Applicability of Critical Chain Scheduling in Construction Projects: An Investigation in the Middle East

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Abstract

Many industries, including construction, have been using CPM scheduling for a very long time. However, due to the increasingly competitive business environment, tighter time constraints are becoming the norm of the industry. And as a result, more projects are slipping behind schedule. This led some to call for more efficient means to plan and schedule projects. Following to the introduction of the theory of constraints (TOC) by Eli Goldratt, a new and innovative project scheduling paradigm emerged; that is Critical Chain (CC). This technique is evolving year after another, with documented success stories in some of the biggest multinational companies in the world. However, it seems to be almost unknown within the construction industry, at least in the Middle East where the study was carried out. To better understand the potential of applying CC in construction, this study aimed to: (1) measure the readiness of construction professionals in two Middle East countries to adopt CC, (2) determine suitable project type(s) for its pilot application, (3) identify any technical obstacles to applying it, and (4) investigate means to overcome such obstacles. To this end, CC introductory seminars were organized in Egypt and Saudi Arabia. Questionnaire surveys were disseminated after these seminars to solicit feedback on these issues. One of the survey's findings is that linear projects, e.g., pipeline construction projects, were pointed out as potentially suitable for CC pilot application. An obstacle identified by construction professionals to hinder CC real life application is estimating the aggressive but achievable duration (ABAD). This term refers to fundamental parameter upon which the CC calculations are based. The paper briefly discusses how the intelligent capabilities of case-based reasoning are utilized to help facilitate the estimation of ABAD.

Keywords: project scheduling, CPM, critical chain, pipeline construction, case-based reasoning (CBR).

1. CPM scheduling for construction projects

The critical path method (CPM) and its underlying concepts evolved in the US back in the 1950s (Aguanno 2002). Today, CPM tools are the norm for planning and scheduling

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construction projects. According to surveys by Kelleher (2004), a staggering 98.5% of surveyed ENR's top 400 construction contractors were using CPM as the fundamental technique for project planning. The smaller size companies employed free-hand bar charts as well, while the larger size ones complemented their CPM planning with the use of Program Evaluation and Review Technique (PERT), 4D schedules, and others.

Many articles have been written about the importance of using CPM in construction planning and scheduling (Hansen 1994). The last decade, nonetheless, has witnessed a debate on the *real* effectiveness of such planning tools. Some even critiqued the construction planning process and argued that there was over-emphasis on the critical path terminology (Street 2000, Winch and Kelsey 2005). Among the arguments was the need to continuously update and revise the schedule, CPM becoming a ritual formality rather than a useful tool, among others (Baki 1998). Other opponents tackled the issue from a different perspective. Goldratt (1997), for instance, argued that there has been nothing really new in project planning and scheduling in 40 years. The traditional CPM inherited certain foundational philosophy in calculating activity duration, activity float, and the project total duration. However, with CPM, it is not uncommon to see projects failing to be completed as planned. There is a myriad of causes behind such failures, but one ought to think if the planning tools themselves are sometimes incapable of safely navigating a project to its end.

2. Critical chain and the need for this study

The critical chain (CC) method was first introduced in 1997 by Dr. Eli Goldratt in his book "Critical Chain" (Goldratt 1997, Raz et al. 2003). Since its inception, CC was realized to be a considerable deviation from the traditional CPM counterpart. Today, it is a well-recognized technique for project planning and scheduling in the literature (PMI 2008). Moreover, many success stories for its implementation have been reported in various industries such as defence, pharmaceutical, IT, research, and others (Leach 2005).

Despite this relative popularity in some other industries worldwide, there was no documentation of applying CC in the construction industry in the Middle East. Admittedly, there have been attempts at applying CC in the international construction industry, e.g., Balfour Betty (1998). Yet, this does not translate, by any means, into CC becoming a well-proven industry practice. The study in hand was initiated – back in 2008 – as an effort to:

1. Gauge the level of awareness of construction industry practitioners in targeted Middle Eastern countries about the CC technique.

2. Investigate the applicability of CC in construction projects, from the perspective of those industry practitioners. Also, investigate the type(s) of construction projects convenient for its pilot application.

3. Point out and possibly tackle an obstacle to its implementation.

To this end, the study proceeded in stages as follows:

1. Publications and earlier researches relevant to planning and scheduling techniques were thoroughly reviewed, particularly those addressing CC. Also, the CC awareness was informally investigated among industry practitioners (to better guide the following stages of the study).

