal paths.
IRS augmented shortest path algorithm

The algorithm for a 2-D grid is shown below. Suppose all the nodes in an M x N 2-D grid have been labeled with (x, y), with x denoting the row number of a node and y denoting the column number of the node. x varies from 1 to M, and y varies from 1 to N. Node (1,1) is the origin of the whole grid and the top-left node. All static nodes are labeled in a way similar to a coordinate system of natural numbers. Part of the grid and the top-left node. All static nodes are labeled in a similar coordinate system of natural numbers. Part of the grid is shown in Figure 1. s is a dynamic source location where a shortest path finding request is issued. s1 and s2 are two static nodes adjacent to s. Notice that any dynamic location is adjacent to two static nodes in the grid and these two nodes are linked by an edge. In Figure 1, s1.x = s2.x and s1.y < s2.y, where s1.x indicates the x coordinate of s1 and the rest are similar.

In this case, the entire grid could be divided into two parts by the dashed line (cut line) parallel to the x-axis. If the target location t is on an arc whose two end nodes are located in different parts of the grid like t1 and t2 and |ss1|+|tt1| < |ss2|+|tt2|, then the path is s-s1-t1-t. The path from s1 to t1 and from s2 to t2 can be found through the interval information stored for each arc, because s1, s2, t1 and t2 are all static nodes with interval information.

If the target location is on an arc whose both end nodes are located on the same side of the dashed line, such as ab or cd, then the shortest path would start from ss1. Likewise, if the target location is on arc ef, the shortest path would start from ss2. In the case of ab, as a.x = b.x and |a.y – s1.y| > |b.y – s1.y|, the path is s-s1-b-t. In the case of cd, as c.y = d.y and |s1.x – c.x| < |s1.x – d.x|, the path is s-s1-e-t. The codes for the computation process are listed bellow:

Program findpath (s, s1, s2, t, t1, t2, G) // in the case of s1.x=s2.x

Begin

if (t2.y>=s1.y) // target location in upper division of the grid

if (t1.x=t2.x)

A=s+interval(s1,t1)+t;
}

else

if (|t1.x-s1.x|<|t2.x-s1.x|)

A=s+interval(s1,t1)+t;
else

A=s+interval(s1,t2)
}

if (t1.x<>t2.x)

if (|ss1|+|t1t|<|ss2|+|t2t|)

else // s1.y=t1.y and s2.y=t2.y

if (t1.x=t2.x)

if (t1.x<>t2.x)

A=s+interval(s2,t1)+t;
else

A=s+interval(s2,t2)+t
}

else // s1.y=t1.y and s2.y=t2.y

if (|ss1|+|t1t|<|ss2|+|t2t|)

else

A=s+interval(s1,t1)+t;
else

A=s+interval(s2,t2)+t
}

return A // return the list of nodes from s to t
end

In case that s1.y = s2.y, a cut line can be made vertically and similar processing can be applied to find the shortest path between two dynamic locations. The new algorithm extends the application of IRS techniques on static nodes to dynamic optimal path finding between any two locations on the network. The IRS techniques augment networks by labeling nodes and giving interval information to each arc before path finding computation can be done. Their application is limited to finding the shortest path between static nodes. Our algorithm extends the application to dynamic systems, which suits the dynamic shortest path finding for the emergency rescue and evacuation system.

Conclusion

In this research, IRS techniques are applied to dynamic inside-building path finding situations. The new shortest
path finding algorithm is expected to be more efficient than Dijkstra’s in dealing with most inside-building topologies. A large building area may consist of a collection of connected element classes. With the idea of the new algorithm, each element can be augmented with IRS respectively. When the dynamic source and target nodes are both in the same element class, the optimal path can be found very fast without Dijkstra’s algorithm involved. If the dynamic source and target nodes are in different element classes, a graph similar to the complete intersection graph in [6] can be constructed in a short time with IRS information in each element. Also, a network with reduced nodes and arcs can be the input for Dijkstra’s algorithm.

