MODELS FOR ESTIMATING CONSTRUCTION DURATION: AN APPLICATION FOR SELECTED BUILDINGS ON THE METU CAMPUS

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**MODELS FOR ESTIMATING CONSTRUCTION DURATION:
AN APPLICATION FOR SELECTED BUILDINGS ON THE METU CAMPUS**

submitted by **ELVAN ODABAŞI** in partial fulfillment of the requirements for the degree of **Master of Science in Building Science in Architecture Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen ____________________
Dean, Graduate School of **Natural and Applied Sciences**

Assoc. Prof. Dr. Güven Arif Sargın ____________________
Head of Department, **Architecture**

Assoc. Prof. Dr. Soofia Tahira Elias Özkan ____________________
Supervisor, **Architecture Dept., METU**

Examining Committee Members:

Assoc. Prof. Dr. Rıfat Sönmez ____________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Soofia Tahira Elias Özkan ____________________
Architecture Dept., METU

Assoc. Prof. Dr. Arda Düzgüneş ____________________
Architecture Dept., METU

Asst. Prof. Dr. Ali Murat Tanyer ____________________
Architecture Dept., METU

Part-time Ins. Erkan Şahmalı ____________________
Architecture Dept., METU

Date: 01.06.2009

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Elvan ODABAŞI

Signature:

ABSTRACT

MODELS FOR ESTIMATING CONSTRUCTION DURATION:
AN APPLICATION FOR SELECTED BUILDINGS ON THE METU CAMPUS

Odabaşı, Elvan
M.Sc. in Building Science, Department of Architecture
Supervisor: Assoc. Prof. Dr. Soofia Tahira Elias Özkan

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The duration of construction of a project depends on many factors, such as: cost, location, site characteristics, procurement methods, area of construction, footprint of the building and its height, etc. It is very important to be able to predict these durations accurately in order to successfully complete a project on time. Various construction duration estimation tools have been developed to make accurate predictions, as "time is money."

The main objective of this study was to develop a model that can be used to predict the construction duration of a project in a reliable and practical way. Contractors can thus use a project's characteristics, as given in the tender documents, to estimate the actual amount time it would take them to complete the construction works.

In this study, factors affecting the duration of a construction project and models for estimating construction durations were investigated. Within this framework, duration estimation models such as; Bromilow's Time-Cost (BTC) Model and Building

Cost Information Service (BCIS) Model were used while Simple Linear Regression (SLR) and Multiple Linear Regression (MLR) analyses were conducted on data related to seven case study buildings that are situated at the Middle East Technical University (METU) campus in Ankara. This data was obtained from the Department of Construction and Technical Works (DCTW) at METU. The closeness in estimation of the regression analyses was investigated and finally an MLR model was obtained which was based on two parameters; the area of the building and the area of its façade. On the other hand, as opposed to studies reported in literature, the effect of cost on duration was not seen to be significant.

Keywords: Construction Duration, Factors Affecting Construction Duration, Models for Estimating Construction Durations, BTC Model, BCIS Model, Regression Analysis.

ÖZ

İNSAAT SÜRE TAHMİN MODELLERİ:
ODTÜ YERLEŞKESİNDEN SEÇİLEN BİNALAR ÜZERİNDE UYGULANMASI

Odabaşı, Elvan
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Bir projenin inşaat süresi, maliyet, yerleşim, sahanın özellikleri, tedarik metotları, inşaat alanı, bina oturum alanı ve bina yüksekliği gibi birçok faktöre bağlıdır. Bir projenin zamanında başarılı bir şekilde bitirilebilmesi için bu süreleri doğru bir şekilde tahmin etmek çok önemlidir. "Zaman paradır" düzeninde doğru tahmin yapabilmek için çeşitli süre tahmin araçları geliştirilmektedir.

Bu çalışmanın temel amacı, güvenilir ve pratik bir yöntemle projenin inşaat süresini tahmin edebilmek için kullanılacak bir model geliştirmek oldu. Böylece yüklenici firmalar inşaat işlerinin tamamlanması için gerekli süreyi hesaplamak için, sunulan belgelerde verilen projenin özelliklerini kullanabilirler.

Bu çalışmada, inşaat süresini etkileyen faktörler ve inşaat süre tahmin modelleri incelendi. Bu kapsamda, Orta Doğu Teknik Üniversitesi (ODTÜ) kampüsünde 2004-2007 yılları arasında yeni inşa edilmiş, 7 eğitim bina projesiyle ilgili bilgiler kullanılarak, Bromilow Süre-Maliyet Modeli ve BCIS Modeli uygulandı ve Basit ve Çok Değişkenli Regresyon Modelleri yürütüldü. Bu veriler ODTÜ Yapı İşleri ve Teknik

Daire Başkanlığı'ndan sağlandı. Bu regresyon analizlerinin yakın tahminde bulunabilme değerleri incelendi ve sonuç olarak toplam inşaat alanı ve cephe alanlarından yola çıkarak oluşturulan çok değişkenli bir regresyon analizi elde edildi. Diğer taraftan, literatürde raporlanan çalışmaların tersine, maliyetin süre üzerinde önemli bir etkisi olmadığı görülmüştür.

Anahtar kelimeler: İnşaat Süresi, İnşaat Süresini Etkileyen Faktörler, İnşaat Süre Tahmin Modelleri, BTC Model, BCIS Model. Regresyon Analizi

To My Parents and My Sister…

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"It was a long way.
It is my thesis story that I have lived…"

This thesis means much more than being only a master thesis. It was my thesis story that I could make my researches about my interests without restrictions, and I learned, finally I found myself.

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I express my appreciation to all of my friends, who have always helped me even over the miles. I always found the power to keep alive even in my worst hopeless times. I am grateful to you for being always on my side, for your forever love, patience and thoughtfulness that encourage me not to give up, but especially thanks to;

Emre Ilgın, Feray Dağlı Önal, Özge Önal, Hikmet Başaran, and Pakize Abu-Hasan…
You are beside me…
İpek Neşe Şener, Özge Başağaç and Aysel Öztürk…
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Finally, I would like to express my special thanks giving to my parents, Sabiha and İsmail, and my sister, Duygu, for their never-ending love, encouragement, trust and for being always with me even in my intolerable times. I can never thank them enough. I dedicate this thesis to them.

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LIST OF ABBREVIATIONS

ADDSS	Activity Duration Decision Support System
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
AUD	Australian Dollar
Av.F.Area	Average Floor Area (m^2)
Av.F.Volume	Average Volume of Floors (m^3)
Av.H.	Average Height of the Floors (m)
BCCI	Building Construction Cost Indices
BCDC	Building Construction Duration Calculator
BCIS	Building Cost Information Service
BTC	Bromilow's Time-Cost
Cost	Adjusted Detailed Cost Values
CPM	Critical Path Method
DCTW	Department of Construction and Technical Works
Façade	Façade Area (m^2)
GFA	Gross Floor Area
MAPE	Mean Absolute Percentage Error
METU	Middle East Technical University
MLR	Multiple Linear Regression
NoB	Number of block
NoF	Number of floors
ODTÜ	Orta Doğu Teknik Üniversitesi
PE	Percentage Error
PERT	Program Evaluation and Review Technique
π	pi value
p-value	Significance level

R^2	Coefficient of Determination
SE	Standard Error
SLR	Simple Linear Regression
Tot.Area	Total Area (m2)
Tot.H.	Total height (m)
Tot.Volume	Total Volume (m3)
TOKİ	T.C. Başbakanlık Toplu Konut İdaresi Başkanlığı (Republic of Turkey Prime Ministry, Housing Development Administration of Turkey)
TÜİK	Türkiye İstatistik Kurumu (Turkish Statistical Institute)

CHAPTER 1

INTRODUCTION

In this chapter are presented the argument, objectives, and the procedure of this study as well as the disposition of the report.

1.1. Argument

If a project is not completed with the stipulated period then the building contractor suffers losses due to escalated costs and penalties and clients suffer because their time minimization objectives cannot be achieved. Therefore, just as keeping a project within budget and quality is important, so is the accurate estimation of construction duration for the successful completion of a project.

Besides a success criterion, estimation of project duration is important for both; contractor and the client. The client can create a financial, cash and material flow plan in a pre-set time and can make optimum funds available to the Project. Moreover, general contractor predicting the construction time accurately and performing the works on time will gain power in the construction market and will take good decisions and take precautions against delays.

Duration estimations in different stages of construction projects, according to the projects data availability and time constraints, are very important for the planning phase of construction. For example, in pre-design stages, forecasting of construction duration is very difficult with minimum design information. The feasibility of construction is a very important step in construction. Client wants to know the approximate duration and cost of the project.

In construction projects, there is most common planning and controlling tools, these are; Bar charts, Critical Path Method (CPM), and Program Evaluation and Review Technique (PERT). One of the most common disadvantages of these techniques is that they can be used properly after a fully detailed construction projects are prepared and it requires a period to implement. Therefore, to form a reliable and practical estimation process without using these techniques depends on the planners' experiences and knowledge and planning process becomes an intuitive and subjective process. Models for estimating construction durations have been developed to get over this subjectivity approach. This study was initiated with the aim of developing a model that can be used to predict the construction duration of a project in a reliable and practical way. Contractors can thus use a project's characteristics, as given in the tender documents, to estimate the actual amount of time it would take them to complete the construction works.

Construction duration estimation models that are based on statistical data are considered to be more representative of the true picture and, therefore, more reliable. For this reason, the Bromilow's Time-Cost Model (BTC), Building Cost Information Service (BCIS) Model also called the Building Construction Duration Calculator (BCDC), the Simple Linear Regression (SLR) Analysis and the Multiple Linear Regression (MLR) Analysis were chosen for this study.

These regression models were selected on purpose in order to prove the applicability of regression analyses to predict construction duration. BTC Model, which is based on the power of regression formula with only cost parameter, was selected because of being the pioneer of duration estimation models in order to verify whether such a relationship holds for the data pertaining to the case study projects. Thereafter the BCIS Model, which is based on data related to 1,500 case study buildings in the UK and is used as? MLR analysis, was also considered for calculating project durations in order to check the conformity of a present model that was not using local data. Next, SLR and MLR analyses were conducted to obtain a model with a best closeness of fit. It was thought that an MLR analysis was the best choice within these models. The reasons of this thought are as follows;

- BTC model is a model based on only cost parameter.
- BCIS model is a model not conducted with local data, though it was formed with six parameters.
- SLR is a model developed by only one dependent variable (with or without cost)
- MLR model has more than one variable and mathematically, the result is expected more accurately than the other models.

Besides the aim of comparing these regression models to achieve the most appropriate one, the usage of cost parameter to predict construction duration was interrogated. It was seen that most of the researchers studied their modeling approach by supposing the effect of cost on duration, although, this conception was not considered as correct. The thesis research was also aimed at testing the validity of this argument too.

1.2. Objectives

The main objective of this study was to develop a model that can be used to predict the construction duration of a project in a reliable and practical way. Contractors can thus use a project's characteristics, as given in the tender documents, to estimate the actual amount time it would take them to complete the construction works. Additionally, the secondary objectives are to determine the following:

- To understand the factors involved in the determination of duration of construction.
- To identify critical factors involved in construction duration estimation models
- State of the art in construction duration estimation models

1.3. Procedure

To start with, various modeling methods for construction duration estimation and factors affecting construction duration were investigated through a survey of relevant literature sources.

The study was carried out on existing educational buildings, which are situated on the METU campus in Ankara, Turkey. The aim was to find the same type of projects' accurate data. Firstly, the information about the buildings was examined by collecting and analyzing the projects' data (duration, cost and design information) from construction documents of DCTW in METU. The characteristics of projects were analyzed with project drawings. Then, the construction duration was calculated by applying BTC, BCIS, SLR, and MLR Models with necessary escalations, and calculations. By comparing, these predicted durations and actual working durations, the closeness of fit of the projects were calculated. Finally, the applicability of the models was investigated.

1.4. Disposition

In this chapter, Chapter 1, the argument for, the objectives of and the procedure followed for this study are presented in brief.

Chapter 2 presents a concise review of the literature sources related to factors affecting duration of construction works and types of construction duration models being used in the world.

Chapter 3 is related to the material used in the study, which was the case study buildings in METU, and the method followed for evaluating the duration models.

Chapter 4 presents a discussion on the results obtained from the application of the models as well as a comparison of the actual duration with that derived from the models

Chapter 5 concludes this study with an overview of the pros and cons of using Construction Duration Estimation Models.

CHAPTER 2

LITERATURE SURVEY

This literature survey is based on factors affecting construction duration and construction duration estimation models. In the first section, the factors affecting construction durations are discussed. Then the types of models for estimating construction durations are defined. In the last part, the examples of modeling type and their comparisons are presented.

There are many definitions of construction duration, but the most apt one has been given by Bhokha (1998) as:

> "The time frame given by the owner for the contractor to complete the project under normal work conditions, normal practice of construction, and based on the minimum costs. It starts when the contractor receives the instruction to proceed and ends at the completion of construction works on site. It also includes delays caused by unanticipated circumstances, e.g. alteration of works (changed conditions and change orders), extra works, and supply of materials, location, weather, and site work conditions. Major changes that after the scope of work significantly are not included."

A study on predictability of duration and cost of projects was based on over 2,700 building projects completed in the UK between 1998 and 2006. Building Cost Information Service (BCIS, 2006) reported that while 40% of projects overrun their contract periods, 20% of them increase their contract costs. BCIS (2006) explained this result as:

> "There are two possible reasons for this:
> - Increases in time taken, unlike increases in costs, always affect the predictability
> - The lack of information on the actual time taken on projects.
>
> Increased costs that occur during a building project will be allocated between the client and the contractor in accordance with the terms of the contract. Therefore, they may, or may not, affect the predicted cost.
>
> Time is much less flexible. Whoever is responsible for a delay, and even if financial settlement is made, the client receives his completed project later than predicted."

Almost all the sectors, it is required to estimate durations and this process is vulnerable for making mistakes. Gören (1998) especially claims that the error of duration estimations in construction industry is more than other sectors because subjected to more difficulties not taken into account.

In the construction industry, both the client and contractor want to finish the project on time for different reasons.

> "Client wants to finish the project on time and in budget, because the finishing of construction part means that a beginning of a new long-term enterprise. Implementation cost of a project is a very important factor for the operating cost of the project. Project completion time affects the interest payable and to begin operation and to get the investment worth." (Uğur, 2007, p.81)

Contractor also wants to finish the project on time not to be influenced from the factors causing increase in costs: the inflation, interest rates, and punitive sanctions of the contract. Nkado (1995) added the effect of bonus in the contract as well as financial penalty as an external pressure on construction duration.

Uğur (2007) made a questionnaire with 26 contracting firms (minimum 11-year firms) members of Turkish contractor association. At the tender stage of internal or external projects, which criteria have priorities for these contracting firms, how the project duration and cost estimations made questions also examined with this questionnaire.

Table 2.1. Techniques used for construction projects' durations. (Uğur, 2007.)

	Internal %	External %
Historical data	62	67
Consulting experts	38	67
Comparing similar jobs	77	78
Calculation of all the durations of works separately	54	44
No duration estimation for being written in the contracts	38	33

According to the Table 2.1, there are two widely used techniques for duration estimation of either internal or external projects, historical data or comparing similar jobs. The other ones are consulting experts, calculation of all the durations of works separately and no duration estimation for being written in the contracts. Consulting expert technique usage increases in external projects very much when compared internal projects. It shows that the contracting firms take into consideration the risk concepts.

> "A high-percentage usage of duration estimation techniques either internal or external projects can be a useful application for the minimization of the risks. All projects have their own optimal duration with their optimal cost. The estimation of duration of any construction projects when the sum of direct and indirect costs is minimum, the comparison of this estimation with the contract duration and performing the project within this estimation time will be very useful applications. Even the possibilities for performing an earlier date than contract date with a lower cost, calculations could be searched. By this cost of duration minimization calculations, cost-time evaluations could be done." (Uğur, 2007, p.88)

Hoffman, Thal, Webb, and Weir (2007) also searched the significant factors influencing duration by developing a regression model. The authors worked on Air Force buildings facility projects in USA, and exemplified the method used for construction duration estimations of Air Force Projects as practical method. Hoffman et al. used benchmark techniques for duration estimation by using cost estimations of projects. In Air Force Projects, they used 365 days for a cost estimate less than $5 million, 540 days for an estimate between $5 and $20 million, and 730 days for an estimate greater than $20 million.

Skitmore and Thomas (2003) state that there are two common methods for estimating construction time and cost: According to the client's available budget and time constraints, the other is the detailed analysis of activities.

Construction duration estimations are made after either detailed design phase or pre-design stages. Both are required for different purposes. This estimation process is very important or the planning phase of construction. There are most common planning and controlling tools: Bar charts, CPM and PERT (which uses three time estimates –optimistic, most likely and pessimistic to achieve expected time for an activity) techniques. One of the most common disadvantages of these techniques is that they can be used after detailed designs. These methods follows known steps, such as; work break down structure, logical relations between activities, durations of work packages, the quantity of materials, productivity rates. These techniques require a lot of information and a big effort and they consist of many errors and accuracies. (Saraç, 1995) On the other hand, Helvacı (2008) points out that these techniques can also be used at the pre-design stages. However, accuracies of these estimates depend on the estimators' experiences. Therefore, it could be said that this process is intuitive. (Karslı, 1998). The modeling of construction duration approach tries to overcome this subjectivity of the estimating process. The initial step for duration estimation is searching for the factors affecting construction durations. Then, according to the type of modeling used, it could be possible to model construction durations.

2.1. Factors Affecting Construction Durations

Starting from the early 1970s, there are many researches into the factors influencing construction durations across various categories of projects for many reasons. The factors found by researchers as published in literature are summarized in Appendix-A in chronological order. The researcher either studied on only the factors affecting construction durations or developed duration estimation models by using these factors. Moreover, all findings of these researchers were summarized in Table 2.2 under seven main headings as: cost, client related, project related, environment related, construction site related, management related factors, and other factors.

Kumaraswamy and Chan (1995) investigated factors affecting construction duration in projects carried out in Hong Kong. Questionnaires were posted to 400 firms and 111 of them responded. The authors had two main aims for this work:

1. To search the relationships between Duration-Cost; Duration-Floor Area and Duration-Number of Floor; and to form an experimental relationship between them.
2. If any delays occurred, to find out their reasons.

The authors constructed a hierarchical chart (Figure 2.1) to show the factors affecting construction duration. This chart can be expanded to accommodate input for further research.

Kumaraswamy and Chan (1995) defined the duration as the function of all of these factors. The authors also underline this characteristic of a project as being unique from the point of view location, besides the architectural design of the building.

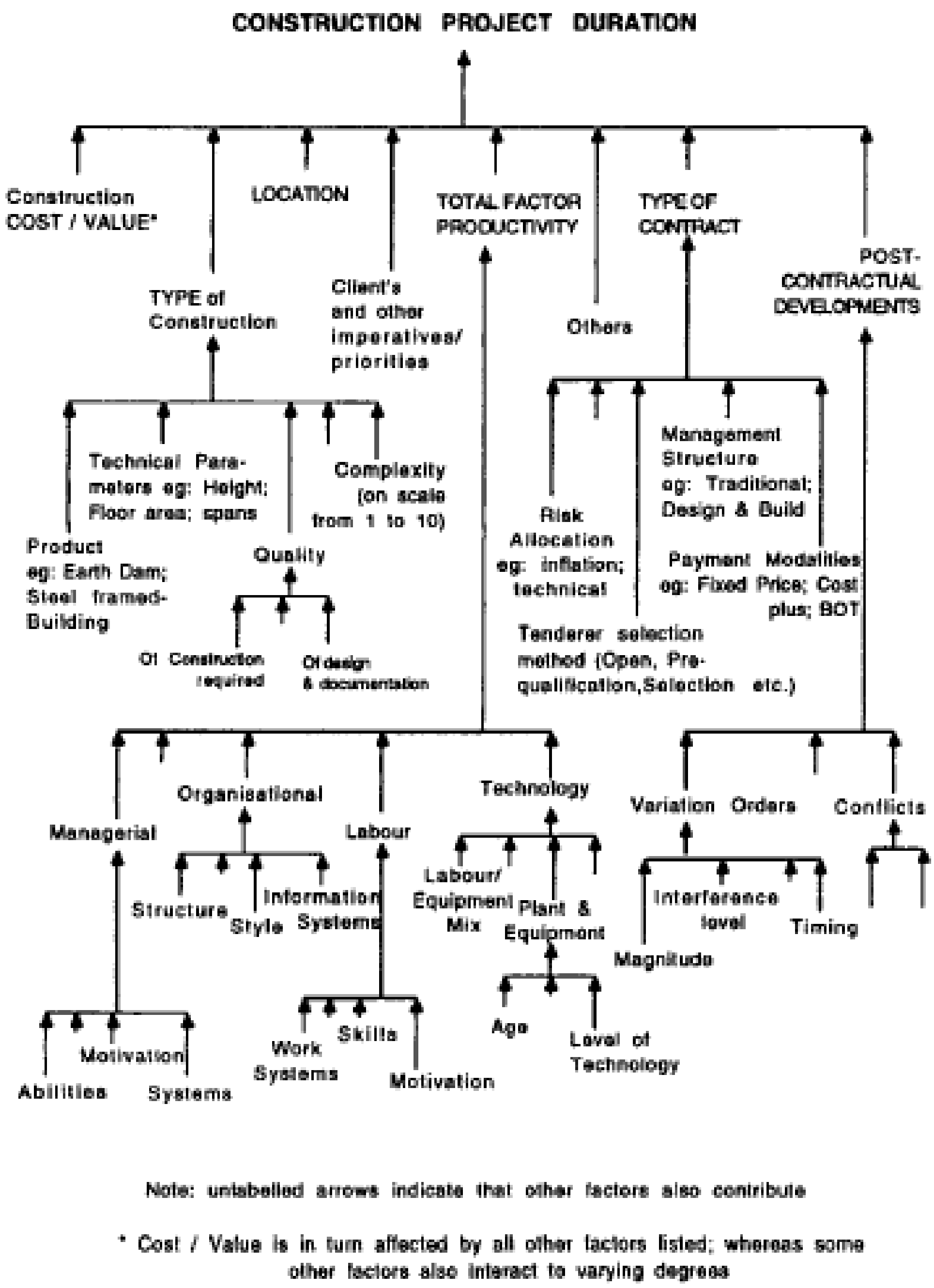


Figure 2.1. Factors affecting construction project duration.
(Chan and Kumaraswamy, 1995.)

Chan and Kumaraswamy (2002) classify time-influencing factors into four major factor categories, which are; project scope, project complexity, project environment; and management-related attributes. These factors are listed in Appendix-A and presented in Figure 2.2.