2. CC awareness seminars in both Egypt (as a representative of North African countries) and Saudi Arabia (as representative of the Arabian/Persian Gulf countries) were conducted. The support of professional societies was sometimes sought in arranging the said seminars, to which industry practitioners were invited.

3. Following each awareness seminar, questionnaire forms were disseminated to the attendants to investigate CC applicability, potential construction project type(s) for its application, obstacles, among other aspects.

4. An obstacle to CC implementation was highlighted and a computerized tool was developed to help overcome such obstacle. The intelligent capabilities of case-based reasoning were particularly sought at this stage.

3. The critical chain terminology

The CC was born out of the theory of constraints (Goldratt 1997). The application of the theory of constraints in the area of project planning is based on the notion that task-time estimates are normally inflated, e.g., weather-related padding added to task estimates (Millhiser and Szmerekovsky 2012). Task owners typically incorporate these safety paddings to ensure as much as possible they would be able complete the work on time, regardless of uncertainties (Raz et al. 2003). In normal CPM scheduling, the safety paddings are inseparable from the activities durations. CC removes the safety paddings from the project activities and pools them to create safety margins for its different paths, figure 1, and eventually the project as a whole. The safety paddings/margin will hereinafter be referred to as the “buffer”. Also, it is to be noted that the durations in CC is frequently called *aggressive but achievable durations* (ABAD).

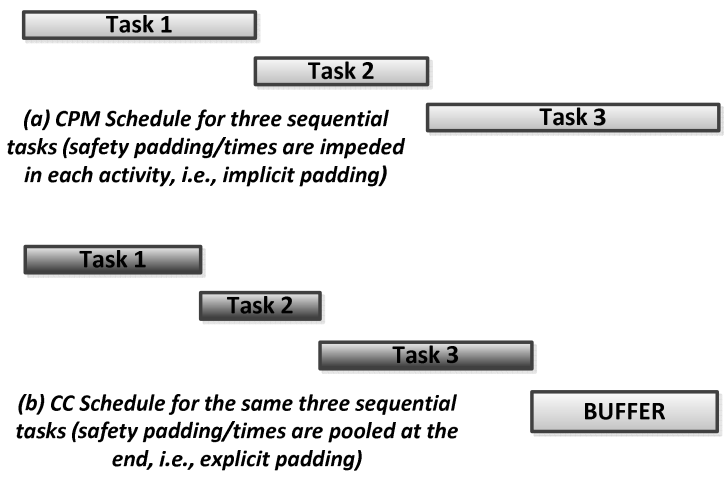

Figure 1: CPM schedule vs. CC schedule for a sample project

3.1 Activity durations and path/project buffers

The buffers which were hidden or impeded inside the activities in CPM schedules become explicit and pooled in CC schedules. Under CC, the buffers appear on the project bar chart (Raz et al. 2003). In other words, it is scheduled and managed. This can help visualize the level of uncertainty in the project. The lengthier the estimated buffer for a path/project, the riskier it is. Raz et al. (2003) further indicate that the combined buffer can be less than the sum of safety margins for the individual activities. This argument is supported by statistical theory that states that the standard deviation of the sum of a number of mutually independent random variables (in this case the duration of activities on the path) is less than the sum of the individual standard deviations. However, in practice, it may be easier to gain task owners' acceptance of polling their individual safety margins if the total is not reduced. This human-related factor needs to be taken into account as well.

The developer of the CC method, Eli Goldratt, suggested halving the durations of project activities under the traditional CPM schedules. Half of this "saved" time is then used to create a buffer for the path/project. Accordingly, the total planned project duration will drop to 75% of the original estimate. This method, which is called the 50% rule, is criticized by some. For instance, Herroelen and Leus (2001) argued that the 50% task duration estimate may be based on a loose ground. Further, the mechanism used for the estimating the task duration in CC will govern the created buffers for the paths and the entire project. Having an accurate buffer size and corresponding estimated completion date is of particular importance when projects must be won through bids that are evaluated, at least partially, based on the delivery date of the project (Millhiser and Szmerekovsky 2012).

Why does one need to account for the buffers of the different paths rather than the longest path alone? This is quite a reasonable question to ask when it comes to CC. After identifying the longest chain of activities based on the CC-estimated task times, the buffer for this chain denotes the project buffer. It is realistic to assume this will govern the actual project duration. Millhiser and Szmerekovsky (2012) claim that such notion simply undermines the significance of buffers on parallel paths. With the variability inherent in project activities, it is possible to encounter a non-critical chain, as per the plan, that leads to unrecoverable delays. The CC response is the insertion of feeding buffers where non-critical sequences join the critical chain, figure 2. Reason of such name is that it denotes where the non-critical chain feeds into the critical chain (Raz et al. 2003).

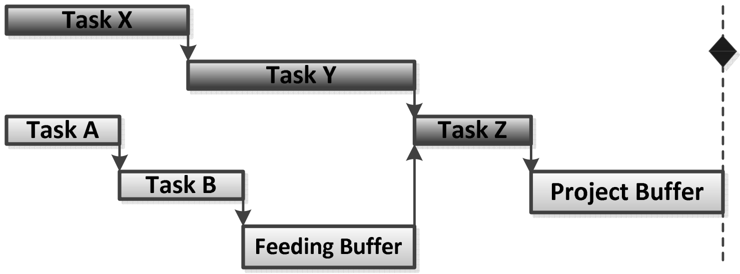

Figure 2: Use of buffers in CC schedules

A third type of buffers is used by CC is called a resource buffer, which is a virtual task inserted prior to the critical chain tasks that require critical resources. Its purpose is to issue a signal to the critical resource that a critical chain task to which they are assigned is due to start shortly (Raz et al. 2003). While working on the critical chain task, the resource is expected to work continuously on this task, so drawbacks of multitasking do not materialize.

3.2 Use of buffers

The buffer sizing is a topic that has been under scrutiny by researchers for some time now. There is no consensus yet on the best method to estimate the size of the project and feeding buffers. A review of many of these methods can be found in Geekie and Steyn (2008). But, assuming one of these methods is used to estimate the buffers, then they become not only protective means against variations but also transducers that provide vital operational measurements and proactive warning mechanisms on the project performance (Herroelen and Leus 2001). If activity variation consumes a buffer by a certain amount, a warning is raised to determine what needs to be done if the situation continues to deteriorate. These plans —expediting, working overtime, subcontract, etc.— are to be put into effect if the situation deteriorates past a critical point. Figure 3 illustrates a graphical tool, called fever chart, for the tracking of project performance as per the consumption of the allotted buffers (Leach 2005). This chart is particularly useful as it relates the buffer consumption to the project clock or completion of the critical chain activities. Three regions are identified and coded with the colours red, yellow and green. In this context, the red region signifies the most alarming scenario that induces proper intervention. Yet, the fever chart incorporates another dimension, which is the percentage of work completed to date, or alternatively said, the percentage of longest chain completion. Reaching the red region will not be as alarming in case of 90% completion as in the case of 10% completion. Only when the two dimensions are tied together, a more informative judgment can be made.

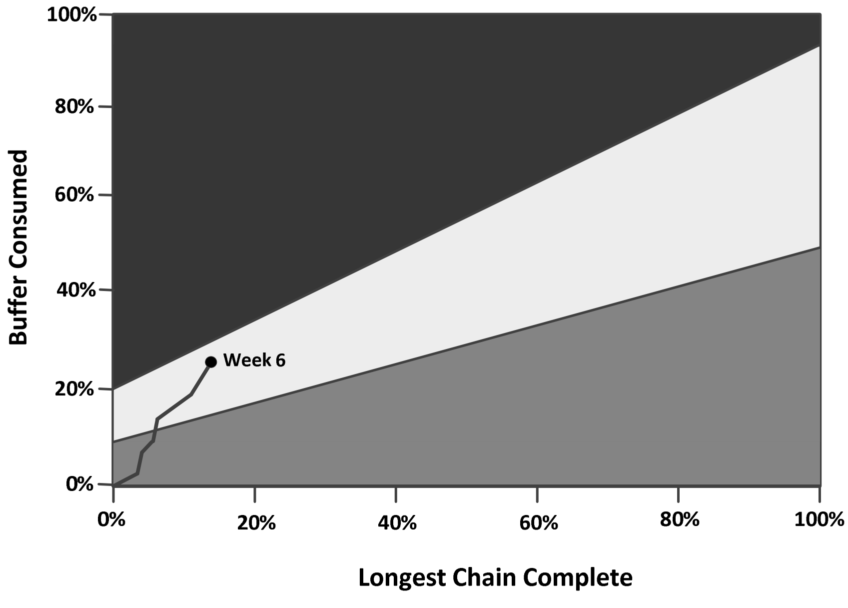

Figure 3: Illustrative fever chart for managing the buffer in CC schedules (Leach 2005)

3.3 CC vs. CPM Scheduling

CC planning seems different from the CPM counterpart. However, they still share some aspects in common. Both are represented by networks and bar charts, and both use forward and backward calculations to predict start and finish dates. However, unlike CPM, the CC terminology refers to the longest path as the critical chain, denote durations by ABAD, safety margins are pooled in the form of project/feed buffers, and the project health is evaluated via the buffer consumption.

4. Awareness sessions and surveys

Following to informal interviews with many industry practitioners in the Middle East, it was realized that the CC technique is, simply said, unknown to all. The exception was two Project Management Professionals (PMPs) who got acquainted with it while preparing for the PMP exam. However, they have not used it in reality or even investigated its use. This guided the research to arranging and conducting awareness sessions in Egypt and Saudi Arabia, followed by a survey to solicit the feedback of industry practitioners on the subject matter.

4.1 Venues and attendants

Three awareness sessions were conducted in three locations in Egypt: (1) an academic institution, (2) an authorized trainer for the Project Management Institute (PMI), and (3) a top Egyptian contractor with multitude of international projects. In addition, one awareness session was conducted in Saudi Arabia during a Quarterly Meeting of the Egyptian Association for Planning Engineers in Jeddah. All attendants of the latter session have many years of experience working in Saudi Arabia. After end of each awareness session, a survey was disseminated. Figure 4 shows the primary information of the participants in the awareness sessions and the surveys that followed. A total of 47 industry professionals took part in this research stage.

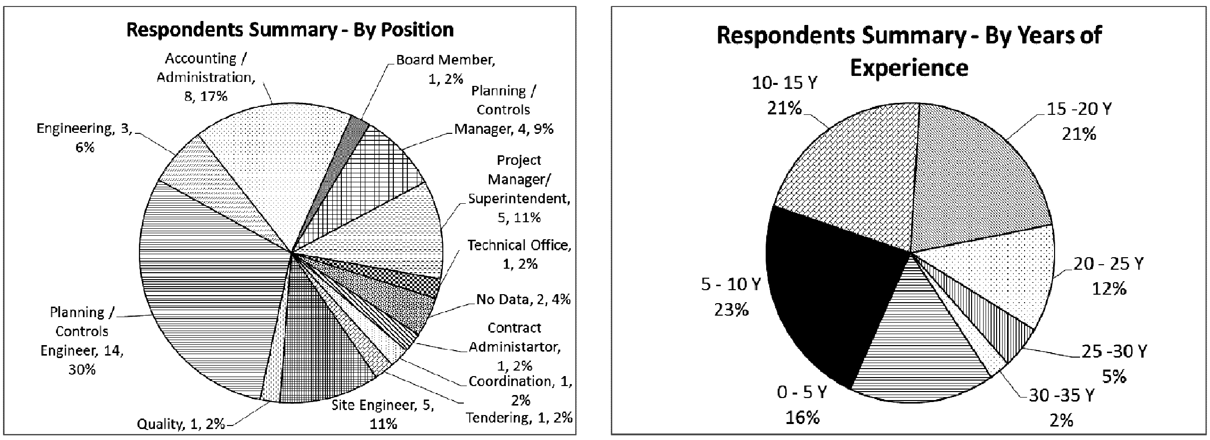

Figure 4: Summary of background and years of experience of participants

4.2 Survey structure and major findings

Survey had 19 multiple choice questions (with sufficient space for comments and out-of-list answers). After the conventional introductory section, two sections followed. First section investigated the current planning practices, including: (1) level of planning in company practices, and (2) the planning tools and techniques in use. The second section addressed CC in more specific details, including: (1) general perception of CC, (2) obstacles to practical implementation, (3) expectations for CC success/failure, (4) construction project type(s) most suitable for its pilot implementation, and (5) willingness of participant to engage in CC deployment in own company.

4.2.1 Current practices

All participants, with no exception, were found to use CPM for planning and scheduling in their companies. Eighteen benefits were identified for the use of CPM in such capacities, table 1. However, the significance of such benefits, denoted by the rank, differs between Egypt and Saudi Arabia. Both groups were in consensus, nevertheless, on “scheduling project activities” to be the top benefit.

Table 1: Benefits of CPM utilisation in construction industry (Middle East perspective)

Benefit	**Rank (Egypt)**	**Rank (Saudi Arabia)**
Improving team buy-in before work starts	13th	16th
Improved estimating/bidding	3rd	12th
Coordination of subcontractors	5th	5th
Coordination of own trades	17th	16th
Tracking shop drawings and submittals	7th	12th
Scheduling project activities	1st	1st
Reduces delays	7th	2nd
Tracking costs	2nd	7th
Calculating payment requests for work performed	10th	2nd
Faster response to problems	13th	5th
Improved understanding of the project	10th	7th
Improved communication among work force	12th	2nd
Helps train future project managers	13th	18th
Positive psychological effects on employees	18th	12th
Cost savings	5th	7th
Minimizes disputes between contractor and owner	7th	12th
Schedule impact analysis and tracking changes	3rd	7th
More control over risk and uncertainty	13th	7th

Survey investigated why the current CPM systems are deployed and will continue to be popular in the future, Figure 5. Construction professionals in Saudi Arabia cited such CPM schedules to be a typical contract requirement, which enforces their use. Construction professionals in Egypt were rather perceptive of their significance in dispute resolution between the project parties. Familiarity of all contract parties about the CPM terminology cannot be overlooked. Among the other reasons is the validity of such technique (which was proven over the years), not needing high/sophisticated skills, and the time/cost savings associated with their use.

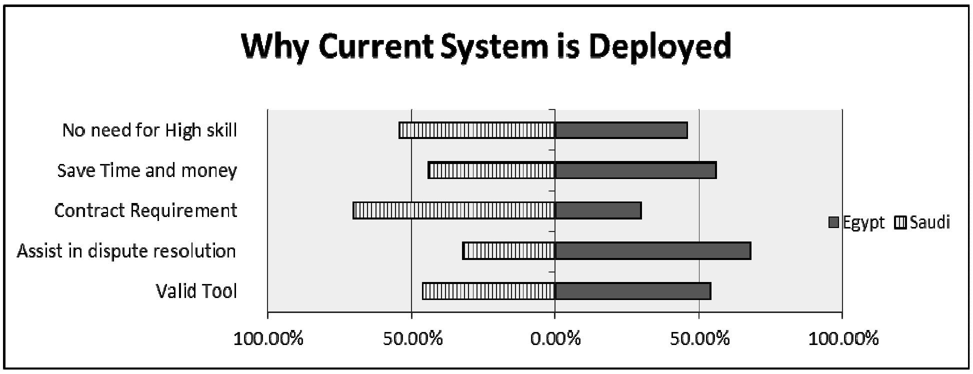

Figure 5: Reasons for adopting (now and in the future) of CPM-based Systems

4.2.2 CC potential and applicability

As per the survey, 10% and 44% of the surveyed industry professionals in Egypt and Saudi Arabia, respectively, had the opinion that CC adds no *real* value in project planning despite the new scheduling approach used. They see that using ABAD has a counterpart in CPM schedules via utilising aggressive activity durations. And then, having a buffer between the planned end date and deadline for completion is not atypical.

Construction professionals appreciated CC as a new and innovative approach, nonetheless. Yet, the majority of the surveyed professionals (68% and 62% in Egypt and Saudi Arabia, respectively) believed it was applicable in construction industry under certain circumstances/constraints.

To clarify the perception of CC applicability in construction practice, ten obstacles for its application were investigated, figure 6. Professionals in Egypt identified the inexperience of project parties, especially vendors and subcontractors, about CC terminology as the most significant hurdle. Among the other pointed-out obstacles is the software changes and reluctance to use new technique (i.e., it was not deployed before in construction projects). The professionals in Saudi Arabia were concerned primarily about the contractual context and the fact that CC application is not a contract requirement. They also showed concern about CC not being a “proven” scheduling and management technique.

Another area of great concern was the estimation of ABAD and the buffers. There are tied together. As per table 2, there was a complete rejection of applying the 50% rule in construction practices. All considered it to be unrealistic due to the nature of construction activities. Construction professionals in Egypt were divided as to which is the better approach for estimating ABAD and the buffer, where approximately half opted for expert judgment and the other half preferred using analytical means to make the estimate. For the surveys in Saudi Arabia, there were more tendencies to use expert judgment as the primary basis for the estimates. The surveyed professionals conveyed an important point in this research; that is ABAD estimation is a main challenge for CC applicability in practice.

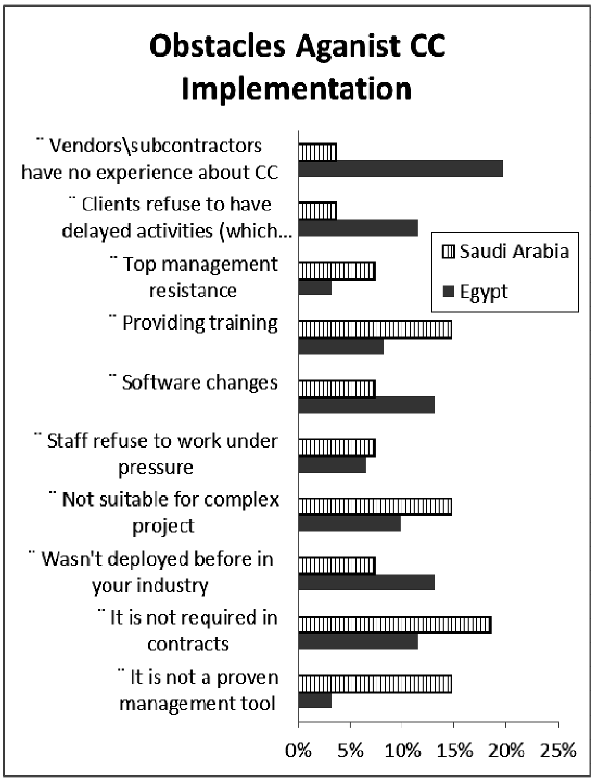

Figure 6: Obstacles to CC application in the construction industry

Table 2: Method for calculating buffers

Method	**Preference by surveyed professionals (Egypt)**	**Preference by surveyed professionals (Saudi Arabia)**
50% rule	0%	0%
Expert judgment	56%	74%
Analytical means, e.g., statistical analysis	44%	26%

An investigation of the project type(s) most suitable for the CC implementation in construction industry, professional in Egypt and Saudi Arabia preferred linear projects, e.g., pipeline/utility projects, over the traditional building counterparts. Other project types that are not construction oriented were presented to the participants. This allows those who feel less convinced about CC suitability in construction to convey their opinions. Results are summarized in table 3.

The choice of linear construction projects that are characterized by their repetitive nature should come as no surprise. Goldratt's theory of constraints, that is the theory upon which the CC method is founded, was developed for managing repetitive production systems (Raz et al. 2003). Another reason is that, in more complex construction projects, it is typical to see paths splitting and merging again at various intermediate points. The resulting maze of paths in the network will make is difficult, if not impossible, to estimate the buffers, especially the feeding buffers (Raz et al. 2003). One ought to think of the scenario of various merging tasks and how much feeding buffer to use.

Table 3: Project types convenient for CC implementation

Project Type	**Preference by surveyed professionals (Egypt)**	**Preference by surveyed professionals (Saudi Arabia)**
Building construction	26%	19%
Linear projects, e.g., pipeline/utilities	32%	37%
IT/software	23%	25%
Research and development (R & D)	19%	19%

In conclusion, the majority of survey participants expected *partial* success for the CC scheduling technique in construction. None of those in management roles agreed to implement it immediately, but rather preferred to wait until implemented by others in the industry. Some even questioned the success stories of CC; they consider it the result of two types of changes, the first is the planning technique and the second is the working environment. Their perspective, which is shared by the authors, is that applying CC requires close supervision and better staff motivation and management. They raised a simple question; that is, *what if these changes in the work environment took place while using a CPM planning system? what will be the result then?*

5. Artificial intelligence tool for estimating ABAD

Building on the previous stage of the research, the development of a tool to help estimate ABAD was sought. As such, different statistical and artificial intelligence (AI) techniques have been investigated in light of studies such as Arditi and Tokdemir (1999) and Kim et al. (2004). Case-based reasoning (CBR) was finally identified as suitable for study implementation. CBR utilises case libraries to estimate parameters of a new case (Aamodt and Plaza 1994, Watson 1997). This section briefly describes this effort; however, the reader can refer to other publications by the authors for full details.

5.1 Preparatory work

Six work types were chosen for the ABAD estimation process; they are: (1) excavation, (2) bedding, (3) pipe laying, (4) cable laying/pulling, (5) cable jointing, and (6) backfilling. For each of the aforementioned work types, a survey was communicated to infrastructure experts to identify the primary factors governing activity duration. Based on the identified factors and with the help of a special-purpose form, data/cases for the six work types were collected and later analysed using SPSS.

5.2 CBR tool development and validation

A set of software tools was bundled together to develop the ABAD module in reference, figure 7. In this context, open database connectivity (ODBC) enables importing data (i.e., project cases) from Microsoft Access. Web interface capabilities and an underlying web server enable the search to be carried out remotely through customized web page. The latter facility allows the module to be used without the need for specialized experience in CBR.

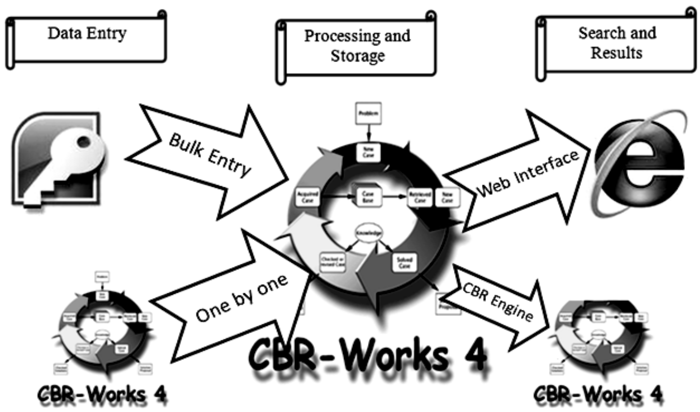

Figure 7: Obstacles to CC application in the construction industry

Similarity is a key notion of CBR. Estimating ABAD of a new target case is contingent upon its similarity to the cases stored in the case library. Similarity mechanisms in CBR can be reviewed in Watson (1997) and Georgy (2006). For quantifiably measurable parameters, e.g., length of pipe, a linear conversion function is used. Levels of qualitative parameters that have no implied relationships are treated as discrete points, i.e., similarity between these values is assumed to be zero. In case of qualitative parameters with implied relationships, similarity rules are established as per the parameter into consideration, figure 8.

Module performance was validated through test cases. With reference to ABAD, accuracy levels ranging from 84.8% to 91.9% were reported for the six work types.

	Gas	Telecom	LV	HV	Sewerage	Water	Storm Water
Gas	1	0.8	0.8	0.6			
Telecom	0.8	1	0.8	0.6			
LV	0.8	0.8	1	0.8			
HV	0.6	0.6	0.8	1			
Sewerage					1	0.7	0.9
Water					0.7	1	0.7
Storm Water					0.9	0.7	1

Figure 8: Similarity matrix for utility line type

6. Concluding remarks

CC may have its success stories in some industries. However, it is still unknown to the construction community in the Middle East. This study has got more of an investigative nature than drawing conclusions based on rigorous statistical analysis. Collecting industry feedback was quite challenging given the need to first educate the industry professionals, who accepted to commit time and attend the awareness sessions, about the CC terminology. The number of professionals/companies included in the data pool cannot be considered representative of the entire construction sectors in Egypt and Saudi Arabia. Yet, the study sheds some light on the potential of applying CC in companies of that region.

The study revealed some interesting thoughts. While several had doubts about having radically positive results in case of full-scale CC implementation, many still showed expectations of partial successes. They reckon that there are other contributing factors like change of management attitude, work culture, etc., that can together lead to the sought results. Also, it did not come as a surprise that linear construction projects were pointed out as potentially fit for the pilot CC implementation. This is in line with the nature of theory of constraints, which addresses the management repetitive production systems. However, industry professionals are rather reluctant to attempt the method in real practice, since it requires a change of project culture. Furthermore, the limited software support for CC scheduling, in comparison to CPM scheduling, can make the move rather difficult.

ABAD estimation, which governs the buffer management, was pointed out as hurdle to applying CC in real practice. All rejected applying the 50% rule claiming it to be unrealistic in the construction industry. Research adopted CBR for predicting ABAD in the project type of choice; that is pipeline construction. CBR creates analogies with available cases to estimate parameters for a new case. Success of the technique was promising, though estimating ABAD needs to be further researched in the future.

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