Abstract:
This paper describes a concurrent engineering (CE) readiness assessment model for the construction industry called the BEACON Model. The model was developed in response to the need for a specific CE readiness assessment tool to facilitate the effective implementation of CE within the construction industry. The model is encapsulated in a software program developed as a Microsoft Access application, and designed to facilitate responsiveness and quick processing. The development of the model and the associated software is discussed in this paper, and it is concluded that the BEACON Model can be successfully used as a CE readiness assessment tool for the construction industry. The model can also act as a useful tool for self-assessment on the four key elements: process, people, project, and technology, even for construction organisations not considering the implementation of CE. The readiness assessment of the construction industry, using the model, is intended to inform the development of guidelines for the effective and more appropriate implementation of CE in the industry.

Keywords:
BEACON Model, Concurrent Engineering, Construction Industry, Readiness Assessment,

1. Introduction

The UK Government-initiated reports such as the Latham Report (1994) and the Egan Report (1998) have recommended the improvement of the construction industry’s business performance. The need for greater co-ordination and integration within the industry has led to the adoption of various concepts from other industries. One of these, which offers major scope for effective co-ordination and integration within the industry, is Concurrent Engineering (Kamara et al., 2000). Concurrent Engineering (CE), sometimes called simultaneous engineering or parallel engineering, has been defined in several ways by different authors. The most popular one is that by Winner et al. (1988), who state that concurrent engineering “…is a systematic approach to the integrated, concurrent
design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements.” In the context of the construction industry, Evbuomwan & Anumba (1998) define Concurrent Engineering as an “...attempt to optimise the design of the project and its construction process to achieve reduced lead times, and improved quality and cost by the integration of design, fabrication, construction and erection activities and by maximising concurrency and collaboration in working practices.” This is in sharp contrast with the traditional approach to construction project delivery.

In order to introduce aspects of CE in the construction project delivery process, various research efforts have been undertaken. A detailed account of these efforts is compiled and presented by Kamara et al. (2000). They have concluded that much more needs to be done if the reported benefits of CE in other industries such as manufacturing can be realised in the construction industry. It is also concluded that an important aspect of CE implementation in the construction industry, which is often overlooked, is the need to carry out readiness assessment of the construction supply-chain for CE implementation. This is expected to establish the level of CE maturity of different sectors of the supply-chain with a view to informing implementation efforts. Therefore, in order to establish the level of maturity and improve planning for CE implementation, a customised readiness assessment model has been developed for the construction industry needs (Khalfan & Anumba, 2000a).

This paper presents the development of the model (called the BEACON – Benchmarking and Readiness Assessment for Concurrent Engineering in Construction – Model) and the associated software. The use of the model is also described and a number of conclusions drawn.

2. Development of a Model for Construction

The BEACON Model (see Figure 1) is divided into four quadrants or sections to represent the four elements or aspects of the model, which are Process, People, Project, and Technology. The first quadrant contains five critical process factors used to assess the process maturity level of a construction organisation. The second quadrant contains four critical people factors used to assess the team level issues within the organisation, while the third quadrant is comprised of three critical project factors used to assess the project-related issues. The fourth quadrant presents five technology-related factors used to characterise the introduction and utilisation of advanced tools and technology within the organisation. The key advantage of the model is that it does not only include the process and the technology aspects as covered in other models but also introduces
two new dimensions, the people and project elements. These elements were covered to a limited extent in existing readiness assessment models and tools but were not adequately emphasised. The rationale behind including the people and project elements is that both of them are as critical to CE as the process and the technology elements and should be distinguished (Ainscough & Yazdani, 1999; Al-Ashaab & Molina, 1999; Brooks & Foster, 1997; Chen, 1996; Crow, 1994; Khalfan & Anumba, 2000b; Lee & Young, 1994; Love & Gunasekaran, 1997; Martin & Evans, 1992; Paul & Burns, 1997). This is one of the novel features in the BEACON model.

For each of the elements, five levels have been adopted from the RACE model (CERC, 1992), which indicate the level of maturity of an organisation with respect to the quality of the project development process, team-working, the completed project itself, and technology deployment within the organisation. These five levels are Ad-hoc, Repeatable, Characterised, Managed, and Optimising and are described in Table 1. The Ad-hoc Level indicates that an organisation is unfamiliar with CE practices or is not ready to adopt CE, whereas the Optimising Level shows that the organisation is ready to adopt CE or is already practising CE within its project delivery process. A model-based questionnaire (called the BEACON Questionnaire) has been developed for use in assessing construction organisations. The questions have five possible answers: “Always”, “Most of the Time”, “Sometimes”, “Rarely”, and “Never”, corresponding roughly to five maturity levels.

3. Software Implementation of the BEACON Model

The software implementation of the BEACON Model involved a number of activities, which included: the establishment of the purpose, scope and desired features of the software, the selection of an implementation environment, and the actual development (or programming) of the system. Following these, the model was validated through use in the assessment of several construction organisations.