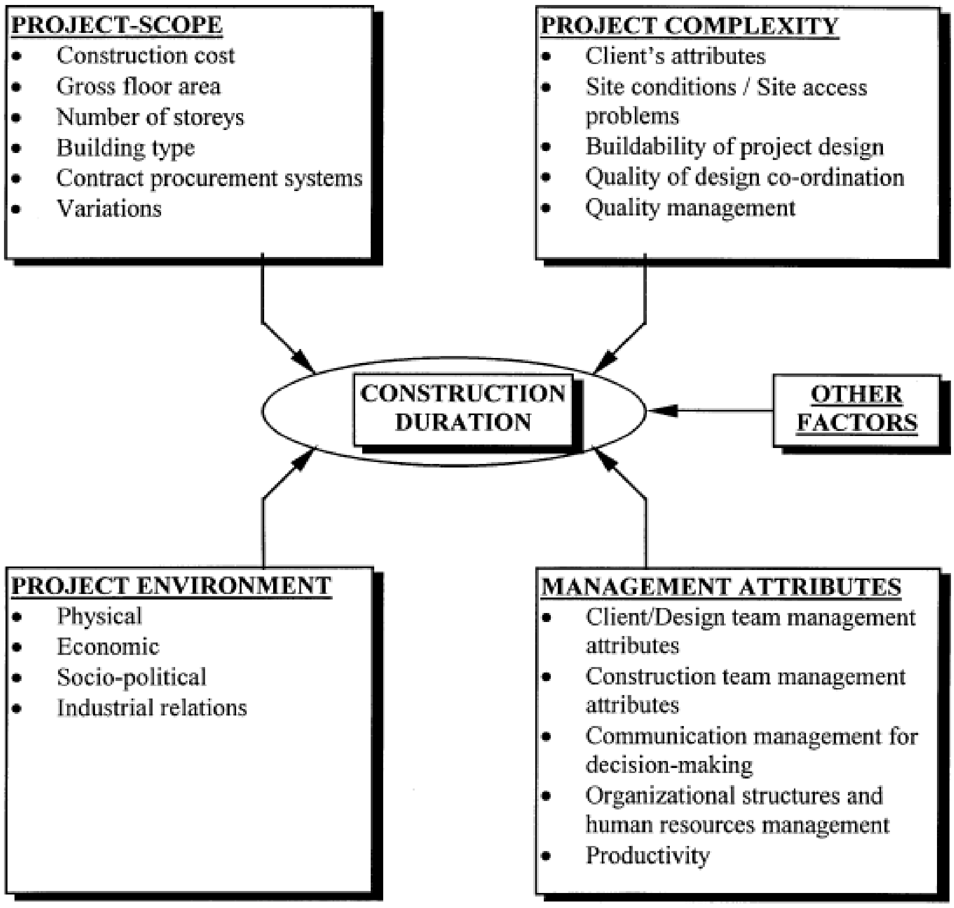


Figure 2.2. Factors affecting construction project duration.
(Chan and Kumaraswamy, 2002.)

The research findings affecting construction duration were summarized in Table 2.2 under seven headings:

1. Project Cost
2. Client or client representative related factors
3. Environment related factors
4. Construction site related factors
5. Project related factors
6. Management related factors
7. Other factors

Table 2.2 Factors affecting construction project duration (Summary Table)

FACTORS AFFECTING CONSTRUCTION DURATIONS

COST

CLIENT RELATED FACTORS

a. Client's experience
b. Type of client
c. Client's attributes

ENVIRONMENT RELATED FACTORS

a. Weather
b. Economic factors (restrictions)
c. Social factors (restrictions)
d. Cultural factors (restrictions)
e. Legal factors (restrictions)
f. Politic factors (restrictions)

CONSTRUCTION SITE RELATED FACTORS

a. Construction site conditions
b. Geographical
c. Whether or not restrictions or easements exist
d. Availability of services
e. Supply of resources
f. Use of major equipment
g. Productivity on site

OTHER FACTORS

a. Financial factors
b. General contractor related factors
c. Subcontractor related factors
d. Speed
e. Uncertainty
f. Engineering Design related factors
g. Experience

PROJECT RELATED FACTORS

a. Factors about project team/designer/design consultants (experience, etc.)
b. Factors about the project
  i. Type of construction
    1. Building type
      e.g. Earth dam; steel framed-building, whether office, retail or other, e.g. Churches
      Whether the building is purpose built or speculative
      New work or refurbishment of existing building
    2. Technical parameters
      e.g. Height, floor area, spans, size of project, gross floor area, form of construction
  ii. Quality of
    1. Construction required
    2. Design & documentation
      Project information completion
      Degree of standardization and mechanization, repetition of work
      Project changes
  iii. Complexity
    1. of construction required
    2. Buildability/constructability of project design

MANAGEMENT RELATED FACTORS

a. Managerial
  i. Abilities
  ii. Leadership and motivation
  iii. Systems
b. Priorities
  i. Client's priority on construction time
  ii. Designer's (project teams) priority on construction time
c. Organizational
  i. Structure
  ii. Style
  iii. Information Systems
  iv. Flexibility in organization
d. Contract related
  i. Type of contract
    1. Risk allocation (e.g., inflation, technical)
    2. Tenderer selection method (open, prequalification, selection etc)
    3. Management structure e.g.: traditional; design and build
    4. Payment modalities e.g.: fixed price; cost plus
  ii. Post contractual developments
    1. Variation Orders
    2. Orders
    3. Conflicts
e. Coordination/Relationships
f. Planning
g. Construction Management
h. Control systems
  i. Managerial control effectiveness
  ii. Contractor's control over site operations
  iii. Effectiveness of supervision
i. Procurement related factors
j. Technology
  i. Resources (Labor / equipment mix)
    1. On time material delivery
  ii. Labor
    1. Work systems
    2. Skills
    3. Motivation
    4. Productivity
    5. Labor relationships
  iii. Plant & equipment
    1. Age
    2. Level of technology
k. Management Attributes

That eleven factors affecting construction duration shown as the most significant ones in literature were selected. These factors were listed and explained as follows:

1. Cost
2. Cash flow
3. Productivity of on-site
4. Procurement
5. Project Related Factors
6. Technology and Methodology of Construction
7. Experience
8. Coordination
9. Weather
10. Construction site
11. The degree of completeness of design project

2.1.1. Cost

In the literature, the first duration modeling approach was the Bromilow's Time-Cost (BTC) Model. Bromilow (1974) developed a model by using cost parameter only. After BTC was developed, many researchers (Table 2.7) searched the validity of this equation. Moreover, there are many other researchers also used cost parameter in their models as a variable affecting construction duration, also (e.g. Boussabaine (2001), Chan and Kumaraswamy (1995, 1999), Walker (1995), Khosrowshahi and Kaka (1996), Skitmore and Thomas (2003), BCIS (2004), Chen and Huang (2006), Hoffman, Webb, and Weir (2007), Helvacı (2008), Bhokha and Ogunlana (1999)

Although most of the sources in the literature, (Chan and Kumaraswamy (1995), BCIS (2004), Chen and Huang (2006), etc.) the cost is an important factor, Love, Tse and Edwards (2005) state that cost is a poor indicator according to their studies. The authors studied 126 Australian construction projects to examine the project time and cost relationship by using project scope factors (e.g. project type, procurement method, tender type, gross floor area (GFA) and number of storey's. see. Appendix-B.1). The authors formed a Multiple Linear Regression Analysis and found that GFA and number of storey are key determinants of time performance in projects. Other important result is that cost is a poor indicator of time performance because it is not possible to know each cost before the work done. Although Love et al. found the cost parameter as an insignificant factor; they found BTC to be applicable with reasonable results, especially early phases. Helvacı (2008) also states that the duration estimation models can be built without using the cost parameter.

Additionally, some examples in literature show that cost does not affect duration. For example, if there are two villa projects having the same design and the only difference between them is the quality of materials. Their costs will be different from each other but their construction durations will not. On the other hand, two different construction projects having different cost values may take the same time to construct. Another possibility is that two different project having same cost values may take same time to construct because of the different working productivity or experience of different construction teams (Karslı, 1998). When any increase of cost occurs, construction duration does not also increase. (Şahmalı 2009) Moreover, Gören (1998) stated that using the qualified workmanship for preventing delays could cause increase the cost as well. Additionally, when the total project duration increases, general overhead cost also increases, it means cost also increases.

2.1.2. Cash Flow

Clients make a yearly payment plan of the project by using cost and duration estimations. Payment for construction works is made to the contractor(s) at designated time intervals. (Gören, 1998)

If there any insufficiency of cash flow exists, it may cause long-term unfinished construction projects or changing of hands to finish the project. If contractor is financially strong, he can continue to finish the work in the contract period by using his own finance as much as possible until he receives payment. He tries to continue his work without any interruptions. It causes delays in the work schedule and lost time. Contractors aiming to make profit can even lose money. (Gören, 1998)

Karslı (1998) stated that delays occur in more than the half of the projects that are run by housing cooperatives because of financial problems. Additionally, Gören (1998) explains the importance of right cost estimation on project duration. If cost estimation is wrong, investment will be insufficient and additional finance will be required. This unexpected financial problem can cause the interruptions or even stop the works.

2.1.3. Productivity of on-site

Productivity is important in all parts of the projects for all parties, for all employees. Especially on-site productivity affects the construction directly. Man-hours used in planning phases define the total construction duration. If the productivity of the workers decreases, it directly affects the speed of the construction works.

Chan and Kumaraswamy (1995-1998), Gören (1998), Karslı (1998), and Nkado (1995) define productivity as overall construction (site) productivity, and labor productivity. Chan and Kumaraswamy (1995) analyzed productivity as micro factors (such as construction site productivity) besides macro factors (project-specific characteristics such as building construction costs, gross floor area, and number of levels). Chan and Kumaraswamy (1998) added that lowered productivity could contribute significantly to project delays.

Chan and Kumaraswamy (1998) and Nkado (1995) listed factors affecting site productivity such as work space availability, attendance of operatives, learning curve, weather, labor relations, project complexity project buildability, foundation condition and effectiveness of supervision.

Karslı (1998) indicated that problems about productivity could be seen mostly in developing countries. The labors coming from rural areas have low salaries, which lowers productivity rates below expectations.

The solution is to find out the causes affecting productivity negatively and improve conditions to motivate employees such as: over-time pay, contribution for the special works, social activities, and to provide better living and working conditions (Kumaraswamy and Chan (1998), Karslı (1998) and Gören (1998)).

2.1.4. Procurement

Gören (1998) and Karslı (1998) pointed out that the importance of procurement related factors on project duration. Either the owner or the contractor takes care of procurement. Not only the materials, but also workmanship should be provided on time for the continuation of works. The aim is that the right amount of material should be available in good condition at the right time and at the right place in order to achieve good work progress. It can be possible with a proper procurement plan.

Dissanayaka and Kumaraswamy (1999) identified particular factors, which are significantly related to time and cost performance; to analyze the relationships of procurement and non-procurement related factors with time and cost performance; and to develop time and cost over-run models using critical factors influencing time and cost in Hong Kong. The authors grouped the factors affecting project performance into two main groups as procurement related factors (work packaging, functional grouping, payment modality, selection modality and conditions of contracts) and non-procurement related factors (factors related to project, factors related to client: client representative, factors related to designer, factors related to contractor, factors related to team performance and factors related to external conditions.) The authors found that although time over-runs affected by mainly non-procurement related factors (on design and construction complexity and variation levels), cost over-runs were affected by both procurement and non-procurement related factors.

Although, Dissanayaka and Kumaraswamy (1999) conclude that time performance was not affected by procurement related factors, there are many researches contradicting this conclusion. Saraç (1995) reported procurement factors affecting construction duration as follows according to the percentage of effects on duration as follows:

1. Delayed procurement of materials (15.5%)
2. Material Procurement being not according to specifications (6%)
3. Non-availability of requisite manpower with proper skill (4.5%)
4. Non-availability of appropriate equipment at the appropriate time (2.5%)
5. Inadequate facilities such as: (2%)
    a. Supply of water, electricity, etc.
    b. Sufficient housing for workers
    c. Recreational facilities
    d. Cafeteria (supply of food) near site.

2.1.5. Project-Related Factors

Project related factors are building type (hotel, hospital, villa, housing project, industrial building, etc.), design aspects (form, uniqueness, complexity of projects, etc.), technical parameters (Area, No Floor, Structure, etc.)

Nkado (1995), Saraç (1998), Gören (1998), Karslı (1998), Bhokha and Ogunlana (1999), and Chan and Kumaraswamy (1999-2002) pointed out the importance of building size and the height of the building (number of floors) as important factors affecting project duration. When the building size (gross floor area) increases, the construction duration will be longer. The reason is being that the size of the building affects the system of construction, the choice of materials that will be used, procurement system and the technology that will be used. Larger building projects require good project and management teams.

Nkado (1995), Saraç (1998), Gören (1998), Karslı (1998), Bhokha and Ogunlana (1999), and Chan and Kumaraswamy (1999, 2002) are agreed that complexity of project affects the duration also. If the level of complexity is low, the construction and the management will be easier. Actually, the complexity of the building is related with the project type (Karslı, 1998). For example, construction of a market building takes shorter time than a hospital building. It is also related with using similar details in projects, because of the standardization of project. (Gören, 1998 and Saraç, 1998) Additionally, Love et al. (2005) state that there is no single agreed way for defining complexity. The authors explained two handling methods for measuring the complexity. First way is using measures such as constructability, inherent site conditions, quality of design coordination, quality management procedures, and site access. The second defines complexity to be a large project.

Gören (1998) and Nkado (1995) also pointed out the effect of design project characteristics on duration, e.g., form of the plan can cause more excavation, more workmanship.

2.1.6. Technology and Methodology of Construction

Gören (1998) stated that usage of new technology, machinery, and materials causes increase in production rates and high quality products by arranging times effectively and reducing lay-off times. There are three types of construction technique. First type is low-tech (manual technique) which is based on workmanship; most of the main works are constructed on site. Hence, labor productivity gains importance. Second type is medium-tech (mechanized technology) which is used to decrease construction durations or to increase the construction speed; for example, using sliding forms to reduce construction time. Third type is high-tech (prefabricated building technique) where components of the building are produced beforehand and then erected on-site, thus, minimizing the duration. The relation between their production rates and construction durations of these three techniques are shown in Figure 2.3.

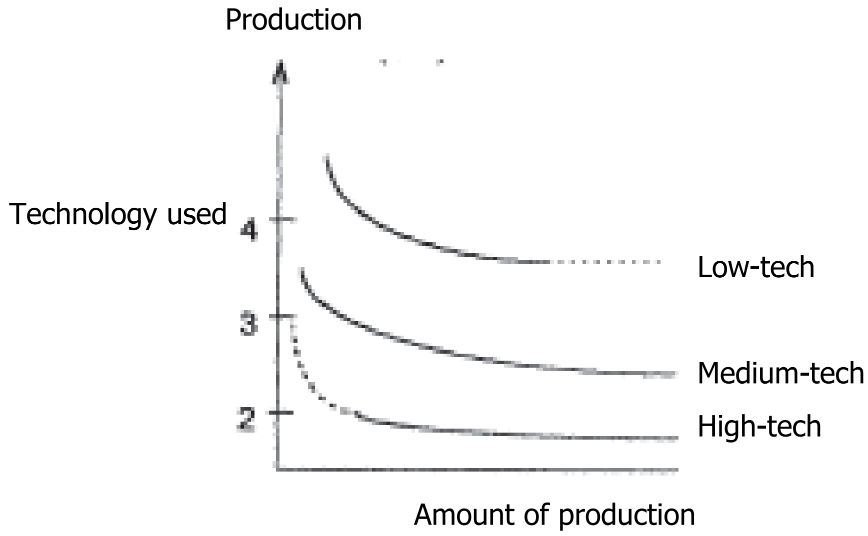


Figure 2.3. The relation between the production rates and construction durations according to the construction techniques. (Gören, 1998.)

Karslı (1998) also arrived at the same conclusions as Gören (1998) that the projects with minimum delays use developed conventional techniques or prefabrication techniques.

The method of construction affects the construction duration significantly, for example if 20 meter height wall is built, there is only way to build this wall i.e. bottom up. Therefore, duration of project could not be decreased because of the method of the construction. (Şahmalı, 2009)

2.1.7. Experience

Walker and Vines (2000), Saraç (1995), Gören (1998), Karslı (1998) emphasize the importance of experience on duration. Experience on similar projects reduces errors and so decreases or even totally eliminate reworks, hence reducing the total construction duration.

Karslı (1998) described the importance of client experience. Especially clients of commercial projects know what their requirements are, so they can give their decisions quickly because of the repetitions of their works. The author also added the importance of contractor's experience. If the contractor has executed similar projects before, he is familiar with the works and does not repeat mistakes. This leads to shortening of the duration

Karslı (1998) and Gören (1998) pointed out that the experience of team members with different parties for design, construction, or management group is valuable in reducing delays. Walker and Vines (2000) studied on factors affecting construction durations of multi-unit housing projects in Australia. The authors found experience as an important factor besides, management quality, environmental factors, and coordination.

2.1.8. Coordination

In every sector, communication between all parties has an important role for the progress of work. Especially in the construction sector, there are many parties coming together for the completion of the project, communication management is critically important between the design team, construction team of contractor subcontractor and consultant firms, suppliers, management teams, and the client's agent. It also affects the motivation of all the employees. Nkado (1995), Chan and Kumaraswamy (1999-2002), Karslı (1998) and Walker and Vines (2000) emphasized the importance of the development of coordination between these various agencies involved in the construction for construction duration estimation.

2.1.9. Weather

Local weather conditions determine the duration also as working periods are defined according to seasonal conditions. For example, if a project starts in Ankara in December, the actual construction of this project will most probably start after 3 to 4 months. Saraç (1995), Kaming (1997), Karslı (1998), Gören (1998), Dissanayaka and Kumaraswamy (1999), Walker and Vines (2000), Chan and Kumaraswamy (2002) all agree that weather conditions affect construction duration.

Gören (1998) states that bad weather can interrupt or abort the works; cause decrease in production rate and quality of works, so the work has to be done again. This kind of delays cause increase in cost since labor and equipments lay idle. The author pointed out that if the weather effects are taken into consideration properly while preparing the working schedule, these losses can be prevented. The effects of weather on construction process and amount of works were shown in Figure 2.4.

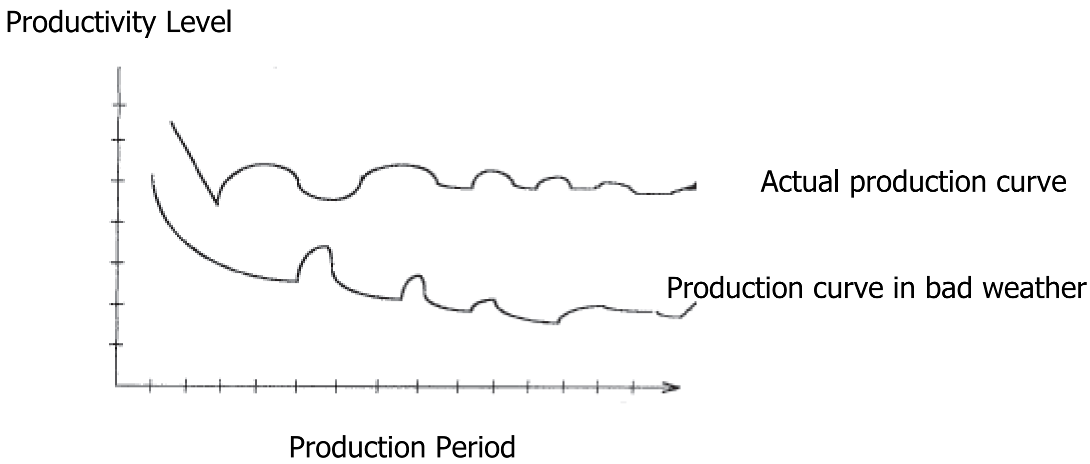


Figure 2.4. The effects of weather on productivity of steel constructions.
(Gören. 1998.)

2.1.10. Construction Site

Chan and Kumaraswamy (1995), Saraç (1995), Gören (1998), Karslı (1998) and Bhokha and Ogunlana (1999) all state that the location of a building has a significant effect on construction duration, i.e. whether or not restrictions or easements exist, and if availability of services, supply of resources, use of major equipment and productivity on site, the accessibility to the site exists. Moreover, construction site conditions, e.g. topography, ground conditions, and the size of the construction site also affects the duration of construction. For example, according to the site conditions, different machinery will be required for either excavations or back fills; these additional steps can cause delays or the large size of the site can decrease the speed of constructions. Finally, no matter what size of construction the required construction site arrangement should be done in a logical way, i.e. site office, storage, shelter for labors, dining hall, etc. should be arranged to facilitate transportation (optimum duration for vertical and horizontal transportation between storage, site and supplier).

Karslı (1998) and Saraç (1995) state that all the decisions are given according to the location of the project: whether a project is in the country or abroad. The condition at location requires a detailed analysis for executing the work; e.g. economic and commercial, such as, interest rate, exchange rate, personnel wages, material costs; social and cultural; legal-political, e.g., traditions, legal and religious holiday and working hours; and technical, etc.

2.1.11. The Degree of Completeness of Design Project

Nkado (1995), Gören (1998), Saraç (1995), and Karslı (1998) agreed that the degree of completeness and precision of project information is very important for project duration. Firstly, this can be affected from the design changes. Any changes in the original design may not be communicated to construction site. This affects construction resource program, cash flow, and material procurement program, therefore, uncertainty of projects can cause delays. Secondly, the details should be completed in project stage for the continuation of project. Finally, the project should meet with the requirement of client.

Saraç (1995) explained the reasons of completion ahead of the schedule, although this situation exists rarely. These are summarized factors affecting construction duration also as follows:

1. The urgency from the client's side
2. The bonus announced by the client
3. Higher safety factor in the allocation of time

4. Procurement of material on or ahead of schedule
5. Previous experience in similar projects
6. Use of modern machinery
7. Employment of more than the estimated number of skilled workers
8. The number of workers employed was the same as that of estimated one, but the level of skill was higher than average.
9. The number of workers employed was less that of the estimated one, but the level of efficiency was much higher
10. The size of the project was reduced
11. The design and drawings were simplified before or during construction
12. Effective coordination of different activities
13. High motivation due to harmonious supervisor and worker relationship

2.2. Duration Estimation Modeling for Construction Projects

Sezgin (2003); Kanoğlu (2003); and Akintoye and Fitzgerald (2000) defined the types of duration and cost estimation models or techniques into four groups;

1. Experienced based models that use algorithms, heuristics, and expert system programming.
2. Simulation models that use heuristics, expert models, and decision rules.
3. Parametric models that use regression, Bayesian, statistical models, and decision rules.
4. Discrete state models that use linear programming, classical optimization, network, PERT, and CPM.

Studies found in literature have been grouped according to this classification and their details are summarized in Appendix B. Some of these studies have been selected as representative models to be explained in detail in the following section.

It should be noted that although simulation models are mentioned in literature only two papers could be traced but could not be accessed from available sources.

Khosrowshahi and Kaka (1996) stated that project cost and duration estimation concept interest could be seen from the late 1960's. In 1968, the Division of Building of Research of the Commonwealth Scientific and Industrial Research Organization in Melbourne studied on the project duration and cost by comparing the actual and estimated ones. According to results actual durations are, on average, 40% more than estimated durations. The importance of prediction of project cost and duration increased during the 1970s and 1980s.

During the second part of the 1980s, artificial neural network a new approach to the estimation of project cost and duration was drawn attention because of its potentials. Since late 1980s, with the consideration of this forecasting /estimation /prediction are a science of approximation, the expectation from the models was low. Other branches of Artificial intelligence (especially Artificial Neural Network) were seen as an alternative search for duration and cost prediction with their ability to learn from experience and a very big number of data. After a while, other forms of Artificial Intelligence like genetic algorithms and hybrid of alternative techniques were started to search. There was a note that these innovations were not the product of market pull, rather the product of technology push. This note actually enlightened the traditional characteristic of construction sector.

The studies of construction duration estimation models names' and their classification according to Fitzgerald according to years were shown in Table 2.3. According to this chart, it can be seen that the studies were done in foreign countries more; by years, the modeling studies have increased and regression analysis method was applied more than other models.

Table 2.3. Duration estimation models' development.

Year	Author	Model
1974	Bromilow, F.J. **(Australia)**	**Parametric**(Power of Regression)
1979	R.I. Carr	**Simulation**
1985	Ireland, V. **(Australia)**	**Parametric** (Multiple Linear Regression Analysis)
	Ahuja HN, Nandakumar V.	**Simulation**
1990	Moselhi, O. and Nicholas, M. J.**(Canada)**	**Experience-based** (Hybrid Expert System - (ESCHEDULER))
1991	Kaka, A. and Price A. D. F. **(UK)**	**Parametric** (Regression Model)
1992	Nkado, R. N. **(UK)**	**Parametric** (Multiple Linear Regression Analysis)
1994	Wu, R. W. and Hadipriono, F. C. **(USA)**	**Experience-based** (Fuzzy Logic- Expert System (ADDSS))
1995	Kumaraswamy, M. M. and Chan, D. W. M. **(Hong Kong)**	**Parametric** (Simple Linear Regression Analysis)
	Chan, D. W. M. and Kumaraswamy, M. M. **(Hong Kong)**	**Parametric** (2 Simple and 1 Multiple Lin. Reg.Analysis)
	Walker, D. H. T. **(Australia)**	**Parametric** (Multiple Linear Regression Analysis)
	Saraç, S. **(Turkey)**	**Parametric** (Linear Regression Analysis)
1996	Khosrowshahi, F. and Kaka, A. P. **(UK)**	**Parametric** (Multiple Linear Regression Analysis)
1999	Chan, D. W. M. and Kumaraswamy, M. M. **(Hong Kong)**	**Parametric** (Multiple Linear Regression Analysis)
	Chan, D. W. M. and Kumaraswamy, M. M. **(Hong Kong)**	**Parametric** (Multiple Linear Regression Analysis)
	Dissanayaka, S. M. and Kumaraswamy, M. M. **(Hong Kong)**	**Parametric** (Multiple Linear Regression Analysis)
	Dissanayaka, S. M. and Kumaraswamy, M. M. **(Hong Kong)**	**Parametric** (Multiple Linear Regression Analysis)
	Bhokha, S. and Ogunlana, S. O. **(Thailand)**	**Discrete State** (Artificial Neural Network)
	Dissanayaka, S. M. and Kumaraswamy, M. M. **(Hong Kong)**	**Discrete State** (Artificial Neural Network)
2001	Boussabaine, A. H. **(UK)**	**Experience-based** (Neurofuzzy Model)
	Blyth, K., Lewis, J. and Kaka, A. **(England)**	**Parametric** (Multiple Linear Regression Analysis)
2003	Kanoğlu, A. **(Turkey)**	**Experience-based** (Performance Based Duration Estimation Model - Expert System Intehrated System (SPIDER))
	Skitmore, R. M. and Thomas Ng, S. **(Australia & Hong Kong)**	**Parametric** (Regression Analysis)
2004	BCIS **(UK-London)**	**Parametric** (Multiple Linear Regression Analysis)
2005	Kumar, V. S. S. and Reddy, G. C. S. **(India)**	**Experience-based** (Fuzzy Logic)
	Love, P. E. D., Tse, R. Y. C. and Edwards, D. J. **(Australia, Hong Kong and U.K.)**	**Parametric** (Multiple Linear Regression Analysis)
2006	Chen, W. T. and Huang, Y. **(Taiwan)**	**Parametric** (Multiple Linear Regression Analysis)
2007	Hoffman, G. J., Jr., A. E. T., Webb, T. S. and Weir, J. D. **(USA)**	**Parametric** (Multiple Linear Regression Analysis)
2008	Helvacı, A. **(Turkey)**	**Parametric** (Multiple and Simple Linear Regression Analysis) & **Discrete State** (ANN)

2.2.1. Experience-Based Models

(Experience-Based Models that use algorithms, heuristics, expert system programming, and fuzzy logic)

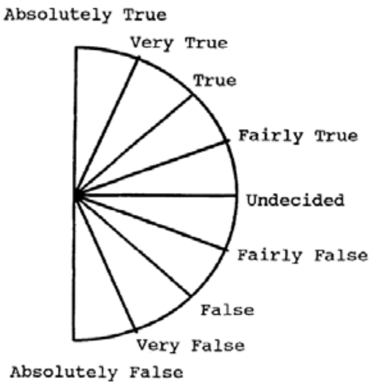
Wu and Hadipriono (1994)'s and Kumar and Reddy (2005) studies using Fuzzy Logic is explained in detail as an example of an experience-based model in the following paragraphs.

Wu and Hadipriono (1994) developed a fuzzy-logic model for duration estimation. The authors classified the factors affecting activity durations in their models into six main groups. These are; site condition, equipment performance, labor performance, weather conditions, material supply, and management performance. The basic steps of this model are based on the trigonometric calculations, which are integrated into the SuperProject software.

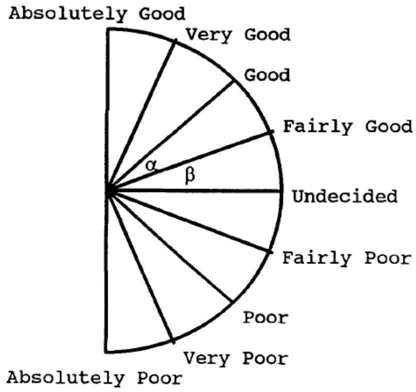
The authors point out that activity durations for construction programming are determined by the estimators or the planning department based on their experiences. Uniqueness of the project is not taken into consideration in such estimations services; the authors suggest a fuzzy logic model to fill this gap.

The name of the model is Activity Duration Decision Support System (ADDSS), which was developed by means of calculating the factors affecting the activity durations using fuzzy logic. In this model which was used by Hadipriono and Sun (1990) the factors that affected construction duration activities were converted from the linguistic values to numerical values.

The ADDSS model was developed to decrease the risk of making wrong decisions by means of using the potential factors affecting activity durations by planners while estimating the activity durations. ADDSS is based on a fast evaluation of giving the linguistic values to the factors affecting activity duration as "very good" or "poor." These linguistic values were changed to mathematical expressions by using trigonometric calculation methods according to angular fuzzy logic theory. The linguistic values related to truth and performance values are seen in Figure 2.5. For example, "absolutely true" equals to π /2; "absolutely wrong" equals to - π /2.



Angular Fuzzy Set Models
for Truth Values



Angular Fuzzy Set Models
for Performance Values

Figure 2.5. Angular fuzzy set models for truth and performance values.
(Wu and Hadipriono, 1994.)

This model was related to the CA-SuperProject, which is planning and programming software. The steps of the developed model are as follows:

1. The data about activities is transferred from CA-SuperProject to ADDSS.
2. The decision maker can change whether only one activity or all of the activities will be used as the inputs and whether or not to use these six factors affecting activity duration.
3. Application decisions were formed by estimators' intuitive decisions on each factor. For example, if site condition is "good", we can be optimistic about the estimated time of the activity.
4. Optimistic or pessimistic values are chosen by decision maker's decisions about each factor's effectiveness on the duration. For example, the construction site may be considerably flat area, but it may require cleaning. For this reason, a decision maker can evaluate the site as "very good" or "good" or "fairly good", after investigating the site.
5. By using the equations developed in accordance with Angular fuzzy logic, the weighted values, which will be used in optimistic calculation, are defined.
6. The mathematical processes of optimistic and pessimistic durations are calculated by using these weighted values obtained from the previous step.
7. Rearranged data is saved as a new data and transferred to CA-SuperProject.

Wu and Hadipriono (1994) tested this model on the construction of the foundations of Ohio University library building and obtained realistic results. However, in this model, which is highly influenced by the decision makers, the results may change according to the in personal experience.

Kumar and Reddy (2005) also developed model by using fuzzy-logic theory invented in 1965 by Zadeh. The authors also emphasized the importance of projects' own characteristics for more accurate duration estimations as Wu and Hadipriono. Kumar and Reddy (2005) developed this model for achieving this objective to estimate the project parameters by incorporating the qualitative and quantitative factors for each activities using fuzzy logic approach.

After analyzing the project activities, appropriate qualitative (linguistic) factors affecting the each construction activity duration were applied, such as, weather conditions; labor and engineer experience, productivity, type of equipment used. The qualitative (linguistic) variables were converted to mathematical values by giving membership values to show the effect of factors on activity.

The steps of the developed model are as follows:

1. The detailed activity list was prepared with their start $S_{(j)}$ and finish node $E_{(j)}$ in a topological manner. Table 2.4 shows a part of a project activity list.
2. Qualitative factors affecting each activity were analyzed by estimators. For example, the frequency of being bad weather is small; its effect on activity duration is large. Table 2.5 shows the qualitative factors, frequencies, and consequences for an activity as an example. The nominal durations of activities are converted to an appropriate range to apply the qualitative factors
    - Weather conditions [bad (B); medium (M); good (G)]
    - Labor experience [high (H), medium (M), low (L)]
    - The engineer's experience [highly experienced (HE), moderately experienced (ME)]

Table 2.4. Project activities. (Kumar and Reddy, 2005.)

S. No (1)	Description (2)	Activity (3)	S (j) (4)	F(j) (5)
1	Preparation of layout	A	1	2
2	Approval of layout plan by RDSO	B	2	3
3	Preparation of detailed structural drawing	C	4	5
4	Procurement of materials	D	4	7
5	Fabrication of steel structure for shed	F	5	6
6	Erection of columns and trusses	F	6	19
7	Tender for office block, DG set and storage sheds	G	4	7
8	Construction of office blocks, DG set and storage sheds	H	7	8
9	Provision of external services	I	8	19
10	Finalization of laboratory equipment by RDSO	J	4	9
11	Placing order for equipment	K	9	10
12	Supply of laboratory equipment at site	L	10	11
13	Casting of equipment foundations	M	11	12
14	Installation of laboratory equipment	N	12	13
15	Testing of laboratory equipment	O	13	19
16	Recruitment of manpower	P	12	14
17	Training of manpower	Q	14	19
18	Tender for curing tanks	R	4	15
19	Construction of curing tanks	S	15	19
20	Tender for steam curing	T	4	16
21	Construction of steam curing tanks	U	16	17
22	Provision of steam mains	V	17	18
23	Testing of boiler	W	18	19
24	Trial production	X	19	20
25	Inspection of RDSO	Y	20	21

Table 2.5. Qualitative description of frequency of occurrence and consequences. (Kumar and Reddy, 2005.)

S. No (1)	Qualitative Factor (2)	Freq. of Occurrence (F) (3)	Adverse Consequences on Duration (C) (4)
1	Weather Conditions (B)	Small	Large
2	Weather Conditions (M)	Medium	Small
3	Weather Conditions (G)	Medium	Very Small
4	Engineer's Experience (ME)	Very Small	Small
5	Engineer's Experience (HE)	Excellent	Quite Small

3. After analyzing the qualitative factors effects' on activities, the duration of activities were calculated by using fuzzy relation and composition rules. Table 2.6 shows the subjective estimation of activity durations. An example from Table 2.6, in the first row, 0.04 is the membership value of the total effect of qualitative factors on duration 61 days for a frequency 0.00.

Table 2.6. Composition of R and T. (Kumar and Reddy, 2005.)

T o R =

	Duration	61	63	65	Sum	Product
Frequency	0.0	0.04	0.64	1.00	1.68	0.000
	0.1	0.04	0.64	0.90	1.58	0.158
	0.2	0.04	0.50	0.50	1.04	0.208
	0.3	0.00	0.00	0.00	0.00	0.000
	0.4	0.00	0.00	0.00	0.00	0.000
	0.5	0.00	0.00	0.00	0.00	0.000
	0.6	0.00	0.00	0.00	0.00	0.000
	0.7	0.00	0.00	0.00	0.00	0.000
	0.8	0.00	0.00	0.00	0.00	0.000
	0.9	0.00	0.00	0.00	0.00	0.000
	1.0	0.00	0.00	0.00	0.00	0.000

The 3rd row, which gives maximum value of product of the row summation, was called subset "D" to explain the fuzzy representation:

P(D=61)=0.04/(0.04+0.50+0.50) = 0.038
P(D=63)=0.50/(0.04+0.50+0.50) = 0.480
P(D=65)=0.50/(0.04+0.50+0.50) = 0.480

The mean, the standard deviation and coefficient of variation of an activity was explained as follows:

d = 61x0.038 + 63x0.48 + 65x0.48 = 63.758days
$\sigma_d^2 = 61^2x0.038 + 63^2x0.48 + 65^2x0.48 =-63.758^2 = 9.436$
σ_d = 3.070days; and COV=3.070 / 63.758=0.048

4. Simulation process: To simulate, activity durations in days were entered to the activity list. simulation procedure was applied, using mean and standard deviation as derived from fuzzy set analysis After simulation; TMIN, critical activities; critical paths, average duration, and standard deviation were found.

There are 4 steps for computational procedure to simulate an activity network:
1) GENRAT : For generating random samples of activity durations
2) FWDPAS : For conducting a forward pass
3) BWDPAS : For a backward pass and identification of critical activities
4) HSTGRM : For putting TMIN's into various ranges for the purpose of histogram

5. Criticality index: Criticality index value shows how many times an activity was critical in running processes. For example, if an activity a is on a critical path, 200 times out of 1000 simulation runs, then the criticality index of a is 0.20. Criticality index of each activity and total project duration of various simulation runs were calculated. At the end of simulation, criticality indices of activities were calculated. The critical path and near critical paths were determined.

The following results were achieved:

1. Kumar and Reddy (2005) tested their models on a prestressed concrete sleeper factory construction in India and obtained almost same results as compared with those obtained from conventional techniques.
2. While in conventional techniques, experts calculate the pessimistic, optimistic and most likely durations, in fuzzy logic analysis broad ranges were given for activity durations. This model opens to use intangible and subjective values.
3. In conventional methods, expert's decision could not be traced, however, with fuzzy logic application; all the steps evaluating the factors on activities could be followed.
4. It is a big advantage of this model that it is not sensitive to small variations of membership values. However, it is sensitive to the fuzzy relation between chosen activity duration and consequence
5. This model enables to get the criticality indices of the activities. In addition, potential critical activities could be seen. Critical path and near critical paths can be seen to be different from PERT.
6. Fuzzy logic reduces the fuzziness in achieving the project completion time.
7. Activity duration uncertainty is converted into mathematical measures by using fuzzy relation and composition rules.

2.2.2. Parametric Models

(Parametric Models that use regression, Bayesian, statistical models, and decision rules)

It seems that parametric models are the most popular ones for forecasting construction duration. Most studies reported in literature use parametric models. According to Morgenshtern (2007), "Parametric models are the models that use historical data to identify the main factors affecting time and effort estimations."

When parametric models are studied, it is seen that regression models are used widely. Regression analysis is used to express a dependent variable (y) in terms of the independent variables x_1, x_2 … x_n for investigating the functional relationship between a dependent variable and one or more independent variables. The equation representation is as follows:

$Y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \ldots + \alpha_n X_n$ .... (Eq.2.1)

Where,

Y=dependent variable

α_0=regression constant

$\alpha_{1,2,3......10}$=partial regression coefficient of $X_{1,2,3....10}$

$X_{1,2,3.....10}$=independent variables

Helvacı (2008) explained the aims of regression analysis as follows:

1. "To determine whether a relationship exists between the variables or not
2. To describe the relationship in terms of a mathematical equation
3. To evaluate the accuracy of prediction achieved by the regression equation
4. To evaluate the relative importance of independent variables in terms of their contribution to variation in the dependent variable"

A simple linear regression (with one independent variable), a multiple linear regression (more than one independent variable), or nonlinear regression analysis can be formed.

Helvacı (2008) emphasizes that it is better to form a parsimonious model that is developed with significant variables (without using unnecessary variables) with adequate fit for multiple linear regression analysis.

Additionally, it is found that there are two types of parametric models. These are time-cost models and other parametric models as Helvacı (2008) also has examined. These are presented in the following section.

2.2.2.1. Time-Cost Models

In Time-Cost Models as implied by its name, duration is calculated by using only the cost factor of a project. The best-known time-cost model is Bromilow's Time-Cost (BTC) Model.

Bromilow is considered to be a pioneer in this field, his model is based on the power of regression formula that is:

$$T=KC^B \text{ .... (Eq.2.2)}$$

Where,

T=duration of construction period from date of site possession to practical completion in working days;

K=constant describing the general level of time performance for a million of AUD project; and

C=final cost of building in millions of AUD adjusted to cost indices

B=constant describing how the time performance is affected by project size as measured by cost.

Bromilow (1974) used this power of regression model ($T=KC^B$) by examining 329 Australian building projects which were constructed between June 1964 to June 1967.

Then, In 1980, Bromilow re-applied the BTC model on 408 Australian building projects completed between 1970 to 1976 to find out if it still holds or not. He found this model to be still valid and applicable.

Table 2.7. Validation researches for the BTC Model.

No	Author	Year of Study	Country of Project Surveyed	Number of Cases	Type of Projects	$T=KC^B$	K	B	R	R^2	Adjusted R^2
A	Bromilow	1969	Australia	329	Building Projects (1964-1967)	$T=350C^{0.30}$	350	0.30	-	-	-
B	Bromilow	1980	Australia	408	Building Projects (1970-1976)	$T=219C^{0.37}$	219	0.37	-	-	-
				290	Government Building						
				118	Private building						
1.	Ireland	1983	Australia	25	High rise commercial building projects	$T=219C^{0.47}$	219	0.47	0.76		
2.	Kaka and Price	1991	UK	661	Building Projects (1984-1989)						
				140	Road Projects (1984-1989)						
					Road Contracts-fixed	$T=258C^{0.469}$	258	0.469	0.84	-	-
					Road Contracts-index	$T=436C^{0.437}$	436	0.437	-	-	-
					Public Buildings-fixed	$T=398C^{0.317}$	398	0.317	0.76	-	-
					Public Buildings-index	$T=486C^{0.205}$	486	0.205	0.68	-	-
					Private Buildings-fixed	$T=274C^{0.212}$	274	0.212	0.49	-	-
					Private Buildings-index	$T=491C^{0.82}$	491	0.82	0.61	-	-
3.	Yeong	1994	Australia	87	Projects						
	**model at 0,00 level of significance			20	Private building	$T=161C^{0.367}$	161	0.367	-	-	-
				67	Government Building	$T=287C^{0.237}$	287	0.237	-	-	-
					All Buildings	$T=269C^{0.215}$	269	0.215	-	-	-
4.	Kumaraswamy and Chan	1995	Hong Kong								
					Government Building	$T=188C^{0.259}$	188	0.259	0.81	-	-
					Private Building	$T=206C^{0.200}$	206	0.200	0.71	-	-
					Civil Engineering	$T=250C^{0.206}$	250	0.206	0.79	-	-
5.	Chan	1999	Hong Kong	110	Building Projects (late 1980's-early 1990's)						
					Private Building	$T=120C^{0.34}$	120	0.34	0.85	-	-
					Public Building	$T=166C^{0.28}$	166	0.28	0.95	-	-
6.	Ng, S. T., Mak, M. M. Y., Skitmore, R. M. and Varnam, M.,	2001	Australia	93	Projects						
				26	industrial projects	$T=96.83C^{0.362}$	96.83	0.362	-	0.810	-
				67	non-industrial projects	$T=152.46C^{0.274}$	152.46	0.274	-	0.538	-
					All Projects	$T=130.86C^{0.311}$	130.86	0.311	-	0.588	-
7.	Chan, Albert P.C.	2001	Malaysia	51	Public Building Projects	$T=269C^{0.32}$	269	0.32	0.638	0.407	0.395
8.	Yousef, G. and Baccarini, D.	2001	Australia	46	Sewerage Projects	$T=158.85C^{0.5367}$	158.85	0.5367	0.9106	-	-
9.	Choudhury, I. and Rajan, S. S.	2003	Texas	55	Residential Projects	$T=18.96C^{0.39}$	18.96	0.39	-	0.7449	0.7401
10.	Love, P. E. D., Tse, R. Y. C. and Edwards, D. J.	2005	Australia	161	Building Projects						
				90	New Build		-	-	-	-	0.589
				43	Refurbishment/Renovation		-	-	-	-	0.574
				14	Fit out		-	-	-	-	0.589
				11	New Build/Refurbishment		-	-	-	-	0.568
11.	Ogunsemi, D. R. and Jagboro, G. O.	2006	Nigeria	87	Building Projects (1991-2000)						
				32	Private Building	$T=55C^{0.567}$	55	0.312	0.567	0.322	0.293
				55	Public Building	$T=69C^{0.255}$	69	0.255	0.443	0.196	0.177
					All Projects	$T=63C^{0.262}$	63	0.262	0.453	0.205	0.193
12.	Hoffman, G. J., Jr., A. E. T., Webb, T. S. and Weir, J. D.	2007	USA	856	Air Force Buildings -facility projects (1988-2004)	$T=26.8C^{0.202}$	26.8	0.202	-	0.337	-
13.	Helvacı A.	2008	USA	17	Continuing Care Retirement Projects (CCRP) (1975-1995)	$T=21C^{0.32}$	21	0.32	0.77	0.59	0.56

Many researchers, have examined whether the equation still holds or not for validation purpose of the BTC Model because of being the pioneer of duration estimation models. Information on these studies is listed in Table 2.7.

Ng, Mak, Skitmore and Varnam (2001) made two different BTC models for 26 industrial and 67 non-industrial Australian construction projects by using BTC Model. Authors stated that construction speed had improved until Bromilow by comparing K and B values of previous researches using BTC model. Ng et al. explained, "B is a constant that describes how the time performance was affected by project size as measured by cost. A larger value for B implies a longer construction time for larger projects. K is a constant describing the general level of time performance for one million AUD project."

2.2.2.2. Other Parametric Models

Other parametric models have been developed by using factors affecting construction duration with or without cost variable. The Building Construction Duration Calculator (BCDC) developed by the Building Cost Information Service (BCIS) in 2004 and models used by Helvacı (2008) are explained in detail in the following paragraph.

BCIS has investigated 1500 new build building projects completed between 1998 and 2002 in the UK and used a multiple linear regression analysis to estimate the construction durations. The six parameters, which were the independent variables in the regression analysis, were as follows: procurement route, contractor selection method, client type, building function, region, and value. (See Figure 2.6 and Table 2.8)

BCIS Model uses adjusted value of cost based on the 2003-2nd quarter index. This adjusted value is calculated by location and year indices for U.K. and these values are used Log Contract Sum Squared to calculate which is squared value for the log of the contract sum. The independent variable is then used as the square root of the construction duration. (See Figure 2.7)

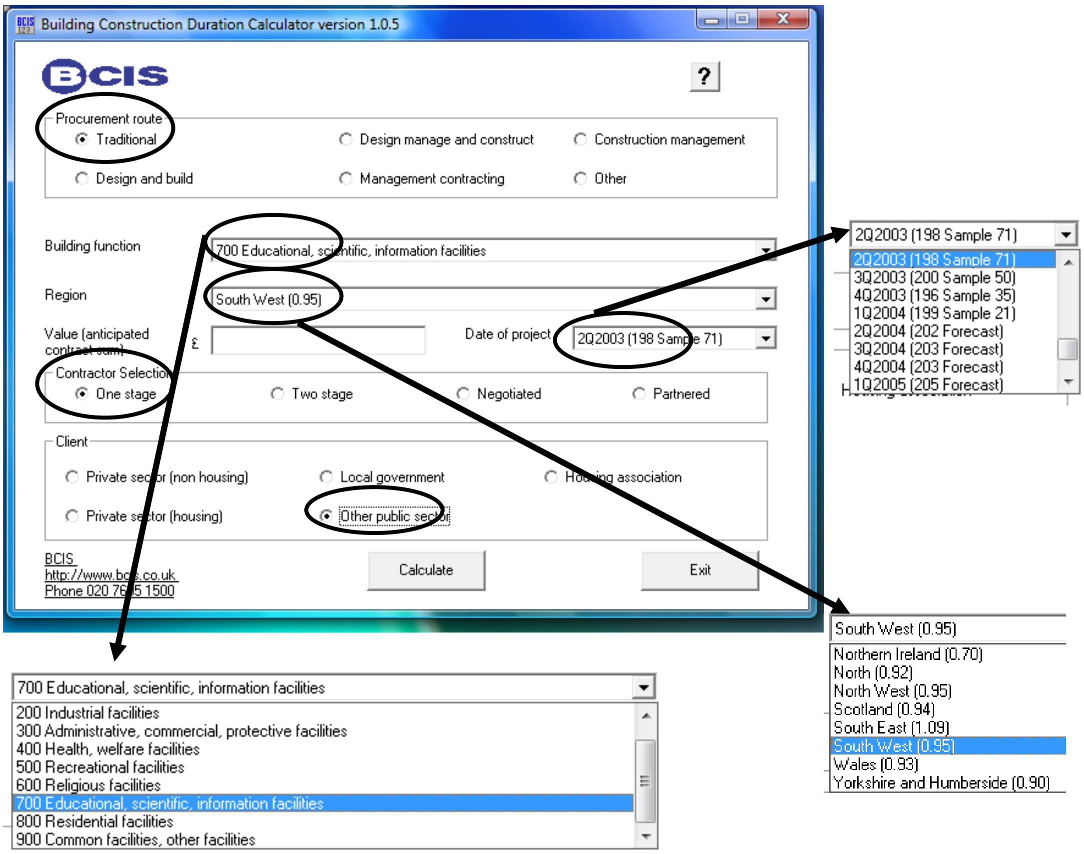


Figure 2.6. BCDC version 1.05 (Screen shot)

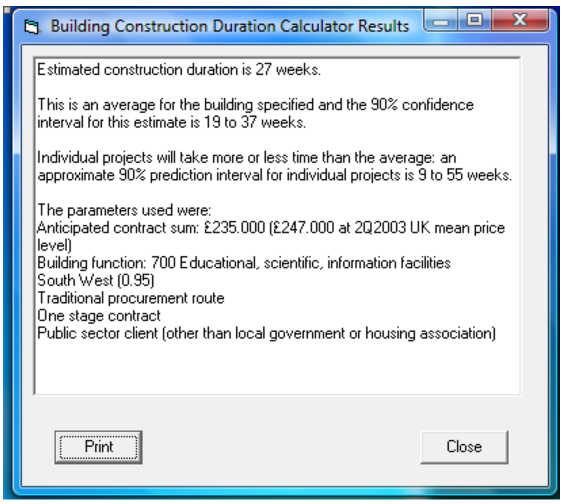


Figure 2.7. BCDC version 1.05 (Screen shot with result page)

The following statistical tests were applied to the data:

- ANOVA (Analysis of variance): to confirm the validity of the results
- SE (Standard Error): to measure of the accuracy with which the coefficient has been measured
- Significance *t*-test: to test whether an independent variable has added anything to the model

Results (Table.2.8) obtained from these tests suggest that:

1. A clear and significant relationship exists between construction duration and total construction cost
2. Housing projects tend to take longer than other schemes of the same value for both public and private sectors, while industrial building projects are completed more quickly; non housing projects above £750,000 for private clients tend to be completed faster than those for public sector clients, although this may well reflect the amount of industrial buildings in the private sector sample
3. The method of contractor selection does not seem to significantly influence the speed of construction.
4. Complexity and design influences the time it takes to build
5. The analyses by location probably reflects the differing mix of projects in each region
6. Projects tendered on a traditional lump sum basis up to £550,000 and design and build projects over £1,3 million, tend to be completed more quickly than other projects.
7. Projects between £750,000 and £10million show a consistent relationship between the log of the cost and durations *i.e.* The spending rate accelerates as the cost increases at a definable rate; for smaller and larger projects, below £200,000 and above £7 million, the change in construction duration is much less marked.

Table 2.8. Results of the multiple linear regression model. (BCIS, 2004.)

	Unstandardised Coefficients			
	B	Standard Error	t	Significance
Project Variables				
Constant	17.413	2.489	6.997	0.000
Final Account (log)	–5,519	0.821	–6.281	0.000
Final Account (log^2)	0.580	0.068	8.522	0.000
Procurement Route				
Management contracting	–0.337	0.304	–1.109	0.268
Construction management	–0.491	0.237	–2.075	0.038
Design and build	–0.274	0.092	–2.970	0.003
Design, manage and construct	0.001	0.297	0.004	0.997
Other procurement methods	–0.272	0.193	–1.405	0.160
Traditional lump sum	0.000	Used in base model		
Contractor Selection Method				
Two stage	0.028	0.146	0.192	0.848
Negotiated	–0.135	0.099	–1.356	0.176
Partnered	–0.265	0.180	–1.473	0.141
One stage	0.000	Used in base model		
Client Type				
Local government	–0.783	0.204	–3.839	0.000
Other public sector	–0.980	0.209	–4.699	0.000
Housing association	0.000	Used in base model		
Private sector (housing)	–0.514	0.152	–3.381	0.001
Private sector (non housing)	1.409	0.185	–7.618	0.000
Building Function				
Utilities and minor civil engineering facilities	–0.740	0.236	–3.140	0.002
Industrial facilities	–0.812	0.209	–3.890	0.000
Administrative, commercial and protective facilities	–0.227	0.196	–1.160	0.246
Health, welfare facilities	0.123	0.197	0.625	0.532
Recreational facilities	–0.248	0.208	–1.190	0.234
Religious facilities	0.133	0.529	0.251	0.802
Educational, scientific, information facilities	–0.281	0.193	–1.149	0.145
Residential facilities	0.000	Used in base model		
Common facilities, other facilities	0.433	0.256	–1.694	0.091
Region				
East Anglia	–0.178	0.169	–1.051	0.294
London	0.356	0.138	2.575	0.010
Midlands	–0.243	0.127	–1.918	0.055
Northern Ireland	–0.043	0.277	–0.153	0.878
North	–0.502	0.195	–2.575	0.010
North West	–0.324	0.155	–2.087	0.037
Scotland	0.019	0.143	0.136	0.892
South East	0.000	Used in base model		
South West	0.026	0.143	0.185	0.854
Wales	–0.203	0.227	–0.895	0.371
Yorkshire and Humberside	–0.484	0.176	–2.755	0.006

Helvacı (2008) studied 17 Continuing Care Retirement Center Projects constructed between 1975 and 1995 in the United States (14 different states). He studied parametric models, which are used at the early stages of projects. He formed five duration estimation models, beside one cost estimation model with these case studies data. These duration estimation models are:

1) BTC validation analysis
2) SLR Analysis (with only cost)
3) Artificial Neural Network (ANN) (with only cost)
4) MLR Analysis (without cost parameter)
5) ANN (without cost parameter)

In this section, 2^{nd} and 4^{th} models are presented. The 2^{nd} model is the simple linear regression analysis; in which only cost parameter was used to predict construction duration. This cost was obtained from a cost estimation model based on multiple linear regression analysis of the data. The equation used for the simple linear regression analysis was:

$T= \alpha_0 + \alpha_1 C$.. (Eq.2.3)

Where,

Y=actual duration (T)
C=detailed cost
α_0=regression constant
α_1=partial regression coefficient of detailed cost (C)
C=detailed cost

The simple linear regression equation derived for these independent variables was:

$T=10.47 + 2.91\ 10^{-7}\ C$.. (Eq.2.4)

Helvacı (2008) used PE (Percentage Error) and Mean Absolute Percentage Error (MAPE) to calculate predictive accuracy. His Simple Linear Regression Analysis had a prediction performance of 14% and duration estimations were varied within an accuracy range of ± 33%.

Helvacı (2008) used Multiple Linear Regression Analysis based on the following six parameters (without cost parameter):

1. Total building area (Area)
2. Number of floors (NoF)
3. Area per unit (Area/unit)
4. Combined percent area of commons and health center (Per(C+H))
5. Percent area of structured parking (Per(P))
6. Type of structural frame of the building (Steel (St), Masonry (Mas), Reinforced Concrete (RC), Precast (Pre), Wood (W))

The Multiple Linear Regression equation used was:

$$Y= \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \ldots\ldots + \alpha_8 X_8 + \alpha_9 X_9 + \alpha_{10} X_{10} \ldots\ldots\ldots (Eq.2.5)$$

Where,

Y=actual duration (T)

α_0=regression constant

$\alpha_{1,2,3....10}$=partial regression coefficient of $X_{1,2,3....10}$

X_1 = Area

X_2 = NoF

X_3 = Area/unit

X_4 = Per (C+H)

X_5 = Per (P)

X_6 = St multiplied by the area

X_7 = Mas multiplied by the area

X_8 = RC multiplied by the area

X_9 = Pre multiplied by the area

X_{10} = W multiplied by the area

For each calculation in the MLR equation, p-value and coefficient of determination (R^2) values were checked for the backward elimination procedure to eliminate the insignificant variables to achieve the parsimonious model. Additionally, the correlation coefficient was used to determine the relationship between the duration and independent variables.

Table 2.9. p-values for 4th model. (Helvacı, 2008.)

Independent variable	Partial coefficients	P-value of the coefficient
NoF	2,313	0,002
Mas	9,93E-05	0,039
W	1,52E-04	0,031

Only NoF, Mas and W were considered to have a significant contribution in the estimated duration as seen in Table 2.9. The MLR equation derived for these independent variables was;

$$T= 4.935 + 2.313 \times NoF + 9.93\times10^{-5} \times Mas + 1.52\times10^{-4}\times W \qquad \text{(Eq.2.6)}$$

This regression model had a prediction performance of 15.2%; while duration estimations varied within an accuracy range of ± 33%.

2.2.3. Discrete State Models

(Discrete State that use linear programming, classical optimization, network, PERT, and CPM)

Bhokha and Ogunlana (1999) and Helvacı (2008) are presented as examples of discrete state models in detail.

Bhokha and Ogunlana (1999) applied Artificial Neural Network (ANN) to forecast the construction duration of buildings at the pre-design stage. 136 buildings (h>23m; A>10,000m2) built between 1987-1995 in Greater Bangkok, Thailand were studied. ANN a 3-layered back-propagation network consisted of 11 input nodes listed in Table 2.10.

Mean squared error was used to test the accuracy of estimates.

There were two different average errors. The first one was 18.2%, resulting from 68 test samples used for validity purpose of the model. The second one was 13.6% for the 136 projects.

Table 2.10. Inputs and building features. (Bhokha and Ogunlana, 1999.)

	Description		**# of Nodes**	**Building Feature**
1	Building function	binary (0, 1)	2	Residence only Office only Dual (residence+office) Others
2	Structural system	binary (0, 1)	2	Cast-in-place RC Frame + PC slab Others
3	Functional area (x10^6 m^2)	Real value	1	
4	Height index	binary (0, 1)	1	# of floor > 25 # of floor ≤25
5	Complexity of foundation works	binary (0, 1)	1	Complex Simple
6	Exterior finishing	binary (0, 1)	2	Brick/cement block Curtain wall/ glass Others
7	Decorating quality	binary (0, 1)	1	Excellent Normal
8	Site accessibility	binary (0, 1)	1	Difficult Easy

Helvacı (2008) formed two different neural network models for conceptual duration estimation. The differences between these neural networks are the parameters. The 3rd model had only one input (cost) and one output (duration). While 5th model had 10 input variables (without cost) and one output (duration).

The 3rd model was a neural network, One input layer (cost), one output layer (duration) with a back-propagation algorithm. Two feed-forward artificial neural networks were developed, Model 3a and Model 3b. The only difference was the number of hidden layers nodes, Model 3a (3 nodes) and Model 3b (6 nodes)

The mean absolute percentage error (MAPE) method was used to test the accuracy of estimates. Model 3b was selected as the final neural network model because of slightly smaller MAPE value (14.8%). Accuracy range of this model was $\pm$ 40%.

The 5th model was also a neural network, ten input layer (without cost; Area, NoF, Area/unit, Per(C+H), Per(P), St, Mas, RC, Pre and W.), one output layer (duration) with a back-propagation algorithm. 20 network models were developed, and prediction performances of each model were analyzed. Variables with their abbreviations are listed in Table 2.11.

Table 2.11. Variables of the 5th Model. (Helvacı, 2008.)

1	Total Building Area (Area)	Real-value
2	Number of Floors (NoF)	Real-value
3	Area per unit (Area/Unit)	Real-value
4	Combined Percent Area of Commons and Health Center (Per(C+H))	Real-value
5	Percent Area of Structured Parking Per (P)	Real-value
6	Steel (St)	binary (0, 1)
7	Masonry (Mas)	binary (0, 1)
8	Reinforced Concrete (RC)	binary (0, 1)
9	Precast (Pre)	binary (0, 1)
10	Wood (W)	binary (0, 1)

NetMaker, Microsoft Excel, BrainMaker programs were used for the analysis. Sensitivity analysis was used to eliminate the input variables, and also the numbers of hidden nodes were changed accordingly. Sensitivities of independent variables for each network model are shown in Table 2.12. The remaining variable was "Area".

Table 2.12. Sensitivities of independent variables for each network of the 5th model. (Helvacı, 2008.)

Independent variables	Sensitivities								
	NM1b	NM2b	NM3a	NM4a	NM5a	NM6b	NM7b	NM8b	NM9a
Area	59,1	61,7	74,8	54,7	13,8	72,1	50,1	66,0	55,3
Per(P)	27,8	1,1	13,8	27,2	7,9	26,5	3,3	72,5	**9,6**
Per(C+H)	10,2	11,4	12,3	11,7	21,1	17,1	23,4	**60,8**	
St	20,0	16,8	39,9	19,0	37,5	35,1	**1,5**		
W	20,0	15,2	20,1	15,6	26,9	**3,5**			
RC	18,6	12,1	36,0	16,3	**0,2**				
NoF	5,3	12,5	47,8	**10,1**					
Pre	9,3	47,8	**1,9**						
Mas	52,3	**0,0**							
Area/unit	**3,9**								

The mean absolute percentage error (MAPE) method was also used to test the accuracy of estimates. NM10a with the smallest MAPE value (15.2%) was chosen as shown in Table 2.13. Accuracy range of this model was ± 40%.

Table 2.13. MAPE results for 20 network developed by the 5th model. (Helvacı, 2008.)

Model	Independent variables in the network model	Prediction Performances	
		MAPE a	MAPE b
NM1	Area, NoF, Area/unit, Per(C+H), Per(P), St, Mas, RC, Pre, W	20,7	**19,3**
NM2	Area, NoF, Per(C+H), Per(P), St, Mas, RC, Pre, W	21,6	**19,0**
NM3	Area, NoF, Per(C+H), Per(P), St, RC, Pre, W	**28,8**	31,1
NM4	Area, NoF, Per(C+H), Per(P), St, RC, W	**18,5**	22,5
NM5	Area, Per(C+H), Per(P), St, RC, W	**20,9**	26,6
NM6	Area, Per(C+H), Per(P), St, W	20,1	**19,6**
NM7	Area, Per(C+H), Per(P), St	26,5	**22,0**
NM8	Area, Per(C+H), Per(P)	19,2	**16,2**
NM9	Area, Per(P)	**18,8**	20,9
NM10	Area	**15,2**	15,4

2.3. The Criticism of the Models

Regression Models are related with mathematical values and very sensitive to data distribution. Therefore, if the variables are not clear, it is not possible to use regression models. (Sezgin, 2003)

Time-cost models and parametric models had close reasonably accurate estimations. The predictive accuracy of time-cost models was slightly better than parametric models. However, parametric estimations do not require cost estimation. (Helvacı, 2008)

In the study carried out by Helvacı (2008), ANN and regression analysis' predictive accuracies had no significant differences. Linear regression analyses were considered to provide an adequate and pragmatic methodology for conceptual duration estimation of construction projects.

The main advantage of the neural network models is their capability to capture the non-linear relations as well as linear relations. (Helvacı, 2008)

However, as Helvacı (2008) points out, an increase in the number of variables increases the complexity of the model. The construction industry is very complex, which contains hundreds of activities. (Bhokha and Ogunlana, 1999) Hence, Artificial Neural Network Models require trained professionals to estimate the construction duration.

Fuzzy Logic Models based on the conversion of linguistic expressions (like very god, good, fairly good) to mathematical values. It means that professionals take a role for making decisions, so it is appropriate for construction industry as compared with Regression Models and ANN's. Experience and institutions gain importance. However, if the people taking decisions are not efficient enough, it may lead to wrong decisions. (Sezgin, 2003)

CHAPTER 3

MATERIAL AND METHOD

Briefly, this chapter presents the survey materials and the survey methodology of the investigation. In the section on survey materials, the actual construction duration and the properties (cost, total area, total volume, façade area, etc.) of case study buildings (as inputs for application in all Models) and the BTC, BCIS, SLR and MLR Models are described. While, in the section on survey methodology, data collection method for the assessment of the survey buildings; and the process of application of these Models is introduced.

3.1. Materials

Data of educational building projects (time, cost and other project characteristics) which were new built projects completed between 2004 and 2007 were obtained from the Department of Construction and Technical Works (DCTW) of Middle East Technical University (METU), in Ankara, Turkey. Data of seven projects were analyzed. Because detailed information for only these projects was available. Further information was gathered from the head of the construction management department at DCTW, Mr. Naim Saraç. The BTC, BCIS, SLR and MLR models were explained in the previous chapter. The case study buildings are presented in the following paragraphs.

Data of actual durations are used in this study. Table 3.2 lists the projects and their data such as: durations (contract duration, actual duration, and effective duration), contract cost, detailed cost, reason of delay, etc. All primary and derived data related to the case study buildings are presented in Appendix-C and Table 3.2.

Three types of durations have been identified in this study, which are:

1. *Contract Duration* which is the duration given by the client, here contract duration included all the days as working days.
2. *Actual Duration* was the time taken from start to finish, actual duration includes the duration extensions but not nonworking days (nonworking season)
3. *Effective Duration* means number of days found out by subtracting nonworking days from actual duration. These nonworking days are the nonworking season time taken from 15th December to 1st April in the works lasting more than 1 year in Construction and Technical Works, METU.

Data for the contract and actual durations was obtained and that for effective duration was calculated to be used in the models for comparing the results. (Table 3.2)

Detailed costs were very close to the actual construction costs. Therefore, detailed costs are used in the models. These values were adjusted by using Building Construction Cost Indices published by Turkish Statistical Institute (TÜİK) and exchange calculations were done where necessary by using Ziraat Bank foreign exchange rate archives.

Other parameters are calculated as follows:

1. Height was calculated from floor to floor. After calculating all floors, the average height was calculated by dividing the sum of heights by the number of floors (basement and mechanical floors included)
2. Some of the projects contain two blocks, therefore, calculations were average for both buildings for the duration estimations.
3. Total areas of buildings were calculated according to the Architectural Plan

of the buildings for each floor and then the average floor areas were obtained.

4. Façade areas were calculated.
5. Volumes of buildings were calculated from the building plans.
6. Additional data were listed also, such as, structural system and the façade materials.

The parameters that were used for the project data are as follows:

1. Number of Block……………………………………………………………(NoB)
2. Number of Floor……………………………………………………………(NoF)
   (basement and service floors are included)
3. Total Height (m) ……………………………………………………….(Tot.H)
4. Average Height of the Floors (m) ………………………………(Av.H)
5. Total Area (m2) ………………………………………………………..(Tot.Area)
6. Average Floor Area (m2) …………………………………………(Av.F.Area)
7. Total Volume (m3) ……………………………………………………(Tot.Volume)
8. Average Volume of Floors (m3) …………………………………(Av.F.Volume)
9. Façade Area (m2) ………………………………………………………(Façade)
10. Adjusted Detailed Cost Values………………………………………(Cost)
   (According to the Models (TL or AUD or GBP)

Data related to only these parameters are given below in Table 3.1.

Table 3.1. Project parameters.

No	NoB	NoF	Tot.H. (m)	Av.H. (m)	Tot.Area (m^2)	Av.F.Area (m^2)	Tot.Volume (m^3)	Av.F.Volume (m^3)	Facade (m^2)	Cost (TL)
Project.A	1	5	20.02	4.00	4,767.28	953.46	19,958.28	3,991.66	2,279.00	4,720,296.32
Project.B	2	2	6.97	3.49	1,684.43	842.22	5,808.73	2,904.37	1,543.10	1,664,179.96
Project.C	2	2	7.06	3.53	1,621.02	810.51	5,604.37	2,802.19	1,544.75	1,653,072.37
Project.D	1	2	7.10	3.55	509.38	254.69	1,808.30	904.15	464.92	367,581.02
Project.E	2	2	6.80	3.40	542.59	271.30	1,844.80	922.40	587.00	527,515.41
Project.F	1	1	8.34	8.34	2,299.33	2,299.33	19,175.57	19,175.57	2,386.36	1,992,787.44
Project.G	1	2	8.20	4.10	2,407.60	1,203.80	9,871.16	4,935.58	1,579.41	1,378,921.53

The costs used in BTC, BCIS, SLR and MLR Models were calculated in the following methods and presented in Table 3.2.

1) In BTC Model, cost data were adjusted for the 2006-2nd quarter by using Building Construction Cost Indices (BCCI) (2005) published by Turkish Statistical Institute (TÜİK). After adjusting the years, the value was also converted from TL to AUD by using the April 1st, 2006 rate of exchange, since, April is the first month of the 2nd quarter. (These indices were obtained from the Ziraat Bank web site)

2) In BCIS Model, cost data are used after adjusting the values to 2003-2nd quarter index by using BCCI (1991 and 2005) published by TÜİK. After adjusting the years, the value was also converted from TL to GBP by using the April 1st, 2003 rate of exchange, since, April is the first month of the 2nd quarter. (These indices were obtained from the Ziraat Bank web site)

3) In SLR and MLR Models, cost data for each project were adjusted for the 2006-2nd quarter (TL) by using BCCI (1991 and 2005) published by TÜİK.

Table 3.2. Data related to the case study buildings.

BUILDINGS	1	2	3	4	5	6	7
PARAMETERS	**PROJECT.A**	**PROJECT.B**	**PROJECT.C**	**PROJECT.D**	**PROJECT.E**	**PROJECT.F**	**PROJECT.G**
ARCHITECT	A1	A2	A2	A3	A3	A4	A4
CONTRACTOR	C1	C2	C3	C4	C2	C5	C5
Total Height	20.02	6.97	7.06	7.10	6.80	8.34	8.20
Average Height of the Floors	4.00	3.49	3.53	3.55	3.40	8.34	4.10
Number of Floor (NoF) (basement and service floors are included)	5	2	2	2	2	1	2
Total Area (m2)	4,767.28	1,684.43	1,621.02	509.38	542.59	2,299.33	2,407.60
Average Floor Area (m2)	953.46	842.22	810.51	254.69	271.30	2,299.33	1,203.80
Total Volume (m3)	19,958.28	5,808.73	5,604.37	1,808.30	1,844.80	19,175.57	9,871.16
Average Volume of Floors (m3)	3,991.66	2,904.37	2,802.19	904.15	922.40	19,175.57	4,935.58
Facade Area (m2)	2,279.00	1,543.10	1,544.75	464.92	587.00	2,386.36	1,579.41
Number of Block	1	2	2	1	2	1	1
DURATION							
Contract Start Date	12.09.2007	31.05.2006	13.09.2007	21.06.2007	10.10.2007	20.04.2007	02.12.2004
Contract Duration (days)	365	200	365	90	66	300	242
Contract End Date (1)	12.09.2008	16.12.2006	11.09.2008	18.09.2007	14.12.2007	13.02.2008	31.07.2005
Any Duration Extension Request	Yes	No	No	No	Yes	Yes	No
Reason for Duration Extension	Design Changes				Weather	Weather	
					Design Changes	Design Changes	
Duration Extension (days)	94				140	70	
Contract End Date (2) with duration extension	15.12.2008				02.05.2008	23.04.2008	
Actual Construction Duration (days)	459	200	365	90	206	370	242
Nonworking days (from 15th December to 1st April)	105		105		105	105	
Effective Construction Duration (days)	354	200	260	90	101	265	242
COST							
Contract Cost with VAT (TL)	4,247,410.00	1,022,824.00	1,239,000.00	266,444.00	396,067.00	1,840,800.00	882,050.00
Rate of Increase	10%	10%	10%	10%	8,69%	10%	5,7782%
Total Construction Cost with VAT and with Rate of Increase(TL)	4,672,151.00	1,125,106.40	1,362,900.00	293,088.40	430,485.22	2,024,880.00	933,016.61
Detailed Cost with VAT (TL)	4,996,191.21	1,664,179.96	1,749,692.20	389,158,10	561,134.84	2,109,764.48	1,072,034.86
Adjusted Detailed Cost Value (TL) (2006-II.Quarter)	4,720,296.32	1,664,179.96	1,653,072.37	367,581.02	527,515.41	1,992,787.44	1,378,921.53
COST ADJUSTMENT							

SLR / MLR

ALL COSTS WERE ADJUSTED 2006-II QUARTER (TL)

	Project.A	Project.B	Project.C	Project.D	Project.E	Project.F	Project.G
Detailed Cost with VAT (TL) (A)	4,996,191.21	1,664,179.96	1,749,692.20	389,158,10	561,134.84	2,109,764.48	1,072,034.86
Contract Start Date	12.09.2007	31.05.2006	13.09.2007	21.06.2007	10.10.2007	20.04.2007	02.12.2004
Contract Quarter	2007-III	2006-II	2007-III	2007-II	2007-IV	2007-II	2004-IV
Building Construction Cost Index at Contract Quarter (B) TUIK -(2005-2008) index	126.22	119.25	126.22	126.25	126.85	126.25	39.907
2006-II Building Construction Cost Index (C) TUIK -(2005-2008) index	119.25	119.25	119.25	119.25	119.25	119.25	51.331
Adjusted Detailed Cost Value (TL) (2006-II.Quarter) (X=A*C/B)	**4,720,296.32**	**1,664,179.96**	**1,653,072.37**	**367,581.02**	**527,515.41**	**1,992,787.44**	**1,378,921.53**

BTC

ALL COSTS WERE ADJUSTED 2006-II QUARTER (AUD)

	Project.A	Project.B	Project.C	Project.D	Project.E	Project.F	Project.G
Detailed Cost with VAT (TL) (A)	4,996,191.21	1,664,179.96	1,749,692.20	389,158,10	561,134.84	2,109,764.48	1,072,034.86
Contract Start Date	12.09.2007	31.05.2006	13.09.2007	21.06.2007	10.10.2007	20.04.2007	02.12.2004
Contract Quarter	2007-III	2006-II	2007-III	2007-II	2007-IV	2007-II	2004-IV
Building Construction Cost Index at Contract Quarter (B) TUIK -(2005-2008) index	126.22	119.25	126.22	126.25	126.85	126.25	39.907
2006-II Building Construction Cost Index (C) TUIK -(2005-2008) index	119.25	119.25	119.25	119.25	119.25	119.25	51.331
Adjusted Detailed Cost Value (TL) (2006-II.Quarter) (X=A*C/B)	4,720,296.32	1,664,179.96	1,653,072.37	367,581.02	527,515.41	1,992,787.44	1,378,921.53
Adjusted Detailed Cost Value (AUD) (2006-II.Quarter)	**4,931,461.50**	**1,738,628.01**	**1,727,023.52**	**384,024.97**	**551,114.12**	**2,081,935.94**	**1,440,608.38**

**3rd April 2006 (1AUD=0.95718 TL) buying exchange rates

BCIS

ALL COSTS WERE ADJUSTED 2003-II QUARTER (GBP)

	Project.A	Project.B	Project.C	Project.D	Project.E	Project.F	Project.G
Detailed Cost with VAT (TL) (A)	4,996,191.21	1,664,179.96	1,749,692.20	389,158,10	561,134.84	2,109,764.48	1,072,034.86
Contract Start Date	12.09.2007	31.05.2006	13.09.2007	21.06.2007	10.10.2007	20.04.2007	02.12.2004
Contract Quarter	2007-III	2006-II	2007-III	2007-II	2007-IV	2007-II	2004-IV
Building Construction Cost Index at Contract Quarter (B) TUIK -(2005-2008) index	126.22	119.25	126.22	126.25	126.85	126.25	39.907
2006-II Building Construction Cost Index (C) TUIK -(2005-2008) index	119.25	119.25	119.25	119.25	119.25	119.25	51.331
Adjusted Detailed Cost Value (TL) (2006-II.Quarter) (X=A*C/B)	4,720,296.32	1,664,179.96	1,653,072.37	367,581.02	527,515.41	1,992,787.44	1,378,921.53
Building Construction Cost Index at 2006-II (D) TUIK -(1991-2006) index	51,331.00	51,331.00	51,331.00	51,331.00	51,331.00	51,331.00	51,331.00
2003-II Building Construction Cost Index (E) TUIK -(1991-2006) index	32,827.00	32,827.00	32,827.00	32,827.00	32,827.00	32,827.00	32,827.00
Adjusted Detailed Cost Value (TL) (2003-II.Quarter) (Y=X*E/D)	3,018,705.41	1,064,269.85	1,057,166.37	235,073.97	337,354.59	1,274,419.62	881,842.49
Adjusted Detailed Cost Value (GBP) (2003-II.Quarter)	**1,128,066.30**	**397,709.21**	**395,054.70**	**87,845.28**	**126,066.74**	**476,240.52**	**329,537.55**

**1st April 2003 (1GBP=2.676TL) buying exchange rates

3.2. Method

A comprehensive literature survey was conducted and the methodologies used in each paper were listed in a Table (see Appendix-B) as well as the types of models used according to years (Table 2.3.). It was seen that the most popular methodology for duration estimation models is the linear regression analysis; hence, it was decided to use 4 different regression analyses applications. These are the BTC model, Building Cost Information Service (BCIS) Model, Simple Linear Regression Analysis (SLR) and Multiple Linear Regression Analysis (MLR).

Data Related to the Case Study Buildings were obtained from the head of the construction management department of DCTW at METU, Mr. Naim Saraç, civil engineer. Information on the method for estimating construction duration adopted by TOKİ as well as the parameters taken into consideration for making these estimations was obtained from the head of the tendering department of Republic of Turkey Prime Ministry, Housing Development Administration of Turkey (TOKİ), Mr. Yavuz Çetin, civil engineer.

First, the BTC Model, which was the pioneer of these duration estimation models, was used to verify whether such a relationship holds for the data pertaining to the case study projects by using Microsoft Excel 2003 for the regression analysis.

Thereafter the BCIS Model, which is based on data related to 1,500 case study buildings, was also considered for calculating project durations. This Model is applied by using its own Building Construction Duration Calculator (BCDC).

Next, SLR analyses were conducted with 10 input variables (Table 3.1). Finally, MLR analyses were carried out taking into consideration the results of the SLR analyses' results. SLR and MLR Analyses were conducted using Microsoft Excel 2003.

3.2.1. Bromilow Time-Cost Model

For statistical verification of the time-cost relationship, the equation was rewritten in the natural logarithmic form for calculating using Microsoft Excel 2003.

$$Ln (T) = Ln (K) + BLn (C) \quad \text{(Eq.3.1)}$$

By letting,

$Y = Ln (T)$

$x = Ln (C)$

$\alpha_0 = Ln (K)$

and $\alpha_1 = B$;

Simple linear regression equation is provided by double log form to convert the non-linear model to linear model. The null hypothesis was that: an increase in Ln (T) is not associated with an increase in Ln (C). If this hypothesis is rejected, then the time-cost relationship of equation is also true.

3.2.2. BCIS Model

The BCIS Model was applied to the data by using the following parameters:

1. Procurement route..(Traditional Lump Sum)
2. Contractor selection method...(One Stage (Method for tendering the works was used)
3. Client type..(Other Public Sector)
4. Building function..(Educational)
5. Region..(South West)
   Actually, the region does not affect the result significantly. Therefore, the region with the closest mean value was selected, South West
6. Cost...(Real Variable)

The necessary parameters were chosen for selected buildings as listed above. These variables were entered in Building Construction Duration Calculator (BCDC) as shown in Figure 2.6 with screen appearance to obtain the result. (Figure 2.7)

3.2.3. Simple Linear Regression Analysis

SLR was conducted to predict the construction duration by checking the effects of each of the following parameters: NoB, NoF, Tot.H., Av.H., Tot.Area, Av.F.Area, Tot.Volume, Av.F.Volume, Façade, Cost (see Table.3.1.).

3.2.4. Multiple Linear Regression Analysis

Based on the results of the SLR analyses, the factors having significant influence on construction duration were used to conduct the MLR analyses. It is aimed to form a parsimonious model that was developed with significant variables (without using unnecessary variables) with adequate fit.

In MLR, insignificant variable was eliminated with p-value (significance level) and R^2 (coefficient of determination). P-value shows significance of the independent variables in the model. R^2 determines how much of the variability of the dependent variable is explained by the independent variables.

3.2.5. Validation of Models

The mean absolute percentage error (MAPE) method was used to find the closeness of fit to the models. The BTC, BCIS, SLR, and MLR analyses prediction results were compared with each other.

To evaluate the closeness of fit of the models, Percentage Error (PE) for the comparison of actual durations and predicted durations is defined as follows:

$$\text{PE} = \frac{\text{predicted duration} - \text{actual duration}}{\text{actual duration}} \quad \text{.............(Eq.3.2)}$$

The validity of the model was tested by comparing the actual values with predicted values. The mean absolute percentage error (MAPE) method was used to test the reliability of the model, using the following equation.

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\frac{\left|(\text{predicted duration})i - (\text{actual duration})i\right|}{\left|(\text{actual duration})i\right|}\times 100 \quad \text{...........(Eq.3.3)}$$

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the closeness of fit of the models (BTC Model, BCIS application, Simple and Multiple Linear Regression Analyses) are compared, and information obtained through informal interviews is presented here.

4.1. Informal Interviews

Information on estimation of construction durations as well as the bidding and award of contract procedures followed by METU-DCTW and TOKİ were obtained through informal interviews carried out with the head of the construction management department of DCTW at METU and that at TOKİ. The information related to procedures followed at TOKİ was not directly related to this study; therefore, it is presented in Appendix-D: while that obtained from METU-DCTW are explained in the following paragraphs.

Information was gathered from the head of the construction management department of the DCTW in METU, Mr. Naim Saraç.

According to the information provided by Mr. Naim Saraç; the client is METU itself the procedure followed by DCTW is as follows:

1. The selected buildings were designed by private architectural offices. In Addition, all of the initial cost estimates were also prepared by them.
2. The bidding team in DCTW (METU) prepared the cost estimates again and definitions of the construction work.
3. Contractor selection method is single stage (A tendering process intended to lead directly to the award of a construction contract to the successful tenderer for the works described in the tender enquiry)
4. The work is given to the lowest bidding price (If the cutting price percentage is over the 40%;the contractor is examined and analyzed by the technical committee, the contractor is asked to explain how they will do their jobs. If it is appropriate they are given the job, if not, the same procedure is applied on the other companies.)
5. Procurement route is lump sum (Design and construction are provided separately -the design is undertaken by a team separately appointed by the client, with construction by a contractor competitively appointed.)
6. The construction period is from the delivery of the construction site to the submission of the work to the client.
7. Two reasons were found for the duration extensions. They are weather and the design changes.
8. Construction duration estimations are done intuitively depending on the experience of the estimators. (such as, the volume of the work (big-small), the difficulties of the work, structure, shapes of the plan).
9. Contract Duration (the duration given by the client) was given as all the days as working days. The nonworking season time taken from 15^{th} December to 1^{st} April in the works lasting more than 1 year in Construction and Technical Works, METU.
10. Especially the projects related to students in METU, the construction works was tried to performed when the university in holiday period.
11. The cost estimations of new projects are better than the refurbishment projects'. Therefore, the estimations are used only by applying the year adjustment.

4.2 Application of Models

The results of the four models that were used in this study are presented in the following paragraphs.

4.2.1 The BTC Model

After converting the power of regression equation to linear model and entering the data in the equation, the results of the BTC Model are shown in Table 4.1.

According to these results,

$$[Y= \alpha_0 + \alpha_1 X_1 \ldots = \ldots \text{Ln}(T) = \text{Ln}(K) + B\,\text{Ln}(C)]$$

$$Y = \text{Ln}(T),\ \alpha_0 = \text{Ln}(K) \text{ and } \alpha_1 = B,\ X = \text{Ln}(C)$$

$$\alpha_0 = \text{Ln}(K)=5.086;$$

Where,

K=161.7383

α_1 = B=0.585

The Time-Cost relationship for these seven educational buildings was determined to be as follows;

$$T=161.74C^{0.58} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(Eq.4.1)}$$

The results of the BTC model given below in Table 4.1, where the relationship between cost and duration of a project is tested as can be seen in Table 4.1 the coefficient of determination (R^2) is very close to 1 therefore, we can assume that the model is able to predict the construction duration based on the cost of the project.

Table 4.1. Regression results of BTC Model.

Regression Statistics	
Multiple R	0.96
R^2	0.93
Adjusted R2	0.91
Significance F	0.01

	Coefficients	*P-value*
Intercept	5.0860	5.00031E-09
Cost	0.5847	0.000471619

Closeness of fit of the model is tested by comparing the actual and predicted durations by using the formula of PE and MAPE in equation 3.3. (Table 4.2)

Table 4.2. Actual duration versus predicted duration. (BTC Model)

	Project No	Effective Duration (days)	Predicted Duration (days)	PE	IPEI
1	Project.A	354	411	16.14	16.14
2	Project.B	200	223	11,75	11,75
3	Project.C	260	223	-14.38	14.38
4	Project.D	90	92	2.70	2.70
5	Project.E	101	114	13.03	13.03
6	Project.F	265	248	-6.29	6.29
7	Project.G	242	200	-17.26	17.26
				MAPE	**11.65**

**PE: Percentage Error

4.2.2 The BCIS Model

The results are presented in Table 4.3 below. As can be seen from this table, project D's value is smaller than the lowest value for entering the BCIS model (£100,000). Therefore, it could not be included in the calculations.

Closeness of fit of the model is tested by comparing the actual and predicted durations by using the formula of PE and MAPE in equation 3.3. (Table 4.3)

Table 4.3. Actual duration versus predicted duration. (BCIS Model)

	Project No	Adjusted Cost Value (£) 2003-II Quarter	Effective Duration (days)	Effective Duration (weeks)	Predicted Duration (weeks)	PE	IPEI
1	Project.A	1,128,066.30	354	50.57	39.00	-22.88	22.88
2	Project.B	397,709.21	200	28.57	30.00	5.00	5.00
3	Project.C	395,054.70	260	37.14	31.00	-16.54	16.54
4	Project.D	87,845.28	90	12.86	---	---	---
5	Project.E	126,066.74	101	14.43	25.00	73.27	73.27
6	Project.F	476,240.52	265	37.86	32.00	-15.47	15.47
7	Project.G	329,537.55	242	34.57	29.00	-16.12	16.12
						MAPE	**24.88**

**PE: Percentage Error

4.2.3. Simple Linear Regression Model

The SLR Model was tested for the 10 independent variables and it was seen that with 95 % level of confidence only 4 were significant for estimating construction duration. These variables are total area, total volume, façade area and adjusted detailed cost value. Results of the regression analyses carried out between the parameters and duration are summarized in Table 4.4, below. In this table the SLR equations are given in column 12.

Table 4.4. The results of simple linear regression analyses.

No	Independent Variable in regression equation	Multiple R	R^2	Adjusted R^2	p-value of the coefficient	Accepted / Rejected	p-value for intercept	p-value for variable	α_0	α_1	SLR Equation
SLR1	NoB	0.29	0.08	-0.10	0.53	R	-	-	-	-	-
SLR2	NoF	0.51	0.26	0.12	0.24	R	-	-	-	-	-
SLR3	Tot.H.	0.70	0.49	0.39	0.08	R	-	-	-	-	-
SLR4	Av.H.	0.33	0.11	-0.07	0.48	R	-	-	-	-	-
SLR5	Tot.Area	0.92	0.84	0.81	0.00	A	0.017	0.003	97.28	0.06	T = 97.28 + 0.06 x_1; where, x_1=Tot.Area
SLR6	Av.F.Area	0.60	0.36	0.23	0.15	R	-	-	-	-	-
SLR7	Tot.Volume	0.85	0.72	0.66	0.02	A	0.016	0.016	119.86	0.01	T = 119.86 + 0.01 x_2; where, x_2=Tot.Volume
SLR8	Av.F.Volume	0.41	0.17	0.00	0.36	R	-	-	-	-	-
SLR9	Facade	0.93	0.86	0.83	0.00	A	0.016	0.016	41.12	0.118	T = 41.12 + 0.118 x_3; where, x_3=Facade
SLR10	Cost	0.89	0.79	0.75	0.01	A	0.012	0.008	113.71	5.82E-05	T = 113.71 + 5.82E-05 x_4: where, x_4=Cost

In addition, the results are presented for each significant independent variable below in Table 4.5-8.

Table 4.5. Actual duration versus predicted duration for SLR1 with total area.

T = 97.28 + 0.06xTot.Area						
	Project No	Total Area (m^2)	Effective Duration (days)	Predicted Duration (days)	PE	IPEI
1	Project.A	4,767.28	354	383	8.28	8.28
2	Project.B	1,684.43	200	198	-0.83	0.83
3	Project.C	1,621.02	260	195	-25.18	25.18
4	Project.D	509.38	90	128	42.05	42.05
5	Project.E	542.59	101	130	28.55	28.55
6	Project.F	2,299.33	265	235	-11.23	11.23
7	Project.G	2,407.60	242	242	-0.11	0.11
					MAPE	**16.60**

Table 4.6. Actual duration versus predicted duration for SLR2 with total volume.

T = 119.86 + 0.01xTot.Volume						
	Project No	Total Volume (m^3)	Effective Duration (days)	Predicted Duration (days)	PE	IPEI
1	Project.A	19,958.28	354	319	-9.76	9.76
2	Project.B	5,808.73	200	178	-11.03	11.03
3	Project.C	5,604.37	260	176	-32.34	32.34
4	Project.D	1,808.30	90	138	53.27	53.27
5	Project.E	1,844.80	101	138	36.94	36.94
6	Project.F	19,175.57	265	312	17.59	17.59
7	Project.G	9,871.16	242	219	-9.68	9.68
					MAPE	**24.37**

**PE: Percentage Error

Table 4.7. Actual duration versus predicted duration for SLR3 with façade area

	T = 41.12 + 0.118xFacade					
	Project No	Facade Area (m^2)	Effective Duration (days)	Predicted Duration (days)	PE	IPEI
1	Project.A	2,279.00	354	310	-12.42	12.42
2	Project.B	1,543.10	200	223	11.60	11.60
3	Project.C	1,544.75	260	223	-14.08	14.08
4	Project.D	464.92	90	96	6.65	6.65
5	Project.E	587.00	101	110	9.29	9.29
6	Project.F	2,386.36	265	323	21.78	21.78
7	Project.G	1,579.41	242	227	-6.00	6.00
					MAPE	**11.69**

Table 4.8. Actual duration versus predicted duration for SLR4 with cost.

	T = 113.71 + 5.82E-05xCost					
	Project No	Adjusted Detailed Cost (TL) (2006-II)	Effective Duration (days)	Predicted Duration (days)	PE	IPEI
1	Project.A	4,720,296.32	354	387	9.46	9.46
2	Project.B	1,664,179.96	200	210	5.12	5.12
3	Project.C	1,653,072.37	260	210	-19.39	19.39
4	Project.D	367,581.02	90	135	50.03	50.03
5	Project.E	527,515.41	101	144	42.88	42.88
6	Project.F	1,992,787.44	265	229	-13.47	13.47
7	Project.G	1,378,921.53	242	194	-19.96	19.96
					MAPE	**22.90**

**PE: Percentage Error

4.2.4 Multiple Linear Regression Model

As seen from the SLR analyses, the variables correlated with duration were total area, façade area, total volume, and cost values. Since, total volume is a product of the total area with the façade area. The multiple linear regression analysis was carried out with the rest of the only three parameters (total area, total volume and cost) to predict construction duration.

The results of these analyses are presented in Table 4.9 below:

Table 4.9. Results of multiple linear regression analyses for 3 and 2 significant parameters

MLR1

Regression Statistics	
Multiple R	0.97
R^2	0.94
Adjusted R2	0.87
Significance F	0.027

	Coefficients	*P-value*
intercept	54.31	0.183
Tot.Area	0.03	0.564
Facade	0.07	0.132
Cost	0.00	0.895

MLR2

Regression Statistics	
Multiple R	0.97
R^2	0.94
Adjusted R2	0.90
Significance F	0.004

	Coefficients	*P-value*
intercept	53.73	0.119
Tot.Area	0.03	0.098
Facade	0.07	0.078

Two regression models were developed. MLR1 has adequate R^2 and p-values. In MLR1, the cost variable has the highest p-value (0.895). Therefore, it is eliminated and MLR2 is developed with the other 2 variables i.e. total area and façade area. This model also has an adequate R^2 and p-values. Moreover, p-values of partial regression coefficients corresponding to independent variables included in the model are also adequate. Therefore, MLR2 can be written in equation form as follows:

T = 53.73 + 0.03xTot.Area + 0.07xFaçade..(Eq.4.2)

Closeness of fit of the model is tested by comparing the actual and predicted durations by using the formula of PE and MAPE in equation 3.3. (as shown in Table 4.10)

Table 4.10. Actual duration versus predicted duration. (MLR)

T = 53.73 + 0.03xTot.Area + 0.07xFacade					
	Project No	Effective Duration (days)	Predicted Duration (days)	PE	IPEI
1	Project.A	354	356	0.64	0.64
2	Project.B	200	212	6.14	6.14
3	Project.C	260	210	-19.04	19.04
4	Project.D	90	102	12.84	12.84
5	Project.E	101	111	10.00	10.00
6	Project.F	265	290	9.34	9.34
7	Project.G	242	237	-2.27	2.27
				MAPE	**8.61**

**PE: Percentage Error

4.3. Concluding Remarks

- The application of the *BTC Model* showed that a relationship existed between the cost and the duration of construction for the seven buildings studied and was represented by the equation,

  $T=161.74C^{0.585}$

  The MAPE value for this model was calculated to be 11,65 %.

- The application of the *BCIS Model* showed that six parameters were significant in predicting the model and the MAPE value for this model was calculated to be 25%.

- The application of the *Simple Linear Regression Analyses* showed that 4 of the 10 independent variables were significant in determining construction duration. The MAPE values and equations for them were:
  - 16,60% for SLR1 (total area)

    T = 97,28 + 0,06xTot.Area
  - 24.37% for SLR2 (total volume)

    T = 119,86 + 0,01xTot.Volume
  - 11.69% for SLR3 (façade area)

    T = 41,12 + 0,118xFaçade
  - 22.90% for SLR4 (cost)

    T = 113,71 + 5,82E-05xCost

- The application of the *Multiple Linear Regression Analysis* showed that only two independent variables; total area and façade area were found to be significant and cost was not one of them.

  T = 53.73 + 0.03xTot.Area + 0.07xFaçade

  The MAPE value for this model was calculated to be 8.61 %.

The list of all of these duration estimation models' closeness of fit values is shown in Table 4.11.

Table 4.11. Closeness of fit of construction duration estimation models.

Model	Explanation	Analysis Technique	MAPE	Closeness of Fit
Model 1	BTC Model	Simple Linear Regression	11.65	±18% (7 projects)
Model 2	BCIS Model	Multiple Linear Regression	24.88	±23% (5 projects)
Model 3	Time-Total Area Model	Simple Linear Regression	16.60	±29% (6 projects)
	Time-Total Volume Model	Simple Linear Regression	24.37	±40% (6 projects)
	Time-Facade Area Model	Simple Linear Regression	11.69	±22% (7 projects)
	Time-Cost Model	Simple Linear Regression	22.90	±43% (6 projects)
Model 4	Time-(Facade & Total Area)	Multiple Linear Regression	8.61	±19% (7 projects)

CHAPTER 5

CONCLUSION

The main objective of this study was to develop models that will be used to predict the construction duration to compare the duration given by the client at bidding stage in a reliable and practical way by using project characteristics. In this context, seven educational buildings in METU, Ankara were used to apply four types of regression models for actual time prediction at pre-design stage. As base models, a power regression model included only cost variable with duration built by Bromilow (BTC Model) was used. Second, a Multiple Linear Regression Analysis which has 6 parameters (procurement route, contractor selection method, client type, building function, region, and value) formed by Building Cost Information Service (BCIS) Model were used. Then, four Simple Linear Regression Models (Total area, total volume, façade area and cost) were developed with duration. Finally, a Multiple Linear Regression Analysis was conducted between total area and façade area. The following conclusions are drawn according to the model results:

- The contractors can use these models to estimate the construction duration and compare it with that given by the client at the tender stage to see if these durations will be realistic for the given project and its budget. For such modeling, they require their own databases. This modeling approach based on the historical data of the contractor will be more practical, concrete and reliable than currently used subjective methods based on intuitive estimations by planners.

- According to the results, forming our own models based on our case studies is a better approach than using a model formed with different country case studies. Since local data was not available in the BCIS Model. Its results cannot be considered represent culture.

- Results of the models developed show that although the closeness of fit of the model with cost parameter is good for the BTC and BCIS models, the MLR model was developed without cost. The model with the least MAPE was the MLR with façade area and total floor area as the characteristics of the building. Actually, the main reason is that though, conventionally, effect of cost on duration is considered, when in reality it is the duration that affects cost.

- The usage of the Multiple Linear Regression Model is limited with the limits of the case study buildings characteristics. The total area of the building should be between 510m^2 and 4,800m^2 and the façade area should be between 1,800 to 20,000m^2. In addition, the other characteristics should be between the limits even though these parameters were not included in the model. For example, the number of floors limits were between 1 and 5 (basement and service floors are included), and the location of building was METU Campus in Ankara.

  If we were to test the MLR model for a 4m high single storey building with 3 different floor areas: 1,250, 12,500, 125,000m2 and built with conventional material and techniques. We see that the construction duration estimation for smallest building is calculated as 4.5 months, for the medium size (12,500m2) building it is calculated as 1.5 years and for the largest building (125,000m2) it is calculated as 11.7 years. However, the durations for areas that do not lay between our model limits (500-5,000m2) the results are not realistic.

Recommendations for future studies would be;

- In this study, data for only seven educational building projects were used to form the models. However, more case study buildings with the same type of project will provide results that are more reliable.

- Most of the researchers studied their modeling approach by supposing the effect of cost on duration, although, this conception was found to be incorrect for all cases. It is necessary to study the effect of duration on cost in order to rectify this error.

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APPENDIX A

FACTORS AFFECTING CONSTRUCTION DURATION

Table A.1. Factors Affecting Construction Duration

No	Author	Year	Factors
1.	**Baldwin**	**1971**	
	It is the agreed result of all 3 gropus' point of views;		1. Weather
	Subcontractors, Contractors and Architects		2. Labour Supply
			3. Subcontractors
	Baldwin, J.		
	Causes of Delays in the Construction Industry		
	Journal of Construction Divison		
	V. 97, October1971		
2.	**Sadashiv**	**1979**	
			1. The height of a building (NoF)
	Sadashiv, M.C. (1979)		2. Project complexity (construction technique, major equipment needed, construction sequence)
	Pre-design Determination of Project Duration and Cost		3. The number of major finishing works
	MEng thesis, Asian Institute of Technology, Bangkok.		4. The location of building (whether or not restrictions or easements exist, availability of services, supply of resources, use of major equipment, and productivity on site)
3.	**Sidwell**	**1982**	
			1. Environmental factors
	Sidwell, A.C. (1982)		2. Client experience
	A Critical Study of Project Team Organisational Forms		3. Project organization model
	within the Building Process		4. Type of client
	Ph.D. Thesis, The University of Aston in Birmingham, UK.		5. Managerial control efectiveness
	Sidwell, A.C. (1984)		6. Project complexity
	The Time Performance of Construction Projects		
	Architectural Science Review, 27, 85-91		
4.	**Ferguson**	**1983**	
			1. The factors affecting site productivity, buildability
	Ferguson, I. (1983)		
	Buildability and the Private House Builder.		
	Building Technology and Management, November, 16-18.		
5.	**Legard**	**1983**	
			1. The size of the project
			2. The shape of the process defined as function of tasks and number of repititions of tasks
6.	**Grant**	**1984**	
			1. Management
	Grant, K.J. (1984)		2. Leadership
	Towards a Leaderless Industry,		
	Building Technology and Management, May, 3-4.		
7.	**Ahuja and Nandakumar**	**1984**	**factors that ultimately affect site productivity;**
			1. Work space availability
	Ahuja, H.N., and Nandakumar, V. 1984.		2. Attendance of operatives
	Enhancing Reliability of Project Duration Forecasts.		3. Learning curve
	American Association of Cost Engineers Transactions, E.6.1–E.6.12.		4. Weather
			5. Labour relations
			6. Project complexity
			7. Foundation condition
			8. Effectiveness of supervision
8.	**Singh**	**1984**	
			A. Physical
	It was emphisized to pay attention to the pre-construction decisions		1. Form of Construction
			2. Size of Project
	Singh, .S. (1984)		3. Number of storeys
	A Rational Approach for Stipulating Completion Time		4. Existence of basement
	for High Rise Commercial Building		**B. Managerial**
	In Proceedings of the Fourth International Symposium		1. Contractual system
	on Organization and Management of Construction		2. Tendering procedure
	CIB W-65, pp. 855-862.		3. Management efficiency of the construction firm
			4. Development of coordination between the various agencies involved in the construction
9.	**Bennett**	**1985**	
			1. Size
			2. Repetition
			3. Complexity
			4. Speed
			5. Uncertainity

Table A.1. Continued

No	Author	Year	Factors
10.	**Ireland**	**1985**	**Managerial**
			1. Construction planning during design
	Ireland, V. (1983), Ph.D. thesis, University of Sydney, NSW.		2. Coordination across the design-construction interface
	The Role of Managerial Actions in the Cost, Time and Quality		3. Variations to the contract
	Performance of High Rise Commercial Building Projects		4. Complexity of building size and form of construtcion
			5. Number of storeys
	Ireland, V. (1985)		6. Extent of industrial disputes
	The Role of Managerial Actions in the Cost, Time and Quality		
	Performance of High Rise Commercial Building Projects		
	Construction Management and Economics, 3(1), 59-87.		
	Ireland, V. (1986)		
	A Comparison of Australia and US Building Performance for		
	High Rise Buildings		
	School of Building Studies, University of Technology, Sydney		
11.	**Russel and McGowan**	**1987**	
			1. Knowledge of subcontractors work
	Russell, A.D. and McGowan, C. (1987)		2. The nature of relationships between the general contractor
	Subcontractor Control for High-rise Construction		3. Subcontractor and client's agent
	Building Technology and Management, JuneI-July, 24-33.		
12.	**Ashworth**	**1988**	
			1. Construction technology changes slightly with the passage of time
	Ashworth, A. (1988)		2. Complexity of projects
	Cost Studies of Buildings. Longman, London.		
13.	**Gordon**	**1988**	
			1. Construction site efficiency
	Gordon, Sir A. (1988)		2. Buildings' constructability factor
	Co-ordinated project information:		3. Management and productivity
	The background to its development,		4. Subcontractors' experience
	Building Technology and Management, JuneIJuly, 14-16.		5. Relationship between subcontractors and client
14.	**NEDO**	**1988**	
	National Economic Development Office of the UK		1. The end use of the building (i.e. whether office,retail or other, e.g. churches).
			2. Whether the building is purpose built or speculative
	NEDO (1988) Faster Building for Commerce. London, NEDO.		3. Whether the project is new work or refurbishment of existing building
			4. The customer (client)
			5. Quality of design or design information
			6. Contractor's control over site operations
			7. Integration of subcontractors into the process of design and construction
15.	**Chaung - Chiang**	**1989**	
			A. Project Related Factors
	Chauhan, R.L. and Chiang, W.C. (1989)		1. Lack of project information and uncertainities of details
	Weighting Factors in Construction Management		2. Work plan
	Performance Evaluation		3. Construction site problems
	Proceedings Applied Construction Management Conference,		4. Defining the project finish date
	Sydney, Australia, 13745		5. Contract conditions
			B. Environment Related Factors
			1. Economic and commercial factors
			2. Socio-cultural factors
			3. Legal-poltic factors
			C. Management Related Factors
			1. Leadership in management, communication and motivation sufficiency
			2. Flexibility in organization
			3. Insufficient and careless management systems
			4. Control systems
			5. Financial factors
16.	**Türesoy**	**1989**	**groups with the most important factors**
			A. Management related factors
	Türesoy, Mürvet		"Preparing effective work plan"
	Yapı Üretiminde Süre Tahmini ve Yapım Süresini Etkileyen Faktörler		B. Environment Related Factors
	Yüksek lisans tezi, 1989		"Weather"
			C. Project related factors
			"Project team experience"
			D. Resource usage related factors
			"On time materal delivery"
17.	**Brensen**	**1990**	
			1. There was only a slight association between type of client or type of project, and construction time performance.
	Bresnen, M.J., Haslam, C.O., Beardsworth, A.D., Bryman, A.E.		2. Insignificant association was found between contract type and construction time performance.
	Performance on Site and the Building Client		3. They also found that new work was built quicker than refurbishment projects.
	Occasional Paper No. 42, Chartered Institute Of Building, Ascot, UK		

Table A.1. Continued

No	Author	Year		Factors
18.	**Walker**	**1990**		
			1.	Scope of works
			2.	Complexity of design
			3.	Buildability
			4.	Client/design/construction team relatonship
			5.	Organizational structure
			6.	Speed of decisionmaking
			7.	Industrial relations climate
19.	**Nkado**	**1991**		**6 main categories (28 factors)**
			1.	Client related factors
	Nkado, R. N. (1991)		2.	Designers and design consultants
	A Construction Time Information System for the Building Industry		3.	Type of the contract
	Phd Thesis, University of Reading, UK		4.	Project conditions
			5.	Management related factors
			6.	External factors
20.	**Naoum**	**1991**		**important factors**
			1.	Project's cost
	Naoum, S.G. (1991)		2.	Procurement method
	Procurement and Project Performance - A Companion of		3.	Designer's experience
	Management Contracting and Traditional Contracting.			
	Occasional Paper No. 45, Chartered Institute Of Building, Ascot, UK.			
21.	**Callahan**	**1992**		
			1.	The height of a building (NoF)
	Callahan, M.T., Quackenbush, D.G. & Rowings, J.E. (1992)		2.	Project complexity (construction technique, major equipment needed, construction sequence)
	Construction Project Scheduling.		3.	The location of building
	McGraw-Hill, New York.			(whether or not restrictions or easements exist, availability of services, supply of resources, use of major equipment, and productivity on site)
22.	**Raymond**	**1994**		**the first 10 factors (28 factors)**
			1.	Work completion sequence determined by clients
			2.	Construction work plans by contractors
			3.	Form of construction
			4.	Project team priorities about construction duration.
			5.	Building complexity
			6.	Assessment of clients' construction duration priority
			7.	Consruction site conditions
			8.	Project constructability
			9.	Suitability of management team
			10.	Project information completion
23.	**Saraç S**	**1995**		
				A. Project Related factors
			1.	Characteristics and complexity of project
			2.	Degree of standardization and mechanization, repetition of work
			3.	The end product defines the duration of production with its characteristics. Simple and simiar details are obtained in shorter times. Standardization affects time as well as mechanization in accordance with the size of the project.
			4.	Conditions of contract povide important information for the programming. Unrealistic commend of the employer may result in false programmes.
	Saraç, S., 1995			**B. Environment Related factors**
	A Time Information System for the Construction Industry		1.	The geographic status of the site
	M. S. Dissertation, Department of Architecture, İTU, Turkey		2.	The accessibility to the site
			3.	Weather (primary reason), the traffic of the land
			4.	The cultural characteristics also affect time;
			5.	The working traditions and styles of people on site play an important role for duration of project.
				C. Management Related factors
			1.	Experince of high level managers and all people involved in time planning increase the probability of obtaining the ideal time for construction
			2.	Planning of construtcion time, using the best programming method for the project, using past experiences in estimating the durations of work packages, defining the actvities
			3.	Degree of expertation, powers of decision-makers, believing that the programme is a useful tool for time control, decrease in variation of work packages
			4.	Subcontractors

Table A.1. Continued

No	Author	Year	Factors
24.	**Nkado**	**1995**	
			1. Client's specified sequence of completion
	Nkado, R. N., 1995.		2. Contractor's programming actions
	Construction Time-Influencing Factors:		3. Form of construction
	the Constractor's Perspective		4. Client's priority on construction time
	Construction Management and Economics, Vol. 13, p. 81-89		5. Designer's priority on construtcion time
			6. Project complexity
			7. Location
			8. Buildability of design
			9. Availability of the construction management team
			10. Timeliness of the project information and documents
25.	**Walker**	**1995**	
			1. Construction management effectiveness;
	Walker, D. H. T., 1995		2. The sophistication of the client and the client' s representative in terms of creating and maintaining
	An Investigation into Construction Time Performance		positive project team relationships with the construction management and design team;
	Construction Management and Economics, Vol. 13, p. 263-274		3. Design team effectiveness in communicating with construction management
			and client' s representative teams
			4. A small number of factors describing project scope and complexity.
26.	**Chan and Kumaraswamy**	**1995**	
			1. Construction Cost / Value
			2. Type of construction
			a. Product eg. Earth dam; steel framed-building
			b. Technical parameters eg.height, floor area, spans
	Kumaraswamy, M. M. and Chan, D. W. M., 1995		c. Quality
	Determinants of Construction Duration		i. Of construtcion required
	Construction Management and Economics		ii. Of design & documentation
	Vol. 13, p. 209-217		d. Complexity (on scale from 1 to 10)
			3. Locaton
			4. Client's and other imperatives / priorities
	Chan, D. W. M. and Kumaraswamy, 1995		a. Managerial
	A Study of the Factors Affecting Construction Durations in Hong Kong		i. Abilities
	Construction Management and Economics		ii. Motivation
	Vol. 13, p. 319-333		iii. Systems
			b. Organisational
			i. Structure
			ii. Style
			iii. Informaton Systems
			c. Labour
			i. Work systems
			ii. Skills
			iii. Motivation
			d. Technology
			i. Labour / equipment mix
			ii. Plant & equipment
			..age
			..level of technology
			5. Total factor productivity
			6. Others
			7. Type of contract
			a. Risk allocation (eg, inflation, technical)
			b. Tenderer selection method (open, prequalification, selection etc)
			c. Management structure eg: traditional; design and build
			d. Payment modalities eg: fixed price; cost plus; BOT
			8. Post contractual developments
			a. Variation Orders
			i. Magnitude
			ii. Interference level
			iii. Timing
			b. Orders
			c. Conflicts
27.	**Kaming**	**1997**	**factors causing delays**
			1. Weather
	Kaming, F. P., Olomolaiye, O. P. (1997)		2. Lack of resources
	Factors Influencing Construction Time and Cost Overruns		3. Experience
	on High-rise Projects in Indonesia.		4. Project changes
	Construction Management and Economics		5. Labour productivity
	v.15 p.83-94		6. Local legal restrictions
			7. Insufficient work programs

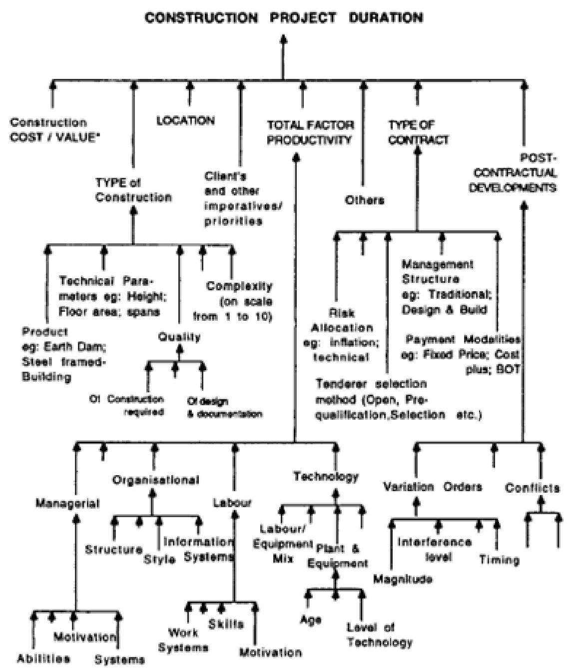
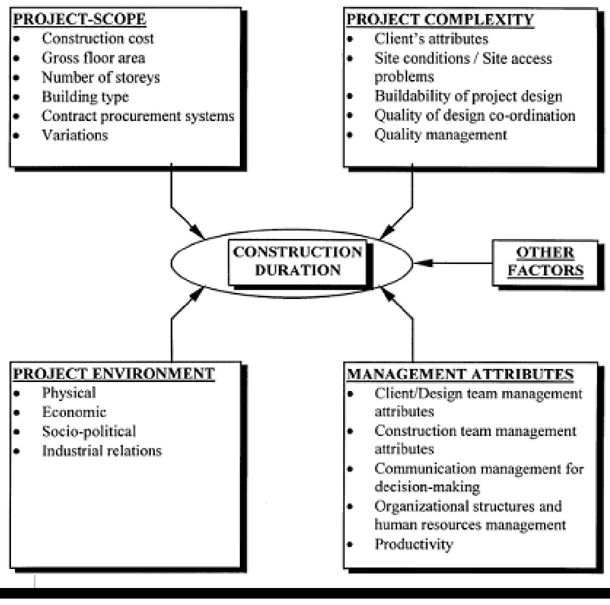


Table A.1. Continued

No	Author	Year		Factors
28.	**Karslı D**	**1998**		
			1.	Factors about client / client's representative
	Karslı, E. D., 1998		2.	Factors about project team
	İnşaat Süresini Etkileyen Faktörler ve İnşaat Süresi Tahmin Modelleri		3.	Factors about general contractor
	M. S. Dissertation, Department of Architecture, İTU, Turkey		4.	Factors about subcontractrors
			5.	Factors about coordination of construction teams
			6.	Factors about the project
			7.	Factors about the construction equipment and material
			8.	Factors about the environment
			9.	Factors about the contract
			10.	Other factors
29.	**Dissanayaka ve Kumaraswamy**	**1999**		**factors affecting project performance**
			1.	Procurement related factors (5 group)
	Dissanayaka, S. M. and Kumaraswamy, M. M.,1999.		2.	Non-procurement related factors (6 group)
	Evaluation of Factors Affecting Time and Cost Performance			
	in Hong Kong Building Projects,			
	Engineering, Construction and Architectural Management,			
	Vol. 6, No. 3 p. 287-298			
30.	**Mulholland ve Christian**	**1999**		**Sources of risks affecting schedule**
			1.	Engineering Design related factors
	Mulholland, B. and Christian,1999		2.	Project management related factors
	Risk Assesment in Construction Schedules		3.	Site construction related factors
	Journal of Construction, Engineering and Management, p. 8-15		4.	Procurement related factors
31.	**Walker and Vines**	**2000**		**4 main category; (22 factors)**
			1.	Management quality
	Walker, D. H. T. and Vines, M. W.,2000		2.	Coordination
	Australian Multi-Unit Residential Project		3.	The degree of experience and expertise for the same type and size of project
	Construction Time Performance Factors		4.	Environmental factors
	Engineering, Construction and Architectural Management			
	Vol. 7, No. 3, p. 278-284			
32.	**Chan and Kumaraswamy**	**2002**		
				A. Project Scope
	Chan, D. W. M. and Kumaraswamy, M. M.,2002		1.	Construction Cost
	Compressing Construction Durations:		2.	Gross Floor Area
	Lessons Learned from Hong Kong Building Projects		3.	Number of Storeys
	International Journal of Project Management		4.	Building Type
	Vol. 20, p. 23-35		5.	Contract Procurement Systems
			6.	Variations
				B. PROJECT COMPLEXITY
			1.	Client's attributes
			2.	Site conditions / Site acess problems
			3.	Buildability of project design
			4.	Quality of design co-ordination
			5.	Quality management
				C. PROJECT ENVIRONMENT
			1.	Physical
			2.	Economic
			3.	Socio-political
			4.	Industrial relations
				D. MANAGEMENT ATTRIBUTES
			1.	Client/Design team management attributes
			2.	Construction team management attributes
			3.	Communication management for decision-making
			4.	Organizational structures and human resources management
			5.	Productivity
				E. OTHER FACTORS



APPENDIX B

TYPES OF DURATION ESTIMATION MODELS FOUND IN LITERATURE

Table B.1. Types of Duration Estimation Models found in literature

No	Name of the article	Type of Modeling (According to Fitzgerald Classification)	Why did they do this study?	When?	Case study	Variables	Additional Information	Results
A.	**EXPERIENCE-BASED MODELS** Algorithms Heuristics Expert System Programming							
1.	**Moselhi, O. and Nicholas, M. J.**, *Hybrid Expert System for Construction Planning and Scheduling*, Journal of Construction Engineering and Management, Vol. 116, No. 2, p. 221-238, **1990. (Canada)**	Hybrid Expert System - EXPERT CONSTRUCTION SCHEDULER (ESCHEDULER)	to develop a prototype hybrid expert system for construction planning and scheduling by integrating available computing methods with expert system technology.		(Montreal - Canada) The building is a two-story warehouse with structural steel framing, and it was divided into 14 activities.	It includes 4 main databases: (1)WEATHER-based on ten-year historical climatological data for the city of Montreal (2)HOLIDAY (3)LISTACT-the list of activities, codes, durations, activity definitions and relationships -2 modules; activity translator ve joblogic helper (4)PROJREC-duration modifier module (5)management performance	Project Management Software (PROMIS); Interface Program (FORTRAN); Knowledge Base Database (GURU) were used. Information of activities can be defined in developed model.	By using softwares, PROMIS and FORTRAN.etc, A system developed to modify the activities which dont have a sequential relation or dont affect each other. Factor affecting construtcion durations effects on activities were analyzed as "less", "middle", "high".
2.	**Wu, R. W. and Hadipriono, F. C.**, *Fuzzy Modus Ponens Deduction Technique for Construction Scheduling*, Journal of Construction Engineering and Management, Vol. 120, No. 1, p. 162-179, **1994. (USA)**	FUZZY LOGIC- Expert System (ADDSS-Activity Duration Decision Support System)	to develop more realistic duration estimation modeling system.		The foundation part of library construction project in Ohio University	(1)site condition (2)equipment performance (3)labor performance (4)weather conditions (5)material supply (6)management performance	(ADDSS-Activity Duration Decision Support System) converted linguistic values to numerical values to reduce making wrong estimates.	Trigonometric calculation methods were used for the main steps in the model. CA-SperProject software integration were provided.
3.	**Boussabaine, A. H.**, *Neurofuzzy Modelling of Construction Projects' Duration I: Principles*, Engineering, Construction and Architectural Management, Vol. 8, No. 2, p. 104-113, **2001. (UK)**	NEUROFUZZY MODELLING						
	Boussabaine, A. H., *Neurofuzzy Modelling of Construction Projects' Duration II: Application*, Engineering, Construction and Architectural Management, Vol. 8, No. 2, p. 114-129, **2001. (UK)**	NEUROFUZZY MODELLING			230 buildign projects	(1) Selection of the tendering method (2) Number of tenders (3) Type of contract (4) Fluctuation in prices (5) Available space in the project site (6) Access to the project site (7) Slope of the project site (8) Ground conditions (9) Type of foundations (10) Type of frame (11) Number of stories (12) Area (m2) (13) Tender price (contract sum)	Neurofuzzy is a combination of the explicit knowledge representation of fuzzy logic with the learning power of neural networks. The basic idea of the compostion method of fuzzy and ANN methods is to achieve fuzzy reasoning by a neural network whose weights represent the parameters associated with a set of fuzzy rules.	Neurofuzzy models are fundamentally different from neural and expert systems. Neurofuzzy systems have the following characteristics: 1. Automatically extract the consequents and the antecedents of a set of fuzzy rules from the original input/output data sets 2. Automatically train and change the shape of member functions according to data patterns 3. The number of neurons are determined from the number of membership functions on each input variable 4. Training and optimisation periods are shorter 5. Allows the inclusion of knowledge and expertise in choosing system topology 6. Leads to a model which can be easily understood Model is reasonably accurate **(R=0,76)**
4.	**Kanoğlu, A.**, *An Integrated System for Duration Estimation in Design/Build Projects and Organizations*, Engineering, Construction and Architectural Management, Vol. 10, No. 4, p. 272-282, **2003. (Turkey)**	PERFORMANCE BASED DURATION ESTIMATION MODEL - Expert System Intehrated System (SPIDER)	to explain the implementation of an experience-based computational model for project duration estimaiton which is integrated with an automation system developed for design/build firms		Türkiye		(1) MITOS (Multi Phase integrated Automation System for Design/Build Organization) (2) ASCE, ASAP, ASCC, MS Project...	
	Sezgin, Y., *Tasarım/Yapım Organizasyonları için Proje Gerçekleşme Süresinin Tahminine Yönelik Bir Bütünleşik Model Önerisi*, M. S. Dissertation, Department of Architecture, Istanbul Technical University, Turkey, **2003. Turkey)**	PERFORMANCE BASED DURATION ESTIMATION MODEL - Expert System Intehrated System (SPIDER)	to develop an experience-based computational model for project duration estimaiton which is integrated with an automation system developed for design/build firms by taking into consideration the mentioned concerns		Türkiye		(1) Defining Project to find out analogous projects in databases (2) quantity surveys, variations by looking the factors affceting construtcion durations and results (optimistic, pessimistic and average) (3) MS Access for database	
5.	**Kumar, V. S. S. and Reddy, G. C. S.**, *Fuzzy Logic Approach to Forecast Project Duration in Construction Projects*, Construction Research Congress, **2005.**	FUZZY LOGIC	to estimate the project parameters by incorporating the qualitative and quantitative factors using fuzzy logic approach.		a prestressed concrete sleeper factory, India		(4) Instead of identifying a single critical path, it identifies activities with various degrees of criticalities and thus reduces the chance of the near-critical activities being ignored by project manager. (5) This methodology is superior to the conventional probabilistic methods, since it incorporates all the available information from the expert's judgement (6) Fuzzy set analysis does not provide a fuzzy answer, but rather, a means of reducing the fuzziness in achieving project completion time.	(1) The applicability of fuzzy set theory to project duration estimaiton has been vindicated by comparison of its results of conventional techniques. (2) The advantage of the model is that it is not sensitive to small variations in the membership values but it is sensitive to the choice of fuzzy relation between the consequences and duration of an activity (3) This model can incorporate all intangible and subjective values into the analysis

Table B.1. Continued

No	Name of the article	Type of Modeling (According to Fitzgerald Classification)	Why did they do this study?	When?	Case study	Variables	Additional Information	Results
B.	**SIMULATION** Heuristics Expert Models Decision Rules							
1.	**R.I. Carr**, Simulation of construction project duration, J. Constr. Div., ASCE 105 2 (**1979**), pp. 117–127.							
2.	**Ahuja HN, Nandakumar V.**, Simulation model to forecast project completion time, J. Construction Eng Managment **1985**, 111 (4), (325-42)							
	PARAMETRIC Regression Statistical Models Decision Rules							
1.	**Bromilow, F.J. (1974)**. Measurement and scheduling of construction time and cost performance in the building industry. *The Chartered Builder*, 10, 57.**(Australia)**	Regression Model - Power of Regression - $T=KC^B$		pre-design stage	Australia 329 Building Projects	Cost		
	Bromilow, F. J., Hinds, M. F., and Moody, N. F., *AIQS Survey of Building Contract Time Performances*, Building Economics, Vol. 19, p. 79-82, **1980. (Australia)**	Regression Model - Power of Regression - $T=KC^B$		pre-design stage	Australia 408 Building Projects	Cost		
2.	**Ireland, V.**, *The Role of Managerial Actions in the Cost, Time and Quality Performance of High-Rise Commercial Building Projects,* Construction Management and Economics, Vol. 3, p. 59-87, **1985. (Australia)**	Multiple Linear Regression Analysis	An analysis of the effects of managerial actions on the objectives of reducing time, reducing cost and increasing quality were undertaken.	post contract stage	Australia 25 high rise office buildings (1970s)	(1)COMPINDX(Complexity of form of construction) (2)CPDD(Construction Planning During Design) (3)AREA (4)DIPT(Disputes per unit of time) (5)DCOORD2(Design Construction Interface Coordination) (6)NoS (7)CVPC(Contract Variation per unit of Bld Cost)	it is possible to relate managerial actions to the achievement of objectives for high-rise commercial building projects...Emphisizing managerial actions which were found to affect time, cost and quality will lead to more efficient projects.	to reduce time; (1)increased CPDD(construtcion plannin during design) (2)reduced CONTVAR(variation to the contract) (3)reduced NoStorey (4)reduced COMPINDX(complexity of form of construtcion) (5)increased DCOORD2(design construction interface coordination) (6)reduced DIPT(disputes per unit of time coordination) **R^2 were used
3.	**Kaka, A. and Price A. D. F.**, *Relationship between Value and Duration of Construction Projects,* Construction Management and Economics, Vol. 9, p. 383-400, **1991. (UK)**	Regression Model	to make comparisons with classifying the data into set of factors and analyzing them to see the effect of each factor on construction duration.		UK 661 building projects and 140 roadwork (1984-1989)	(1) type of client (public, private) (2) type of project (building, civil engineering) (3) type of tender (open competition, selected competition, negotiated competition) (4) form of tender (fixed price tender, fixed adjusted tender)		(1) the type of tender has no effect on the duration. (all the others influenced) (2) Construction durations of projects with adjusted price contracts generally took longer than projects with fixed price contracts. (3) Construction durations of public buildings were shown to be longer than that of private buildings. (4) Construction durations of building projects took generally longer than that for civil engineering projects of similar value.
4.	**Nkado, R. N.**, *Construction Time Information System for The Building Industry,* Construction Management and Economics, Vol. 10, p. 489-509, **1992. (UK)**	Multiple Linear Regression Analysis	to prioritize factors which are taken into consideration by accomplished contractors in planning the construction time of buildings.	pre-design stage	29 commercial, privately funded blds	(1) Gross floor area (GFA) (m2) (2)Height from ground to eaves levels (m) (3) Type of cladding (prefabricated panels, curtain wall, brick) (4) Number of floors excluding basement floor (5) Location (London, elsewhere) (6) Type of structural frame (concrete, steel, other) (7) Storey height (8) Approximate volume of bld (m3)	5 activity groups; (1) substructure (2) superstructure (3) cladding (4) finishes (5) services and 4 sequential lag times	The model can be used for estimating construction durations and producing outline construction plan of buildings in the early design stages, as the models provided reasonably accurate results.....A significant degree of consistency in ranking 'time influencing factors' was found. The most important factors are apparently those which can readily be identified or deduced from project information and whose impact on construction time can generally be assessed explicitly by mathematical and judgemental analyses. ****tested with other 3 office blds' data.**
5.	**Kumaraswamy, M. M. and Chan, D. W. M.**, *Determinants of Construction Duration,* Engineering, Construction Management and Economics, Vol. 13, p. 209-217, **1995. (Hong Kong)**	Simple Linear Regression Analysis	The **first phase** of an investigation; to search factors affecting construction project duration..	pre-design stage		Floor Area	Cases are divided as public-private; housing-civil engineering	(1) There is significant relationship between duration and Floor Area (2) Public Buildings' durations are lower than private ones in Hong Kong. (standardization of designs) (3) Public or private, There ise no difference in UK (4) Private buildings are more efficient in Australia

Table B.1. Continued

No	Name of the article	Type of Modeling (According to Fitzgerald Classification)	Why did they do this study?	When?	Case study	Variables	Additional Information	Results
	PARAMETRIC Regression Statistical Models Decision Rules							
6.	**Chan, D. W. M. and Kumaraswamy, M. M.**, *A Study of the Factors Affecting Construction Durations in Hong Kong*, Construction Management and Economics, Vol. 13, p. 319-333, **1995. (Hong Kong)**	**(1) Simple Linear Regression Analysis** - 2 simple linear regression model (duration with GFA and duration with NoF) **(2) A Multiple linear regression model** (duration with cost and GFA)	The **second phase** of an investigation: 2 main objectives: (1) (1) to explore and compare the empirical relationships between duration and cost; duration and total gross floor area; duration and total number of storeys; and any other significantly related variables in representative samples within different categories of projects completed during 1990-1993 in Hong Kong. (2) The second was to determine the main causes of delays, if any, in these projects.	pre-design stage	Hong Kong 111 projects (1990-1993)	focused on project scope variables such as (Macro Variables); (1) Cost (2) Floor Area (3) Number of Floors		(1) There is a significant relationship between duration with GFA and cost. (2) Besides Macro variables, Micro variables affecting productivity (plant utilization-efficiency of site labourers) affects duration also. (a) Plant utilization levels such as tower cranes and truckmixers (b) A comparison of the average productivity of different concrete placing methods such as pump and crane and skip; (c) The activity analysis profiles of construction workers such as formwork riggers, steel bar benders, steel-fixers and concretors on site. ****tested and confirmed**
7.	**Chan, D. W. M. and Kumaraswamy, M. M.**, *Modeling and Predicting Construction Durations in Hong Kong Public Housing*, Construction Management and Economics, Vol. 17, p. 351-362, **1999. (Hong Kong)**	Multiple Linear Regression Analysis	to derive benchmark measures of standard norms for overall construction duration by modeling the primary work packages of the building construction projects	pre-design stage	Hong Kong 56 housing projects standard "Harmony" type (1990-1996)	(1) Actual Construction Cost (2) Total Volume of Building (3) Type of Housing Scheme (rental/purchase) (4) Presence/Absence of precast facades (5) Ratio of Total GFA (m^2 to the number of storeys)		Reliable model (The model was applied 9 new building data, and results also compared with planners' estimations, (**R^2**,the significance level of variables)
	Chan, A. P. C. and Chan, D. W. M., *Developing a Benchmark Model for Project Construction Time Performance in Hong Kong*, Building and Environment, Vol. 39, p. 339-349, **2004**.							
	Chan, A. P. C. and Chan, D. W. M., *Benchmarking Project Construction Time Performance – The Case of Hong Kong*, Project Management-Impresario of the Construction Industry Symposium, **2002**.							
8.	**Walker, D. H. T.**, *An Investigation into Construction Time Performance,* Construction Management and Economics, Vol. 13, p. 263-274, **1995. (Australia)**	Multiple Linear Regression Analysis	to contribute to the study of CTP improvement by identifying factors that influence CTP and demonstrating how this knowledge may be applied within the context of continuous performance improvement and adoption of best practice...a systematic method for CTP has been developed (for developing, a duration estimation model was developed also)	post contract stage	Australia 33 construction ptojects (1987-1993)	(1) Building construction costs (2) Additional period/construction duration ratio (3) Work type (new, refurbishment, fit out etc.) (4) Client / Client representative' objectives about quality (5) Client representative' effectiveness on construction management (6) Use of information technology (7) Communication (between architect/engineer and contractor)	Developed duration estimation model was used for comparison of Construction Time Performances (CTP). It was found that 4 factors affected CTP; (1) Construction Managemenet (CM) effectiveness (2) Sophistication of client and the the client representative -relations with desing and CM teams- (3) Design Team Effectiveness related to communication with both CM and clients representative. (4) Other factors related with project scope and complexity	(1) This model couldn't be used at pre-design stage. (2) Construction Management (CM) team performance was found as the most important factor for Construction Time Performance (CTP). (3) Representative management effectiveness was also found as an important factor for CTP. **(1) p-values<0,05 (All variables)** **(2) R2 value=0,9987**
	Karslı, E. D., *İnşaat Süresini Etkileyen Faktörler ve İnşaat Süresi Tahmin Modelleri*, M. S. Dissertation, Department of Architecture, Istanbul Technical University, Turkey, **1998. (Turkey)**	Walker's Model was chosen to apply as the most appropriate model for Turkey.	(1) to search factors affecting construction duration. (2) to search models for estimating construction duration. (3) to chose the most appropriate model to apply in Türkiye.	-	-	-	(1) 8 case buildings in Istanbul, Turkey. (2) Adjusted cost (1990 Australia Dollar) (3) Comparing working days (8-10 hours per day in Turkey; 7,6hours in Australia)	(1) Australia and Turkey has really different Construction Time Performances. (2) Total Floor Area, contract type are not parameters (3) Financial flow does not considered for coorperations especially. (4) All countries should develop their own models (local models), because of all the places has their own characeristics. and they should have their information systems

Table B.1. Continued

No	Name of the article	Type of Modeling (According to Fitzgerald Classification)	Why did they do this study?	When?	Case study	Variables	Additional Information	Results
	PARAMETRIC Regression Statistical Models Decision Rules							
9.	**Saraç, S.**, *A Time Information System for the Construction Industry,* M. S. Dissertation, Department of Architecture, İstanbul Technical University, Turkey, **1995. (Turkey)**	Lineer Regression Analysis	to establish a time information system for time planning of a project at early design from minimal information.	pre-design stage	Turkey 33 projects of Turkish Ministry of Public Works and Resettlement (school and housing projects)	(1) Function of a project (Nominal) (2) Type of structural frame (Nominal) (3) Location (Nominal) (4) Accessibility to site (Nominal) (5) Type of cladding (Nominal) (6) Atrium existence (Nominal) (7) Intensity of services (Nominal) (8) Number of storeys (Ratio) (9) Height from ground to eaves level (Ratio) (10) Area of ground floor (Ratio) (11) Gross Floor Area (Ratio) (12) Approximate volume of excavation (Ratio)	5 activity groups; (1) substructure (2) superstructure (3) cladding (4) finishes (5) M&E services and 4 sequential lag times	There is a relationship between the durations of the main work groups and project variables that can be easily assessed at the early design stages. A very simple and easy to be used model.
10.	**Khosrowshahi, F. and Kaka, A. P.**, *Estimation of Project Total Cost and Duration for Housing Projects in the U.K.*, Building and Environment, Vol. 31, p. 373-383, **1996. (UK)**	Multiple Linear Regression Analysis	(1) a fast, cheap and easy production of a forecast (2) to identify the most influential variables and quantify their influence	pre-design stage	UK 54 housing projects	(1) No of units (2) project operation (3) project sub-type (4) abnormality (5) start month (6) horizontal access	The cost value used in the duration estimaiton model was the result of their cost models'.	Two separate simply applied models. **Adjusted R2 (%92,7)**
11.	**Chan, D. W. M. and Kumaraswamy, M. M.**, *Forecasting Construction Durations for Public Housing Projects: A Hong Kong Perspective*, Building and Environment, Vol. 34, p. 633-646, **1999. (Hong Kong)**	Multiple Linear Regression Analysis	to generate standards for overall completion periods of public housing blocks by modelling the durations of the primary work packages		Hong Kong 15 standard housing blocks New Cruciform type	(1) No storeys (2) GFA (3) Ratio of GFA to Area of ground floor plan (4) Ratio of Area of external cladding to GFA (5) Type of foundations used (6) Information flows between architect:engineer and contractor (7) Ground conditions for construction (8) Labour productivity	5 activity groups; (1) Piling (2) Pile caps /raft (3) Superstructure (4) E+M services (5) Finishes and their respective sequential start-start lag times	
14.	**Dissanayaka, S. M. and Kumaraswamy, M. M.**, *Comparing Contributors to Time and Cost Performance in Building Projects,* Building and Environment, Vol. 34, p. 31-42, **1999. (Hong Kong)**	Multiple Linear Regression Analysis	to identify the relative strengths of the linkages between procurement sub-systems any other relevant variables and project outcomes in Hong Kong based building projects.		Hong Kong 32 building projects	(1) procurement related (2) non-procurement related factors		procurement sub systems variables are less significant than the non-procurement related variables in predicting time and cost performance levels on Hong Kong building projects.
15.	**Dissanayaka, S. M. and Kumaraswamy, M. M.**, *Evaluation of Factors Affecting Time and Cost Performance in Hong Kong Building Projects,* Engineering, Construction and Architectural Management, Vol. 6, No. 3 p. 287-298, **1999. (Hong Kong)**	Multiple Linear Regression Analysis	1. to identify and group particular factors (variables) which are significantly related to time and cost performance; 2. to analyse the relationships of procurement and non-procurement related factors with time and cost performance; 3. to develop time and cost over-run models using critical factors influencing time and cost performance.		Hong Kong	(1) procurement related factors a) work packaging b) functional grouping c) payment modality d) selection modality e) conditions of contracts (2) non-procurement related factors a) factors related to project b) factors related to client:client representative c) factors related to designer d) factors related to contractor e) factors related to team performance f) factors related to external conditions	(1) MLR and ANN were used for duration and cost estimaitons (2) The results indicate that ANNs should be applied to achieve better results, after initially applying MLR to a larger database and confirming the significant variables. **(1) MAPE** (Mean Absolute Percentage Error) **(2) R2,** **(3) RMSE** (Root Mean Square Errors) were used.	(1) time over-runs appear to be greatly influenced by non-procurement related factors, apart from indirect influences (on design and construction complexity and variation levels) arising from the selection of the design team; (2) cost over-runs appear to be greatly influenced by both procurement and non-procurement related factors; (3) the 'payment modality' procurement sub-system appears to influence cost over-runs; (4)Artificial neural networks (in addition to multiple linear regression) are useful in forecasting time and cost escalations; and it is also useful to examine patterns of differences in the average time and cost over-runs, between groups of projects that have used different procurement systems.

Table B.1. Continued

No	Name of the article	Type of Modeling (According to Fitzgerald Classification)	Why did they do this study?	When?	Case study	Variables	Additional Information	Results
	PARAMETRIC Regression Statistical Models Decision Rules							
16.	**Skitmore, R. M. and Thomas Ng, S.**, *Forecast Models for Actual Construction Time and Cost*, Building and Environment, Vol. 38, No. 8, p. 1075-1083, **2003. (Australia & Hong Kong)**	Regression Model -(A forward crossvalidation regression analysis + A standard crossvalidation regression analysis)	to develop several models for actual construction time and cost prediction	post contract stage	Australia 93 construction projects	(1) client sector (2) contractor selection method (3) contractual arrangement (4) project type (5) contract period (6) contract sum	Sensitivity analysis were used	(1) The errors in predicted actual construction time become smaller as the contract period increases. (2) In contrast, the errors in predicted actual construction cost are virtually the same for large and small projects. (3) The actual construction time for industrial project is the longest when compared with residential, educational and recreational projects (4) significant savings in actual construction time can be achieved when negotiated tender and design and build contract are used instead of the traditional open tendering and lump sum contract approaches.
17.	**BCIS**, *Guide to Building Construction Duration*, MFK Chiltern Press, England, **2004. (UK-London)**	Multiple Linear Regression Analysis - (least squares linear regression)	This guide presents and analyses on the "actual time" taken to construct buildings. It provides an aid to clients and their consultants in estimating or benchmarking the construction duration the construction duration at the earliest stages of future projects.	pre-design stage	UK BCIS database 1500new build building projects (1998-2002)	(1) procurement route (2) contractor selection method (3) client type (4) building function (5) region (6) value (2nd quarter 2003 - UK mean location;location and year indexes were used) "Log Contract Sum Squared" dependent variable: "the square root of construction duration"	This search also contains a CD (BCIS Building Construction Duration Calculator); Ability to predict the time a buildingwill take to construct is considerably is worse than its ability to predict how much it will cost... 25% of projects experience increased costs over the construction period, nearly 40% overrun their agreed contract period. (7) projects between £750.000 and £10million show a consistent relationship between the log of the cost and durations ie. the spend rate accelerates as the cost increases at a definable rate; for smaller and larger projects, below £200.000 and above £7 million, the change in construtcion duration is much less marked (1) **ANOVA** -Analysis of varience-(to confirm the validity of the results) (2) **SE**-Standard Error- (measure of the accuracy with which the coefficient has been measured) (3) **Significance-t test**- (to test whether an independent variable has added anything to he model)	(1) A clear and significant relationship between construction duration and total construtcion cost. (2) Housing projects tend to take longer than other schemes of the same value for both public and private sectors, while industrial building projects are completed more quickly; non housing projects above £750.000 for private clients tend to be completedfaster tha those for public sector clients, although this may well reflect the amount of industrial buildings in the private sector sample (3) The method of contractor selection does not seem to significantly influence the speed of construction. (4) Complexity od design influences the time it takes to build. (5) The analyses by location probably reflects the differing mix of projects in each region. (6) projects let on a traditional lump sum basis up to £550.000, and design and build projects over £1,3 milion, tend to be completed more quickly than other projects
18.	**Blyth, K., Lewis, J. and Kaka, A.**, *Predicting Project and Activity Duration for Buildings in the UK*, COBRA **2001** Conference Papers. **(England)**	Multiple Linear Regression Analysis	to be able to reliably predict overall project and activity duration for the sample of UK buildings, based upon a number of qualitative and quantitative project characteristics.	pre-design stage	UK 56 building projects	**21 PRE-DETERMINDE PROJECT CHARACTERISTICS** **8 non-interval variables:** (1) project function (1-11) (2) location (1-8) (3) type of procurement (1-4) (4) main frame (1-5) (5) site access (1-5) (6) service intensity (1-3) (7) presence of atrium (1-2) (8) cladding type; **13 interval variables:** (1) storeys above ground (2) height above ground (3) ground floor area (4) GFA (5) excavation area (6) average storey height (7) volume of building (8) ratio of floor area to ground floor area (9) average floor area per storey (10) average volume of storey (11) depth of foundations (12) ratio of height of building to depth of foundations (13) actual durations -weeks-	Work packages and time lags	One can rapidly produce an outline construction programme at the early stages of design from limited project information.The 85% minimum reliability for activity duration, coupled with the 93% for overall duration. Contractors could provide an objective basis for the evaluation of stipulated completion times, as implied by the client.

Table B.1. Continued

No	Name of the article	Type of Modeling (According to Fitzgerald Classification)	Why did they do this study?	When?	Case study	Variables	Additional Information	Results
	PARAMETRIC Regression Statistical Models Decision Rules							
19.	**Love, P. E. D., Tse, R. Y. C. and Edwards, D. J.,** , *Time–Cost Relationships in Australian Building Construction Projects*, Journal of Construction Engineering and Management, Vol. 131, p. 187-194, **2005. Australia, Hong Kong and U.K.**	Multiple Linear Regression Analysis (weighted least squares)	to examine the project time and cost relationship by using project scope factors	pre-design stage	Australia 126 construction projects	the final model have 2 variables: (1) GFA (2) NoF project scope factors: (1) project type (1.new build-2.refurbishment/renovation-3.fit out-4.new build/refurbishment) (2) procurement method (3) tender type (4) gross floor area (GFA) (5) Number of storeys		(1) GFA and number of storeys are key determinants of time performance in projects. (2) Cost is a poor indicator of time performance (it is not possible to know the eact cost before the work done) (3) New build projects experienced poor project time performance than the others (4) When GFA decrease or NoF increase; Speed decrease (5) Labour wages are related with Speed of construction and Materials is related with GFA (6) BTC is applicable with reasonably judgments especially early phases.
20.	**Chen, W. T. and Huang, Y.**, .*Approximately Predicting the Cost and Duration of School Reconstruction Projects in Taiwan*, Construction Management and Economics, Vol. 24, p. 1231-1239, **2006. (Taiwan)**	Multiple Linear Regression Analysis - for only DURATION estimation.	to find the relationships between floor area, cost and duration of the reconstruction projects and to build simple estimation models to estimate the cost and duration of reconstruction projects in order to assist the decisionmaking process in the early disaster recovery planning phase.	pre-design stage	Central Taiwan 132 school reconstruction projects	(1) Cost (2) Duration (3) Floor Area	Data were analyzed according to; (1) Type of Contractor (central agency; local governement; pivate sector) (2) Type of Contractor ****R2** for Regression Models / Average Percentage Error **(PE)** for ANN models were used	(1) Data were collected from reconstrutcion of school projects, after the earthquake (Chi-Chi Earthquake) in Central Taiwan, cost ve duration estimations were done by using Regression and ANN Models. (2) Floor Area was the most essential variable for COST estimations (3) Cost and Floor Area were the essential variables for DURATION Estimations (4) ANN Models results were better than Regresson Analysis Results'
21.	**Hoffman, G. J., Jr., A. E. T., Webb, T. S. and Weir, J. D.**, *Estimating Performance Time for Construction Projects,* Journal of Management in Engineering, Vol. 23, p. 193-199, **2007. (USA)**	Multiple Linear Regression Analysis	to gain insight into the significant factors impacting duration by developing a regression model.	pre-design stage	USA 856 Air Force Buildings Facility projects (1988-2004)	(1) Cost (2) ACC-Air Combad Command (3) AETC-Air Education Training Command (4) AFSOC-Air force special operations Command (5) Nourthwestern COE Region (6) in-house design/construction agent	(1) **p value** (2) **R2** (3) **sensitivity analysis**	(1) MLR analysis is better to provide acceptable predictions (2) There was a significant relationships between cost and duration in BTC ve MLR Models
22.	**Helvacı, A.**, *Comparison of Parametric Models for Conceptual Duration Estimation of Building Projects,* M. Sc. Dissertation, Department of Civil Engineering, Middle East Technical University, Turkey, **2008. (Turkey)**	(1) BTC validation (2) **Simple Linear Regression** (only with cost and duration) (3) ANN (with only cost and duration) (4) **MLR** (without cost) (5) ANN (without cost) **Cost Model were done with MLR for cost used im models.	to develop and compare reasonably accurate and practical methodologies for conceptual duration estimation of building projects. • To develop a parametric model for conceptual cost estimation since cost estimates are also required in the assessment of prediction performances of the time-cost models. • To test the time-cost model proposed by Bromilow (1974) • To develop time-cost models (models where cost is used to estimate the duration of the projects) • To develop parametric models for conceptual duration estimation • To compare all the models developed in terms of their predictive abilities.)	at the early stages of projects.	USA 17 building projects (CCRC-continuing care retirement community) (1975-1995)	1) Total building area (Area) 2) Number of floors (NoF) 3) Area per unit (Area/unit) 4) Combined percent area of commons and health center (Per(C+H)) 5) Percent area of structured parking (Per(P)) 6) Type of structural frame of the building (Steel (St), masonry (Mas), reinforced concrete (RC), precast (Pre), wood (W))	(1) **MAPE**-Mean Absolute Percentage Error (2) **PE** (Percentage Error) (3) Regression analysis (backward elmination procedure for parsimonious model; **p-value and R2**)	• Modeling approach is an alternative method to current intuitive planning approach for early stages of the projects with reasonably accuracies. • Time-cost models and parametric models had close reasonably accurate estimations. Time-cost models' predictive accuracy was slightly better than parametric models. However, parametric estimations don't require cost estimation. • ANN and regression analysis' predictive accuracies had no significant differences. Therefore, Helvacı stated "linear regression analysis provides an adequate and pragmatic methodology for duration estimation of construction projects." · 13-15% prective accuracy was achieved with 17 cases at conceptual phase.

Table B.1. Continued

No	Name of the article	Type of Modeling (According to Fitzgerald Classification)	Why did they do this study?	When?	Case study	Variables	Additional Information	Results
	DISCRETE STATE (Other) Linear programming Classical Optimization Network							
1.	**Bhokha, S. and Ogunlana, S. O.**, *Application of Artificial Neural Network to Forecast Construction Duration of Buildings at the Predesign Stage*, Engineering, Construction and Architectural Management, Vol. 6, No. 2, p. 133-144, **1999. (Thailand)**	ANN - Artificial Neural Network (3 layered back-propogation (BP) network consisting of 11 input nodes)	to apply of ANN to forecast the construction duration of buildings at the predesign stage	pre-design stage	Greater Bangkok-Thailand 136 blds (h>23m; A>10.000m2) (1987-1995)	(1) building function (two nodes) (2) structural system (two nodes) (3) functional area (one node) (4) height index (one node) (5) complexity of foundation works (one node) (6) exterior finishing (two nodes) (7) decorating quality (one node) (8) site accessibility (one node).	**MSE** (mean squared error with generalized Delta Rule)	
2.	**Dissanayaka, S. M. and Kumaraswamy, M. M.**, *Evaluation of Factors Affecting Time and Cost Performance in Hong Kong Building Projects,* Engineering, Construction and Architectural Management, Vol. 6, No. 3 p. 287-298, **1999**.	ANN						
3.	**Helvacı, A.**, *Comparison of Parametric Models for Conceptual Duration Estimation of Building Projects,* M. S. Dissertation, Department of Civil Engineering, Middle East Technical University, Turkey, **2008. (Turkey)**	(1) BTC validation (2) Simple Linear Regression (only with cost and duration) (3) **ANN** (with only cost and duration) (4) MLR (without cost) (5) **ANN** (without cost) **Cost Model were done with MLR for cost used im models.	to develop and compare reasonably accurate and practical methodologies for conceptual duration estimation of building projects. • To develop a parametric model for conceptual cost estimation since cost estimates are also required in the assessment of prediction performances of the time-cost models. • To test the time-cost model proposed by Bromilow (1974) • To develop time-cost models (models where cost is used to estimate the duration of the projects) • To develop parametric models for conceptual duration estimation • To compare all the models developed in terms of their predictive abilities.)	at the early stages of projects.	USA 17 building projects (CCRC-continuing care retirement community) (1975-1995)	1) Total building area (Area) 2) Number of floors (NoF) 3) Area per unit (Area/unit) 4) Combined percent area of commons and health center (Per(C+H)) 5) Percent area of structured parking (Per(P)) 6) Type of structural frame of the building (Steel (St), masonry (Mas), reinforced concrete (RC), precast (Pre), wood (W))	(1) **MAPE**-Mean Absolute Percentage Error (2) **PE** (Percentage Error) (3) Regression analysis (backward elimination procedure for parsimonious model; **p-value and R2**)	• Modeling approach is an alternative method to current intuitive planning approach for early stages of the projects with reasonably accuracies. • Time-cost models and parametric models had close reasonably accurate estimations. Time-cost models' predictive accuracy was slightly better than parametric models. However, parametric estimations don't require cost estimation. • ANN and regression analysis' predictive accuracies had no significant differences. Therefore, Helvacı stated "linear regression analysis provides an adequate and pragmatic methodology for duration estimation of construction projects." · 13-15% precitive accuracy was achieved with 17 cases at conceptual phase.

APPENDIX C

DATA RELATED TO THE CASE STUDY BUILDINGS

	BUILDINGS	1	2		2	3		3	4	5		5	6	7
	PARAMETERS	**PROJECT.A**	**PROJECT.B / 1**	**PROJECT.B / 2**	**PROJECT.B**	**PROJECT.C / 1**	**PROJECT.C / 2**	**PROJECT.C**	**PROJECT.D**	**PROJECT.E / 1**	**PROJECT.E / 2**	**PROJECT.E**	**PROJECT.F**	**PROJECT.G**
	HEIGHT(m)												average height was calculated in proportion to the areas with heights	average height was calculated in proportion to the areas with heights
1	BASEMENT	5.00												
2	GROUND FLOOR	4.00	3.57	3.38	3.48	3.78	3.40	3.59	3.55	3.40	3.40	3.40	8.34	4.10
3	1ST FLOOR	4.00		3.49	3.49		3.47	3.47	3.55		3.40	3.40		4.10
4	2ND FLOOR	4.19												
5	3RD FLOOR (TECHNICAL FLOOR)	2.83												
6														
7	TOTAL HEIGHT	20.02	3.57	6.87	6.97	3.78	6.87	7.06	7.10	3.40	6.80	6.80	8.34	8.20
	AVERAGE HEIGHT OF THE FLOORS	**4.00**	**3.57**	**3.44**	**3.48**	**3.78**	**3.44**	**3.53**	**3.55**	**3.40**	**3.40**	**3.40**	**8.34**	**4.10**
	****heights were calculated from top of the floor to another.**													
	AREA OF FLOORS (m^2)													
1	BASEMENT	1,098.66												
2	GROUND FLOOR	693.65	168.25	758.09	926.34	104.82	758.10	862.92	254.69	204.37	169.11	373.48	2,299.33	1,203.80
3	1ST FLOOR	1,292.97		758.09	758.09		758.10	758.10	254.69		169.11	169.11		1,203,80
4	2ND FLOOR	1,292.97												
5	3RD FLOOR (TECHNICAL FLOOR)	389.03												
6														
7														
	Number of Floor (NoF) (basement and technical floors are included)	5	1	2	2	1	2	2	2	1	2	2	1	2
	Total Area (m2)	**4,767.28**	**168.25**	**1,516.18**	**1,684.43**	**104.82**	**1,516.20**	**1,621.02**	**509.38**	**204.37**	**338.22**	**542.59**	**2,299.33**	**2,407.60**
	Average Floor Area (m2)	953.46	168.25	758.09	842.22	104.82	758.10	810.51	254.69	204.37	169.11	271.30	2,299.33	1,203.80
	VOLUME OF FLOORS (m^3)													
1	BASEMENT	5,493.30												
2	GROUND FLOOR	2,774.60	600.65	2,562.34	3,163.00	396.22	2,577.54	2,973.76	904.15	694.86	574.97	1,269.83	19,175.57	4,935.58
3	1ST FLOOR	5,171.88		2,645.73	2,645.73		2,630.61	2,630.61	904.15		574.97	574.97		4,935.58
4	2ND FLOOR	5,417.54												
5	3RD FLOOR (TECHNICAL FLOOR)	1,100.95												
6														
7														
	Number of Floor (NoF) (basement and technical floors are included)	5	1	2	2	1	2	2	2	1	2	2	1	2
	Total Volume (m3)	**19,958.28**	**600.65**	**5,208.08**	**5,808.73**	**396.22**	**5,208.15**	**5,604.37**	**1,808.30**	**694.86**	**1,149.95**	**1,844.81**	**19,175.57**	**9.871.16**
	Average Volume of Floors (m3)	3,991.66	600.65	2,604.04	2,904.37	396.22	2,604.07	2,802.18	904.15	694.86	574.97	922.40	19,175.57	4,935.58
	ADDITIONAL INFORMATION													
1	VERTICAL STRUCTURE	R.C. Columns	R.C. Bearing Walls (outside) and Steel Columns (interior)	R.C. Bearing Walls (outside) and Steel Columns (interior)	R.C. Bearing Walls (outside) and Steel Columns (interior)	R.C. Bearing Walls (outside)	R.C. Bearing Walls (outside) and Steel Columns (interior)	R.C. Bearing Walls (outside) and Steel Columns (interior)	R.C. Columns	R.C. Columns	R.C. Columns	R.C. Columns	R.C. Columns	R.C. Columns
2	FLOOR SYSTEM	R.C.	-	Steel Beams + Ribbed Sheet + R.C. Top	Steel Beams + Ribbed Sheet + R.C. Top	-	Steel Beams + Ribbed Sheet + R.C. Top	Steel Beams + Ribbed Sheet + R.C. Top	R.C. (Floor Block)	R.C. (Floor Block)	R.C. (Floor Block)	R.C. (Floor Block)	-	R.C.(for A-B Blocks 2 storey heights)
3	ROOF	(1) Flat Roof (2) Metal Sheet Roof-Facade Structure and Sunbreakerand Rooflight	Steel Beams and Roof Covering Panel	Steel Beams and Roof Covering Panel	Steel Beams and Roof Covering Panel	Steel Beams and Roof Covering Panel	Steel Beams and Roof Covering Panel	Steel Beams and Roof Covering Panel	Timber framing Roof with aluminium roof covering	Timber framing Roof with aluminium roof covering	Timber framing Roof with aluminium roof covering	Timber framing Roof with aluminium roof covering	Steel Roof and Falt Roof (a small percentage)	C Block: Steel Roof A-B Blocks: Flat Roof
4	FACADE	(1) SiliconeCurtain Glass Wall (2) Metal Sheet Roof-Facade Structure and Sunbreakerand Rooflight	(1) R.C. Bearing Walls (h=4 and 5m) (2) Compact Lam. Panel (h=3,8m)	(1) R.C. Bearing Walls (h=8,30 and 7,80m) (2) Compact Lam. Panel (h=7,25m)	(1) R.C. Bearing Walls (2) Compact Lam. Panel	(1) R.C. Bearing Walls (h=4,5 and 5m) (2) Compact Lam. Panel (h=4m)	(1) R.C. Bearing Walls (h=8 and 9,50m) (2) Compact Lam. Panel (h=7,25m)	(1) R.C. Bearing Walls (2) Compact Lam. Panel	R.C. Beams; Brick Wall (plaster, insulation, exterior coating)	R.C. Beams; Brick Wall (plaster, insulation, exterior coating)	R.C. Beams; Brick Wall (plaster, insulation, exterior coating)	R.C. Beams; Brick Wall (plaster, insulation, exterior coating)	Exterior Wall Panels with isolation + Silicone Curtain Wall	(1) Silicone Curtain Glass Wall (2) Aerated Concrete with exterior coating
5	Facade Area (m2)	2,279.00	316.09	1,227.01	1,543.10	260.94	1,283.81	1,544.75	464.92	243.00	344.00	587.00	2,386.36	1,579.41
6	Number of Block	1	1	1	2	1	1	2	1	1	1	2	1	1

APPENDIX D

INFORMAL INTERVIEW

An interview was arranged in April, 2009 with the head of the tendering department of Republic of Turkey Prime Ministry, Housing Development Administration of Turkey (TOKİ), Mr. Yavuz Çetin, civil engineer.

According to the information provided by Mr. Yavuz Çetin, the workflow of TOKİ for Social Housing buildings, (It is thought that bidding stage is made under normal conditions.)

1. Client is TOKİ.
2. According to the private Public Procurement Authority, TOKİ can start bidding without occupation of land and with first draft of the projects to achieve required speed for constructions. Although, this operation can cause some problems also, because of not being prepared detailed production drawings, the construction speed is higher than normal conditions. There is one more reason for this speed; the usage of tunnel formwork as a construction technique for these social houses. The first drafts are prepared by either by the project department of TOKİ or service procurement according to the workload of the department (the number of projects and the type of the projects affects this choice. For example, a social housing project is easier than a hospital projects.)
3. The bidding team in TOKİ prepared the cost estimates and definitions of the construction works.

4. Contractor selection method is *single stage* (A tendering process intended to lead directly to the award of a construction contract to the successful tenderer for the works described in the tender enquiry)
5. The work is given to the lowest bidding price (the contractor is examined and analyzed by the technical committee, the contractor is asked to the firms who works with them before. If the committee is persuaded, it is appropriate they are given the job, if not, the same procedure is applied on the other companies.)
6. Winning contractor finds an architectural office to complete this first draft of the projects. TOKİ project team controls these detailed projects.
7. Procurement route is *lump sum* (Design and construction are provided separately -the design is undertaken by a team separately appointed by the client, with construction by a contractor competitively appointed.)
8. The construction period is from the delivery of the construction site to the submission of the work to the client.
9. TOKİ works with a consultant firm to control the works on the site regularly. Moreover, TOKİ technical team also controls the works in a period.
10. The construction duration estimations of Social Housing Projects constructed by Republic of Turkey Prime Ministry are done according to the willing of the republic of Turkey Prime Ministry as client. The willing is to construct as fast as possible. Additionally, according to the location of the construction, official nonworking season for the construction industry days are added to the total duration. Because, this housing projects are done in all over Turkey. After completion of projects, experienced information is applied on future projects.
11. The provisional and final acceptances are done by TOKİ.

Mr. Yavuz Çetin also added that duration, cost and quality are the inseparable part of a project. Any modification of these affects the others also. When construction duration increases, overhead expenditure continues. Therefore, it directly affects project cost. To decrease the construction duration, number of formworks or teams could be increased. It causes also increasing of cost. He summarized as that duration affects cost.

Mr. Yavuz Çetin also listed factors affecting construction duration as follows;

1. *Occupation of land*: especially urban transformation projects required occupation process significantly; this process affects duration very much.
2. *Preparing projects*: It takes time to prepare detailed projects according to given first draft projects. This elapsed time affects also total construction time, especially hospital like complex projects. (degree of completion of project information)
3. *Experience of Similar Jobs*: For example, experienced contractors who used these tunnel formworks before are more successful on the projects requiring using tunnel formwork. Because they passed their period of probations passed before. They know how to work, in which sequence. They perform their work in a systematic way. Therefore, their speed of construction is higher than speed of inexperienced contractors'. For example, they leave a hole in the floors, and also they dig small size excavations enough for working place. These hints are all cut the duration.
4. *Weather:* TOKİ works in different cities. The working times and working conditions change city to city. This affects duration very closely.
5. *Construction Site*: (Distance from the center, landscape designs, and ground of the site): The land is given by civic government, therefore, land could be far from the center, the ground conditions could be very harsh. The site could be very inclined. These factors affect procurement, foundation, and all the works negatively. Therefore, these problems affect the duration.
6. *Finance Flow:* For example, if different ministries tender the same job, the work could be performed in different periods and even with different prices according to the provided cash flows of the ministries' even using the same technology.
7. *Project type*: a hospital project is more complex than a social housing project
8. *Construction technique*: for example, in social housing projects tunnel formworks are used to increase the speed of construction.