### References


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### Predicting the Loss of Chemically Bounded Moisture in Hardened Cement Paste

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**Jeffrey Ng Leng Ping** (jeff_ng@pmail.ntu.edu.sg)

#### Introduction

Hardened cement paste starts to lose moisture when heated. At temperature below 105 °C, hardened cement paste experiences loss in evaporable moisture residing in the capillary pores and on the surface. Once it is heated beyond 105°C, it will experience microstructural changes which include dehydration of hydrates and conversion of various compounds. The most prominent moisture loss for temperature greater than 105 °C is the decomposition of portlandite within hardened cement paste occurring between 400 °C to 550 °C. The release of chemically bounded moisture during transient heating limits the applicability of Fourier’s law of heat conduction in heat transfer analysis. Presence of moisture was observed to delay heat transfer and thermal gradient obtained from Fourier’s law of heat conduction is significantly under estimated.

There is a need to understand the decomposition of hydrates and to predict chemically bounded moisture release during transient heating in order to improve the prediction of heat transfer in hardened cement paste. An equation is proposed to predict chemically bounded moisture loss in hardened cement paste based on the volumetric phase composition of the products of hydration. Hardened cement paste of water/cement ratio (w/c) 0.35, 0.40, 0.45 and 0.40 (10% silica fume replacement) were used in the investigation. Powdered specimens were subjected to Thermo Gravimetric Analysis (TGA). The rate of heating is 10 °C/min and combustion took place in a nitrogen gas environment. The use of nitrogen gas is to prevent oxidation of compounds which will affect mass reading. Any change in mass will be attributable to the dehydration of products of hydration.

#### Decomposition of various phases

A rapid decrease in the mass within a short interval will indicate the decomposition of a particular phase within the specimen. The rapid decrease in mass will correspond to a peak in the derivative mass loss. The hydrates are amorphous in nature and will decompose between 105 °C to 800 °C. The crystalline form of portlandite was known to decompose between 450 °C to 550 °C [1]. Hence, it is possible to identify the effects of each phase on the mass loss by analysing the derivative mass loss.

The principle behind the procedure is to remove the effects of decomposition of portlandite between 400 °C and 550 °C in the time derivative of the percentage of mass loss rather than at the percentage of initial mass (Figure 1(a)). This is to ensure continuity in the rate of decomposition of hydrates and will mathematically ensure continuity in the percentage of initial mass loss for the curve without portlandite (Figure 1(b)). This approach is valid as compounds experience a continuous rate of decomposition except at the peak value.

Figure 2 shows a typical decomposition profile for the hydrates and portlandite in hardened cement paste from 105 °C to 900 °C. The profiles were determined by calculating the percentage of mass loss at various temperatures with respect to the total mass loss measured at 900 °C for the hydrates and portlandite. All specimens showed similar decomposition profile for the hydrates and portlandite which indicate that difference in w/c, addition of pozzolana and degree of hydration does not affect the decomposition profile. The decomposition profile of the
Figure 1. Effects of portlandite on mass loss at elevated temperature (w/c=0.35)

Figure 2. Typical decomposition profile of various phases of hydration products subjected to elevated temperature. The volumetric ratio of products of hydration caused by the difference in w/c, addition of pozzolana and degree of hydration does not change this behaviour. Hence, the decomposition profile is independent of the mix design.

Besides the presence of products of hydration, there will be some unreacted cement particles remaining in hardened cement paste if hydration is not completed. Unreacted cement particles does not experience a loss in chemically bounded water and can be considered as a dead weight within the sample. Since the procedure calculates the decomposition profile from the percentage of mass loss of each component, dead weight within the sample does not appear in percentage of mass loss and would have no effect on decomposition profile.

Calculating the loss of chemically bounded moisture

Equation (1) is used to calculate the total mass loss of chemically bounded moisture per unit volume of hardened cement paste (kg/m³) for $T > 105^\circ$C.

$$M_d (kg/m^3) = 0.662 \left( \sum_{i=a,c,p} f_i(T) V_i k_i \rho_i \rho_{w,i} k_i \right)$$

The subscript $i$ denotes the calcium aluminate monosulphate hydrates (a), C-S-H hydrates (c) and portlandite (p) phase in hardened cement paste. The decomposition function, $f_i(T)$, is obtained from Figure 2. The same decomposition profile is applied for both AFm and C-S-H hydrates. Volumetric ratio of each phase, $V_i$, can be calculated using available hydration model of cement paste [2]. The volumetric ratio of moisture within a phase, $k_i$, is determined using volume stoichiometry relationship. Density of moisture in the phase, $\rho_{w,i}$, is assumed to be 1000 kg/m³. The regression constant, 0.662, was determined from experimental results.

The predicted chemically bounded moisture loss per unit volume of fully hydrated hardened cement paste using Equation (1) is shown in Figure 3. It can be observed that hardened cement paste with low w/c will experience large losses in chemically bounded moisture due to high volumetric ratio of products of hydration. Blended cement paste can also be predicted using the proposed approach. Pozzolanic reaction lowers the volumetric ratio of portlandite and increases volumetric ratio of C-S-H hydrates. Hence, the mass loss for silica fume blended cement paste (w/c=0.40, 10% replacement) between 400 $^\circ$C to 550 $^\circ$C is lower than normal cement paste (w/c=0.40) due to pozzolanic reaction.

Conclusion

Decomposition profile for different components of hardened cement paste was observed to be unaffected by the mix proportion. A method to predict the loss of chemically bounded moisture loss due to elevated temperature for various types of hardened cement paste is proposed. It requires the determination of the phase volume using existing hydration model. Chemically bounded moisture loss obtained in this research will be used in heat and mass transfer simulation for hardened cement paste.

References


Effects of Temperature on Porosity in Hardened Cement Paste

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Introduction

Mechanical properties of concrete, such as compressive strength and durability, are dependent on the microstructure of concrete, in particular the porosity. At elevated temperature, porosity and threshold diameter starts to increase. This will lead to a reduction in mechanical properties. In addition, the presence of pores in concrete affects the tendency of spalling. Moisture are released and vaporised when heated beyond 105 °C. Water molecules fill the pores of the concrete leading to an increase in pore pressure. When the pore pressure generated tensile stress larger than the tensile strength of the pore walls, explosive spalling can occur [1]. An understanding on the effects of temperature on porosity is required to predict spalling.

The relationship between porosity and elevated temperature is used in the simulation of heat and mass transfer in heated concrete [1]. Limited works have been published on the behaviour of porosity of cementitious materials at elevated temperature. The analysis on the pore size distribution is also scarce. Thus, researchers are often unsure of the porosity-temperature profile that will be implemented in the simulation of heat and mass transfer for various types of heated concrete. The objective of the research is to propose a model that is able to predict residual porosity for different mix design and to understand the behaviour of pore structure at elevated temperature. Mercury Intrusion Porosimetry (MIP) is used to determine the porosity of specimens subjected to various elevated temperature.

Experimental procedure

Hardened cement paste of water/cement ratio (w/c) 0.35, 0.40 and 0.40 (10% silica fume replacement) were used in the investigation. The specimens were cured in water tank for 90 days at 20 °C and left to dry for a month. The specimens were heated to 105 °C, 200 °C, 400 °C, 600 °C and 800 °C using an electric furnace at 10 °C/min. The temperature was maintained for another two hours to achieve steady state before cooling takes place inside the furnace. The specimens were then placed in a vacuum desiccator while waiting to be tested. The heated specimens were tested in MIP within 24 hours after being removed from electric furnace.