3.1 Objectives of the BEACON Software

The primary objective of the BEACON software was to automate the CE readiness assessment of the construction industry using the BEACON model questionnaire. It was also intended to improve the efficiency of the assessment process by automatically generating the BEACON model diagram, which graphically illustrates the assessment results.
Table 1: BEACON Model Maturity Levels (adapted from RACE model)

<table>
<thead>
<tr>
<th>Maturity Level</th>
<th>Description</th>
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<tbody>
<tr>
<td>Ad-hoc</td>
<td>This level is characterised by ill-defined procedures and controls, and by confused and disordered teams that do not understand their assignment nor how to operate effectively. Informal interaction with the client is observed, management of the project development process is not applied consistently in projects, and modern tools &amp; technology are not used consistently.</td>
</tr>
<tr>
<td>Repeatable</td>
<td>Standard methods and practices are used for monitoring the project development process, requirements changes, cost estimation etc. The process is repeatable. There are barriers to communicate within the project development team. Interaction with the client is structured but it is only at the inception of the project. Minimal use of computer and computer-based tools.</td>
</tr>
<tr>
<td>Characterised</td>
<td>The project development process is well characterised and reasonably well understood. A series of organisational and the process improvements have been implemented. Teams may struggle and fall apart as conflicts are addressed but a team begins to respect individual differences. Most individuals are well aware of client’s requirements but client is not involved in the process. Moderate use of proven technology for increasing group effectiveness.</td>
</tr>
<tr>
<td>Managed</td>
<td>The project development process is not only characterised and understood but is also quantified, measured, and reasonably well controlled. Tools are used to control and manage the process. The uncertainty concerning the process outcome is reduced. Work is accomplished by the project development team and conflicts are addressed. Client is involved throughout the process. Appropriate utilisation of available technology and computer-based tools.</td>
</tr>
<tr>
<td>Optimising</td>
<td>A high degree of control is used over the project development process and there is a major focus on significantly and continually improving development operations. Team performance is regularly measured, and performance measures are continuously validated. Client is a part of project development team from inception and all project decisions are prioritised based on client’s needs. Optimal utilisation of appropriate plant and technology &amp; technology-mediated group work is observed.</td>
</tr>
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3.2 System architecture

To ensure that the desired objectives of BEACON software were satisfied, architecture for the software, illustrated in Figure 2, was developed. Three modules provide:
- The means for defining current status by data collection;
• Questionnaire response analysis; and
• Result generation and presentation.
These modules facilitate the storage and retrieval of information from the data storage facility. The user interface interacts with all three modules, which are interconnected. The arrows linking the modules indicate that input, storage, viewing and editing of responses, can be done at any stage in the process.

![Diagram of BEACON Model](image)

**3.3 Selection of Implementation Environment**

The implementation environment for a software and general system development is usually based on a number of options that, according to Britton and Doake (1996), include:
• Programming in a procedural, third-generation language (3GL) (e.g. FORTRAN) where the programmer has to describe in detail how every task is to be carried out;
• Programming in a problem oriented fourth-generation language (4GL) (e.g. C, C++) where the programmer merely has to define what must be done;
• Using a general-purpose integrated package which incorporates facilities such as word processing, spreadsheets, database and report generators; and
• Use and customisation of specific application (commercial) packages.

Fig. 2: System architecture of the BEACON Model

In the development of the BEACON software, a general-purpose database package (Microsoft Access 97 for Windows) was chosen, assisted by a general-purpose spreadsheet package (Microsoft Excel 97 for Windows). This was due to the need to quickly develop the software program at minimal expense. The choice of Microsoft (MS) Access 97 and MS Excel 97 for the development of the software was also based on the following rationale (Kamara and Anumba, 2001):

• As part of the generally popular MS Office suite of programmes, it is compatible with other Windows-based packages such as MS Word, etc;
• It utilises the full graphical capability of Windows, and provides visual access to data and simple, direct ways to view and work with information;
• Access facilitates, through the use of macros, the automation of many tasks without the need for programming; and
• In-built design tools in MS Access assist in the development of forms and the generation of results by exporting data to MS Excel for generating diagrams and importing those back for presentation.

3.4 Development of the BEACON Software within MS Access

The BEACON software allows users not only to fill in the assessment questionnaire on their own, but also to view the results in the form of a radial diagram, similar to the BEACON Model diagram. The development of the software followed the general procedure for developing Access applications. The development of tables, queries, forms, reports, and macros for the software was carried by using the facilities provided within Access, and liked with Microsoft Excel for calculating and plotting the results of the readiness assessment.

The questionnaire is implemented as ‘Forms’ in MS Access. Each check box on the forms is given a specific score or value, as shown in Table 2. All the comments and scores are automatically recorded in ‘Tables’ linked to the Forms. ‘Macros’ are used while developing the Forms for different functions such as saving the responses, and switching from one form to another. A built-in Macro is used for exporting data to MS Excel. For this purpose, a ‘Save’ button is provided on the main menu form of the questionnaire, which is linked to the macro using OLE (Object Linking and Embedding) and when that button is clicked, it opens a new spreadsheet with the same name and exports all the data to it automatically. It also updates the responses in the spreadsheet when they are changed and saved again.