Modelling of Porosity

Porosity of hardened cement paste increases when heated. This is because the space previously filled by chemically bounded moisture within the hydrates becomes available when heated and connects with capillary pores. Therefore, an increase in the amount of chemically bounded moisture released at an elevated temperature will also lead to an increase in porosity. A calibration and verification approach is used to model the porosity subjected to the elevated temperature. The proposed equation to predict porosity for hardened cement paste is given below.

\[ n_2 = n_0 + k_1 \left( 1 - \frac{n_0}{100} \right) \left( T - T_0 \right) \]

where \( n_0 \), \( n_2 \), \( T_0 \) and \( T \) are initial porosity (%), porosity subjected to elevated temperature (%), initial temperature (°C) and elevated temperature (°C) respectively. \( k_1 \) was found to be 0.00585 while \( k_2 \) is 1.3 and 1.26 for normal and blended cement paste respectively. The equation is simple and able to account for specimens with various w/c. Good predictions were achieved using Equation (1) (Figure 1).

![Figure 1. Experimental and Predicted Porosity (w/c=0.35)](image)

The behaviour of porosity change was observed to be dependent on the temperature increment instead of the rate of heating. The term \( \left( \frac{n_0}{100} \right) \) is included in the formulation to account for the volume of hydrates within the specimens. This term is dependent on w/c and degree of hydration. Specimens with low w/c tend to have low \( n_0 \) which indicate the potential of a high percentage of hydrates within the specimen. Specimens with high degree of hydration will have more hydrates within the specimen which will in turn affect the change in porosity at elevated temperature. At this stage, the proposed equation assumes that the degree of hydration for the specimen is close to one. This will imply that there are no unreacted cement particles within the specimen and the volume remaining in the specimen is due to hydrates.
**Pore structure**

Porosity within a specimen is made up of capillary and gel pores. Capillary pores are pores that were left behind by previously water filled space after expansion of hydration products. Gel pores are pores within the hydrates and have approximately a porosity of 28%. Capillary and gel pores can be identified as pores having a diameter greater and less than $10 \times 10^{-9}$ m respectively [2]. Due to the limitation of MIP, it is only possible to measure gel porosity having diameter between $3 \times 10^{-9}$ m and $10 \times 10^{-9}$ m.

Figure 2 shows the pore size distribution of unheated and heated (600 °C) specimen. $dV/d\log D$ represents the volume of pores with respect to a change in diameter. The dashed lines represent the threshold diameter. When the specimen is exposed to elevated temperature, the threshold diameter starts to shift towards the right indicating a larger mean diameter. The change in pore volume at threshold diameter also increases with heating. This phenomenon is due to the enlargement of pores within the specimen. Isolated pores which were previously undetected in unheated specimen connect with capillary pores and increase the threshold diameter. It can also be observed from Figure 2 that the total volume of capillary pores, which is denoted by the area enclosed by the curve for pore diameter greater than and equal to $10 \times 10^{-9}$ m, increases when heated. The increase in pore volume is due to the decomposition of the products of hydration.

The behaviour of gel pores when exposed to elevated temperature is different from capillary pores. The total volume of gel pores, which is denoted by the area enclosed by the curve for pore diameter up to $10 \times 10^{-9}$ m (Figure 2), starts to decrease when heated. The presence of gel pores is dependent on the existence of C-S-H gel. Gel pores are destroyed when decomposition of C-S-H gel into $\beta$-dicalcium silicate and moisture [1] occurs. The peak which appeared in the region of gel pores of unheated specimen starts to shift towards the region of capillary pores when heated. This is due to the volume of pores previously residing within C-S-H gel gets connected with the capillary pores.

**Conclusion**

An equation is proposed to predict porosity of hardened cement paste subjected to elevated temperature. The equation is found to be dependent on the volume of hydrates in the unheated state. The equation is applicable to both normal and blended cement paste. Porosity and capillary pores of heated specimens increase when heated while gel pores were observed to decrease. Works are in progress to identify the effects of pore size distribution on the tendency of spalling.

**References**


Overall Benefit-Duration Optimisation (OBDO) and its Application with Genetic Algorithm (GA) in Large-Scale Construction Projects

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Introduction

Given a normally scheduled project network with a set of activities to be completed according to their precedence relationships, schedule compression can occur if opportunity income exceeds cost increment. The objective is to make a sequence of decisions to crash activities on the network and hence compress the schedule to a desired limit where the overall economic benefit of the owner is optimized. This problem is referred to as overall benefit-duration optimisation (OBDO) [1]. This research utilizes a genetic algorithm (GA) application to the OBDO problem. The Visual Basic Application (VBA) macro language of Microsoft Project is used to write the programs. First, the objective function of OBDO is formulated. A test example is illustrated to prove the feasibility and practicability of the OBDO concept using the GA application in the VBA programming environment.

Problem statement

For a construction project, compressing network to maximize an owner’s economic benefit, whilst considering factors that influence the profitability of the project, is indispensable. In practice, the economic benefit of an owner is closely influenced by various factors, such as total construction cost, interest reimbursement and future revenue. They are of paramount importance and deserve simultaneous considerations in project scheduling. For instance, if an owner finances a construction project with bank loans, it is not difficult to understand that different project schedules lead to different costs and investment allocations [2] since interest rate and future revenue exist. In practice, network compression usually increases direct cost. It also introduces more opportunity income due to earlier completion and usage of the project. Opportunity income refers to the summation of an owner’s interest saving and future revenue from the compressed schedule. Owners want their projects completed in the shortest time that their financing ability will allow. In a construction project, when the duration is compressed, the opportunity income is also increased as well as the total construction cost. However, under the prerequisite that opportunity income exceeds the total cost increment, the project network can be compressed to durations where the maximal cut-off between the opportunity income and total cost increment occurs. Under the condition that the potential benefit exceeds cost increment, an owner will prefer to compress the project schedule to maximize his economic benefit. Therefore, owners have the greatest incentive to schedule compression. This creates an optimization problem called overall benefit-duration optimization (OBDO). The objective function of OBDO is as follows:

\[
\text{Maximize } \Delta Z = (\Delta R_c + \Delta I_c - \Delta C_t) \tag{1}
\]

Figure 1 shows the objective function of OBDO. In practice, revenue \(R_c\) and interest savings \(I_c\) both increase with schedule compression. The summation of these two portions is considered as the opportunity income of owner. \(\Delta T_t\) is the compressed duration where maximized overall benefit is reached. \(\Delta R_c\), \(\Delta I_c\) and \(\Delta C_t\) denote marginal revenue increases, marginal interest saving and marginal total cost increases respectively. \(\Delta Z\) denotes the marginal overall benefit. Under the condition that marginal opportunity income \((\Delta I_c + \Delta R_c)\) is more than marginal cost increase \(\Delta C_t\), the objective is to optimize such that the maximal overall benefit is obtained.

\[
\Delta C_i = C_i - C_n = \Sigma C_{ai} - \Sigma C_{wi} \tag{2}
\]

Since the precise curve of \(\Delta C_i\) is difficult to obtain either in practice or theoretical analysis, the purpose of drawing the figure is to illustrate the objective of maximizing \(\Delta Z\) by schedule compression. \(\Delta C_i\) is expressed as follows:

\[
\Delta R_c + \Delta I_c > \Delta C_t \tag{3}
\]

Equation 2 indicates that the increased total cost can be calculated by subtracting normal total cost from compressed total cost. The following constraint is the prerequisite to the feasibility of OBDO concept:
GAOBDO and its application with a test example

Known as a robust search technique and capable of efficiently locating global optimum in complex solution space, GA is considered as a feasible way to facilitate optimization search. A VBA-based GA program is developed to solve the OBDO problem which is put into the commercial project scheduling software Microsoft Project 2003. The VBA program is called GAOBDO with the procedures shown in Figure 2. It is able to provide output results and plot GA convergence situation.

From the final output of GAOBDO, the crashed project duration is 103 days, compressed by 26 days. Total cost is increased by $15,900. The overall benefit of owner, which is the objective function of OBDO, reaches its maximum at $3,600. The GA output was checked by manual calculations for this simple case.

Conclusion

The VBA-programmed GAOBDO method overcomes the limitations of traditional heuristic or mathematical methods. This method provides greater computational efficiency, especially for the OBDO problems in large-scale construction projects with hundreds of activities in the networks.

References


Table 1. Data regarding crashing of activities

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Figure 2. GAOBDO Flow Chart.

A test example is generated to verify the GA solution to OBDO in the VBA programming environment. A 10-activity network is applied to include activity number, normal duration, crashing time and crashed cost. The normal project duration is 129 days. The relationship between the crashed cost and crashed time of individual activities is assumed to be linear. This is given in Table 1. For the owner, the interest cost from the bank loans is $100 per day. Future revenue is assumed to be $650 per day.
Recycled Coarse and Fine Aggregates for Precast Concrete Elements

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Introduction

In recent years the wisdom of continued wholesale extraction and use of aggregates from natural resources has been questioned at international level. Depletion of supplies of high grade conventional aggregates in certain regions, the need for better methods of solid waste disposal, and energy conservation have contributed to the interest of the technology in recycling concrete. One of the most environmentally responsible ways of meeting the challenges of sustainability in construction is the use of recycled C & D waste as aggregates in new concrete construction. In many countries, a considerable amount of demolition waste is generated and concrete forms a significant proportion of the waste. However, there are still various reasons for not using the recycled aggregate widely. Limited data and standards are available on commercial grade recycled concrete aggregate with regard to mixture proportions and durability.

Most researchers had made the recycled aggregates from crushing laboratory mixed concrete for better control of the properties and mix proportions of the original concrete. This allowed the study of some specific properties of recycled concrete under controlled conditions. However, these results may differ from those obtained when field-demolished concrete is used to produce recycled aggregate. While past studies on the engineering properties of concrete made with laboratory-crushed recycled concrete aggregate abound, limited data are available on commercial grade recycled concrete aggregate, including concrete mixture proportions, fresh concrete performance, and durability characteristics.

Recycled aggregates

Both the coarse and fine aggregates used in this research are derived from construction waste. Deleterious materials such as pieces of bricks, plaster, dried cement paste, ceramic tiles, glass, wood, metal nails and cardboard are present in these aggregates. The fine aggregate or recycled sand has most of its organic contents removed through the washing and filtering process. For the coarse aggregates, the majority of the weaker components are crushed and separated. The bricks and tiles, clearly distinguished by the red colour (Figure 1), amounts to less than 10%. 90.4% of the recycled aggregates are made up of natural aggregates (55.2%) and gravel or mortar (35.2%) with a deviation of about 3%. The remainder 9.6% is made up of bricks (7%), tiles (1.5%) and glass (1.1%) with a deviation of about 3%. The impurities affect the strength, water demand, and cohesion of the concrete mix, the extent depending on the amount.

Workability of concrete mix

The deleterious materials in the recycled aggregates not only weaken the aggregate strength but also increase the water requirement of the concrete mix. The porosity of the recycled aggregates is much greater than conventional aggregates. The mix derived using recycled concrete coarse and fine aggregates was generally not very workable. Therefore, more water was required than a concrete mix using natural aggregates to achieve the same workability. To keep to the same water cement ratio, more cement had to be added to achieve the desired strength. However this meant increased production cost. Admixture was hence added for improved workability without increasing water or cement. The addition of admixtures reduces the amount of water required for the concrete to reach a required slump. Hence a higher strength concrete can be obtained without increasing cement. The treated concrete can maintain higher workability at a low water-cement ratio. However the use of these admixtures must be minimized as it incurs a higher cost on the concrete production.

Compressive strength tests

Figure 2 compares the experimental results and the theoretical compressive strengths for different water cement ratio. The theoretical compressive strength is for normal concrete. The mean error of the experimental results was found to be 8.6% below the targeted strength. This meant that the strength achieved from concrete cubes using recycled aggregates was slightly lower than the theoretically calculated design mix strength values.

Although the size and gradation of aggregates affects the compressive strength, it was observed that the decrease in compressive strength was more significant due to the presence of deleterious materials in recycled aggregates.
Crushing and the other processes of recycling, together with the presence of other weaker materials such as plaster and cement paste weakens the strength and quality of the recycled aggregates. The failure plane of normal concrete usually occurs through the cement paste and around the aggregates. Since recycled aggregates are weaker, the failure plane may cut through some of the weaker aggregates or waste components. As such, the compressive strength achieved is lower for the same water-to-cement ratio.

C-drain tests

With the current state of the art, the mix design can be used to make precast products such as C-drains, road curbs, concrete pave as well as concrete blocks depending on demand. Greater amount of fine aggregates had been incorporated in the mix design to cater to the recycling process. The compressive strength, deflection and stiffness of precast concrete C-drains produced using recycling aggregates from construction waste were compared to that produced using conventional aggregates. As expected the mode of failure is the same for both types of specimen. Some of the failed specimens are shown in Figures 3 and 4. The load-displacement graphs of the HCH recycled aggregates C-drains and the conventional C-drains are shown in Figure 5. From this experiment, the stiffness of the C-drain derived from recycled aggregates is comparable to the conventional ones. The strengths are also similar. It can be safely concluded that the C-drains using recycled aggregates are comparable to the conventional ones.

Pilot test of C-drains with the Public Utilities Board

The selected optimum mix for Grade 25 concrete was used to make the precast C-drains (Figures 6 and 7) in the pilot project on July 2002 with Public Utilities Board (PUB). The pilot project was arranged with the help of the National Environment Agency. The trial site was along Trevose Crescent near the junction with Merryn Road. The total length of the drain is about 40 m, of which the research group utilized a continuous stretch of 20 m. The remaining stretch is laid by another PUB’s contractor using conventional precast C-drains for comparison. The drain (Figures 8 & 9) was monitored monthly and the recycled aggregates had performed as well as the conventional precast C-drains.
After six months (Figure 9), no noticeable difference was observed between the precast drains using recycled aggregates on the left and the commonly used precast drains. The commonly used precast drains have some stains due to the higher porosity.

**Pilot test of road curbs with the Land Transport Authority**

In November 2002, a pilot project was arranged with the Land Transport Authority to carry out a trial test of precast road curbs using recycled aggregates. The selected optimum mix for Grade 25 concrete was used to make the road curbs (Figure 10). The trial site was at car park C4 at the East Coast Park Road. After only a month, tire marks can be seen on the road curbs. After three months, more tire marks can be observed showing what punishment road curbs can be subjected to (Figure 11). The road curbs had been monitored regularly and the road curbs using recycled aggregates had performed well.

**Commercial production and quality control**

Various control measures and processes to ensure consistent product quality that complies with the required test standards had been put in place, e.g., computerized batching system and stringent quality control tests are done for product quality and consistency (Figures 12 and 13). The rebound hammer...
tests are used to ensure that every batch of precast products is of the minimum strength quality.

Summary and conclusion

Using a patented sorting, crushing, washing and screening process, the hardcore from construction and demolition wastes can be used to recover aggregates for recycling. Recycled aggregates differ from natural ones mainly in the presence of deleterious materials and having a higher porosity. This results in different concrete properties like workability, strength and durability. The use of recycled aggregates for precast concrete products is viable with proper understanding of how recycled aggregates affect the properties of concrete. There is greater variability of the properties because of the greater variability of the recycled aggregates compared to the conventional aggregates. This can be overcome by increasing the design strengths specified instead of not ignoring its use totally.

The results of the research had been published in numerous seminars and conferences as given in the reference list. This research was carried out on the use of these recycled aggregates to produce concrete of sufficient compressive strength for common use. The potential is thus only limited by our natural bias against using recycled products. In this green age, we have to slowly change our perceptions against recycled products. Performance, not origin, becomes the new key word. The research team is exploring further with Hock Chuan Hong Waste Management Pte Ltd to find more economical trial mixes for higher concrete grades and to develop the use of recycled aggregates for other precast products. Exploration in more economical trial mixes for different concrete grades of precast elements will be continued, as there is great potential in this recycling attempt. Further product development for recycling such as lightweight concrete will be explored. The entire research was carried out with local expertise.

References