<table>
<thead>
<tr>
<th>Responses ⇒</th>
<th>Always</th>
<th>Most of the Time</th>
<th>Sometimes</th>
<th>Rarely</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score ⇒</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

A separate Excel spreadsheet, which is linked to the spreadsheet that is automatically opened when the data is exported from MS Access, may also be created. The link between these two spreadsheets is such that when there is a change in the data in original spreadsheet, it is reflected in the second one. The second spreadsheet is used to plot a radial graph from the data. This radial graph, which has a similar format of presenting data as of BEACON Model diagram, is
then imported back to the MS Access file in a form format and can be viewed when the result button is clicked.

4. Using BEACON Model Software

Running the software requires the installation of MS Access 97 and MS Excel 97. When the file containing the software is opened, the welcome screen (Figure 3) is displayed. A button on the screen, ‘Continue’, allows the user to proceed to the next stage. Clicking on the ‘Continue’ button will open the introduction section, which contains buttons for next and previous screens. By clicking the ‘Next’ button, users can enter to control form, which contains links to all the other forms in the application. When the ‘Save and Exit’ button is clicked, the user is prompted to confirm the decision to quit the application. The control form contains the questionnaire forms of all the critical factors of all four elements. It also contains links to the background information, appendices, and results. In order to view the results, it is necessary to save the questionnaire responses by clicking the save button. It also shows the links to the previous and next screens, and ‘Save and Exit’ button if the users want to exit the application. One of the features of the programme is that all these links on this ‘Main Menu’ screen are available in the form of a tool bar, having all these links in a drop-down format. By clicking any of the critical factors, either using buttons or tool bar, a questionnaire form appears that allows users to fill in the questionnaire by clicking their mouse and if required type the comments. An example of such forms is shown in Figure 4, which also contains links to the previous, next, and main menu screens. After completing the whole questionnaire, users should save their responses by using save applications provided in the programme. In order to view the results, result application should be used either by clicking button on the main menu or viewing result facility from the tool bar. If there are any messages appearing on the screen, click ‘yes’ and ‘ok’ to continue with the results screen, which looks like as shown in Figure 5.
The BEACON Model: Concurrent Engineering Readiness Assessment Tool for Construction Industry

Figure 3: Welcome Screen of the BEACON Model Software

Figure 4: A Typical Questionnaire Form of Critical Factors
5. Discussion

The development of the BEACON model is important for the implementation of CE within the construction industry. The benefits of the model are outlined below:

- The BEACON model and its associated questionnaire are specifically tailored to meet the needs of the construction industry and its supply chain;
- It addresses four key elements and aspects of CE implementation which are only partly addressed by other models;
- The model will enable the development of guidelines for the effective and more appropriate implementation of CE in construction;
- The model will enable construction organisations to identify the aspects of its project delivery process that require improvements to facilitate CE implementation;
- The survey and assessment could be carried out either in the form of structured interviews; alternatively, the electronic version of the questionnaire could be completed by remote respondents;
- The model is simple and easy to use, as the questionnaire can be completed using tick boxes and the graphical representation readily generated; and
• Even for organisations not considering the implementation of CE, the model can act as a useful tool for self-assessment on the four key elements: process, people, project, and technology.

The model is now being used to assess the construction supply chain participants, and some of the results are also reported in a couple of conferences (Khalfan et al., 2001a & 2001b).

6. Conclusions

This paper has discussed CE readiness assessment of the construction industry and presented the development of a new CE readiness assessment model, the BEACON model and its associated questionnaire and software. It has also presented some of its major features and benefits. The following conclusions can be drawn:

• Implementation of CE within the construction industry has the potential to contribute towards client satisfaction by improving quality, adding greater value, reducing cost, and reducing construction schedules;
• It is necessary to carry out CE readiness assessment of the industry before CE implementation so as to ensure that maximum benefit is achieved;
• In order to assess the industry, a specific CE readiness assessment model is required because existing models are not appropriate in their present form; and
• The BEACON model has been developed specifically for CE readiness assessment of the construction supply chain, and will facilitate the formulation of strategies for effective CE implementation in the construction industry.

In summary, the BEACON can be successfully used as a CE readiness assessment tool for the construction industry. On the other hand, the model can also act as a useful tool for self-assessment on the four key elements even for construction organisations not considering the implementation of CE. Therefore, it is expected that the readiness assessment of the construction organisations will enable the development of guidelines for the effective and more appropriate implementation of CE in the construction industry. The construction industry can realise significant benefits from the adoption of CE. Readiness assessment of the industry will ensure that the right approaches are adopted for this purpose. The work presented in this paper is contributing in this regard and will, in future, provide detailed guidelines for the effective implementation of CE in the construction industry.
References:


