An integrated system for duration estimation in design/build projects and organizations

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Keywords

Architectural practices; construction duration estimation; design/build organizations; information system; time performance; AEC firms.

Abstract

Overruns to planned schedules are common in civil construction projects worldwide. Yet, the construction industry fails to recognize the criticality of the problem; and whilst models have been developed, their lack of adequate sophistication fails to alleviate the problem. Additionally, there is resistance from construction professionals to use such models due to the lack of software integration models and modular functionality. This paper presents a performance-based duration estimation model integrated with an automation system model, MITOS - **M**ulti-phase **I**ntegrated Au**to**mation **S**ystem, that was designed primarily for design/build firms. An experience-based computational model is used for the estimation of the duration of construction projects and the performance results are discussed.

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Introduction

The basic characteristics and purpose of project duration estimation are unique for the various phases of the building production process. Current scheduling methods using CPM algorithmic techniques (i.e., deterministic or probabilistic network techniques such as Precedence Diagrams, PERT) and others (i.e., Bar chart, LOB) are applicable after detailed design is completed. Due to insufficient clarity of information at the design stage, construction duration can not be suitably estimated to give the necessary accuracy. Current models attempt to solve the problem by using alternative approaches and techniques including multiple linear regression, neural networks, expert systems and heuristics.

The estimated project duration may incorporate significant variations due to the effects of unforeseen factors related to basic parameters of *design* (e.g., constructability, complexity, etc.) or *construction* (e.g., location of project, weather conditions, etc.)

Researchers have addressed the problems associated with estimating project duration by estimating the node point using Monte Carlo simulation (Crandall and Woolery, 1982), Delphi techniques and drawing upon the experience of project managers (Levitt and Kunz, 1985), determining the relationships between value and duration of construction projects (Kaka and Price, 1991), and determining the standard times of events and total project duration by time series analysis (Sey and Kanoglu, 1990). The Activity Duration Decision Support System, a computerized model developed by Wu and Hadipriono (1994) uses fuzzy modus ponens deduction techniques to assess the impact of six factor groups on activity duration. Chan and Kumaraswamy (1999) analyzed the data of a case through a series of multiple linear regression exercises that assisted in establishing a time prediction model, to determine a set of significant variables influencing construction duration.

Determination of the risk factors affecting the time performance in building construction projects is a significant consideration. Different factors and sub-groups of factors have been suggested: Walker and Vines (2000) identified four categories (i.e., management competence, relationship building, sound operational management and situational or environmental issues) including 22 factors affecting the

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construction duration. Mulholland and Christian (1999) suggested a partially integrated computerized risk assessment model that defines four categories as sources of risk (i.e., factors related to engineering design, procurement, site construction, and project management) incorporating 80 sub-factors. Dissanayaka and Kumaraswamy (1999) identified the factors affecting project performance as procurement and non-procurement related factors; non-procurement factors were sub-divided into six groups (i.e., factors related to project, client, designer, contractor, team performance, and external conditions). This work is arguably of significance as such factors were classified in terms of their effects on both time and cost performances for a construction project. Indeed, some of the factors affecting the time performance also impacts upon the cost performance of the construction projects and *vice versa*. Yet, according to their study, factors affecting the cost performance (24 items) do not completely match with the factors affecting the time performance (12 items). However, the above studies addressing the time and cost performance models state that time and cost performances of a construction project are, to some extent, affected by the same factors.

The modeling tools used in time and cost estimating are classified into four groups: experience-based (i.e., algorithms, heuristics, expert system programming), simulation (i.e., heuristics, expert models, decision rules), parametric (i.e., regression, statistical models, decision rules), and discrete state (i.e., linear programming, classical optimization, network). Akintoye and Fitzgerald (2000) investigated the reliability of various cost estimating techniques. Their findings can also be applied for time estimation problem due to the similarity of characteristics of both problems and their solutions. Arguably, the most popular three methods are within the domain of experience-based models, resulting from range estimating techniques combining Pareto analysis, heuristics and Monte Carlo simulation, that significantly reduce the risk associated with estimating. Dissanayaka and Kumaraswamy (1999) reported that multiple linear regression (MLR) and artificial neural networks (ANN) were applied in developing such quantitative models for determining time and cost performance; and that ANN had superior prediction capabilities when compared with MLR. A model using ANN was developed by Bhokha and Ogunlana (1999) to forecast the construction duration of buildings at the pre-design stage. The model uses twelve factors affecting time performance in construction (e.g., building function, structural system, functional area, etc.). Of note, these twelve factors differ from those previously discussed, allowing empirical comparison of determinants to be carried out.

Problem statement

Schedule overruns are common in construction projects worldwide, and various models applying alternative techniques were developed for a possible solution to the problem. However, the construction industry appears not to recognize and accept these models due to various reasons. Akintoye and MacLeod (1997) identified that the reasons for not using such methods were the lack of familiarity with the techniques, the degree of sophistication involved, and doubts regarding the applicability such techniques to the construction industry. Regardless of the theoretical underpinning of the computer-based models, the resistance of the construction industry will continue, arguably, due to the fragmented structure of the industry and software currently being used.

Duration estimating models should take into consideration the *construction* phase parameters (i.e., labor productivity, weather conditions, etc.) and the *design* phase characteristics (i.e., number of stories, constructability, etc.) for more accurate estimation in the design stage. Such models stated above are suitable for individual cases, but no attempt has been made to apply these computational models in a fully integrated application. The opportunity exists for such models to be applied to the design/build organizations that have the benefit of sharing information and experience gained from completed projects, thus promoting knowledge development among the design and construction groups.

This paper aims to explain the implementation of an experience-based computational model for project duration estimation which is integrated with an automation system developed for design/build firms. The architecture of the automation system (MITOS) will be explained first.

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MITOS: multi-phase integrated automation system for design/build organizations

The concept of managing efficiently the functional components of a construction company or a design firm by means of computer applications is not new and various studies that attempt to solve the integration problem (Sanvido and Paulson, 1992; Teicholz and Fischer, 1994; Luiten and Tolman, 1997) can be located in the literature in addition to examples of reference models (Bjork, 1994; Brandon *et al*., 1994; Rezgui *et al*., 1998; Dubois *et al*., 1995, etc.).

MITOS - **M**ulti-phase **I**ntegrated Au**to**mation **S**ystem (Kanoglu 2001), a relational database model, was designed for solving the integration problem. The conceptual structure of the model is presented in Figure 1.

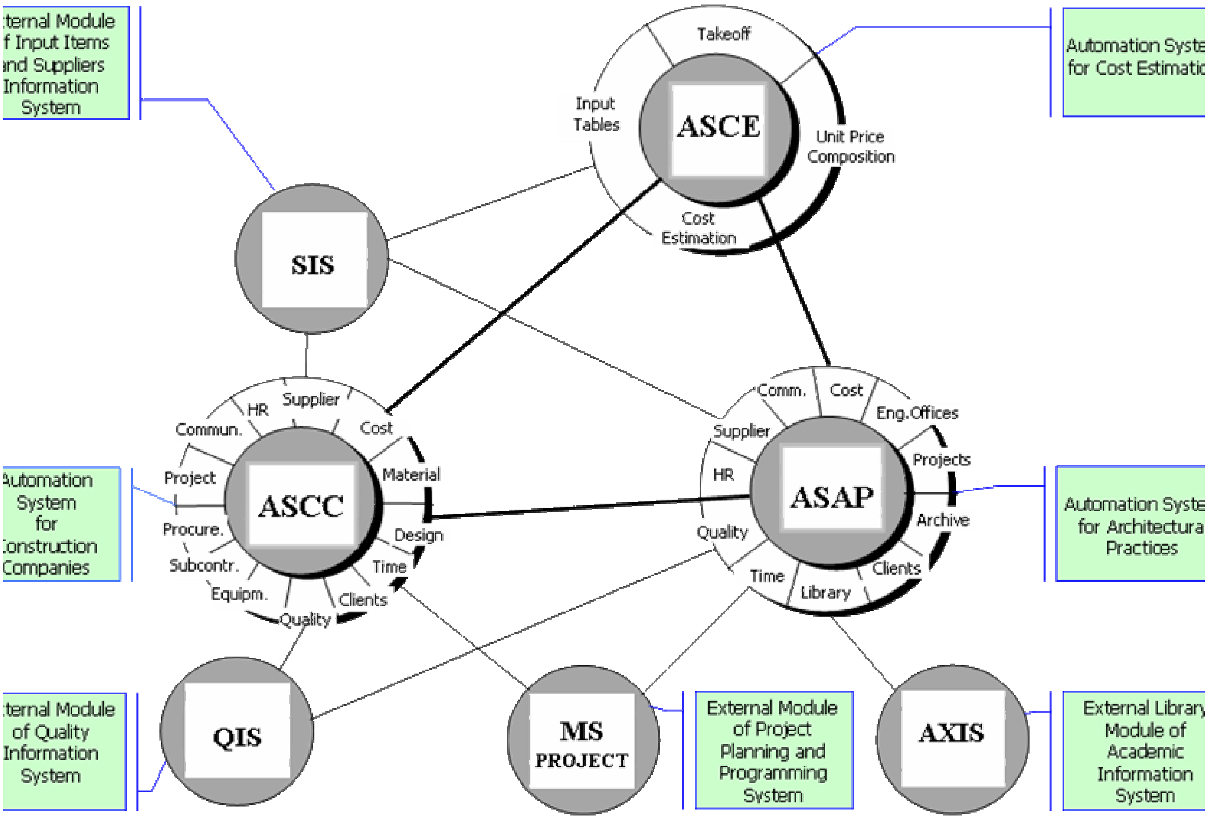

Figure 1 The conceptual structure of MITOS

The principal components of MITOS are:

- ASAP - **A**utomation **S**ystem for **A**rchitectural **P**ractices
- ASCC - **A**utomation **S**ystem for **C**onstruction **C**ompanies

These principal components of MITOS use the same external components for dedicated functions. These components can be applied individually and independently or can be integrated with the system. The shared components are:

- ASCE - **A**utomation **S**ystem for **C**ost **E**stimation
- MS Project - Project Planning and Programming Software
- SIS - **S**uppliers and **I**nput Items **I**nformation **S**ystem
- QIS - **Q**uality **I**nformation **S**ystem
- AXIS -**A**cademic e**X**ternal **I**nformation **S**ystem
- Nemetschek - CAD Software

Upon completion of the conceptual model, MITOS was modified into a relational database model (Figure 2). The model was developed in *MS Access 2000*. The *Help* and *Content* files were prepared by *MS Access Help Workshop*. *MS Access Developer Toolkit* was used to compile files and to prepare the software structure for an automatic setup process.

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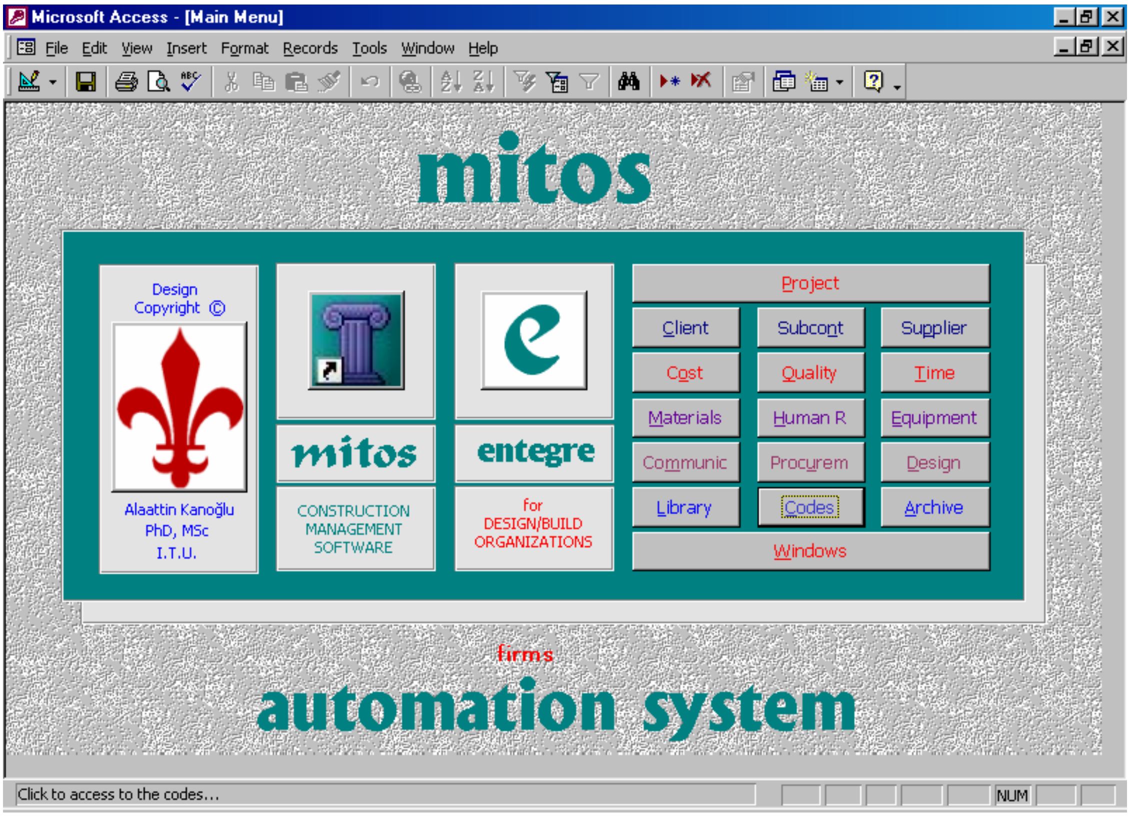

Figure 2 The main interface of MITOS

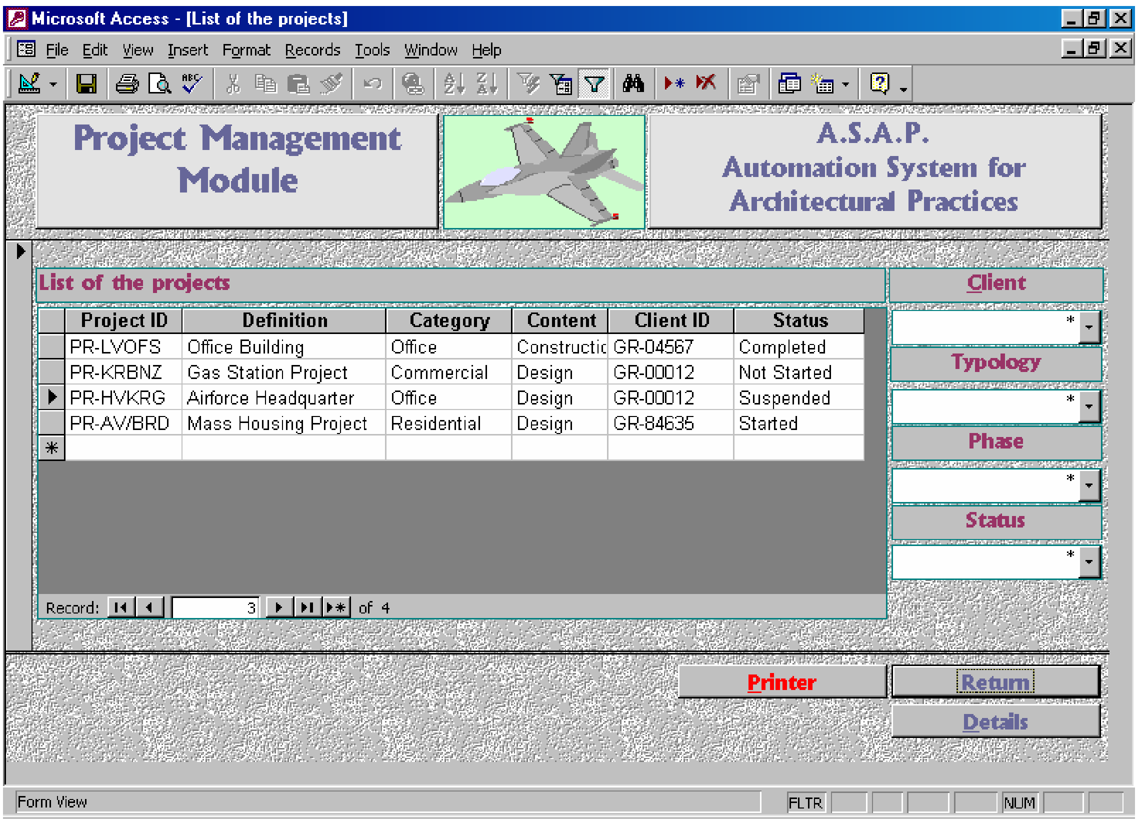

Figure 3 List of the projects

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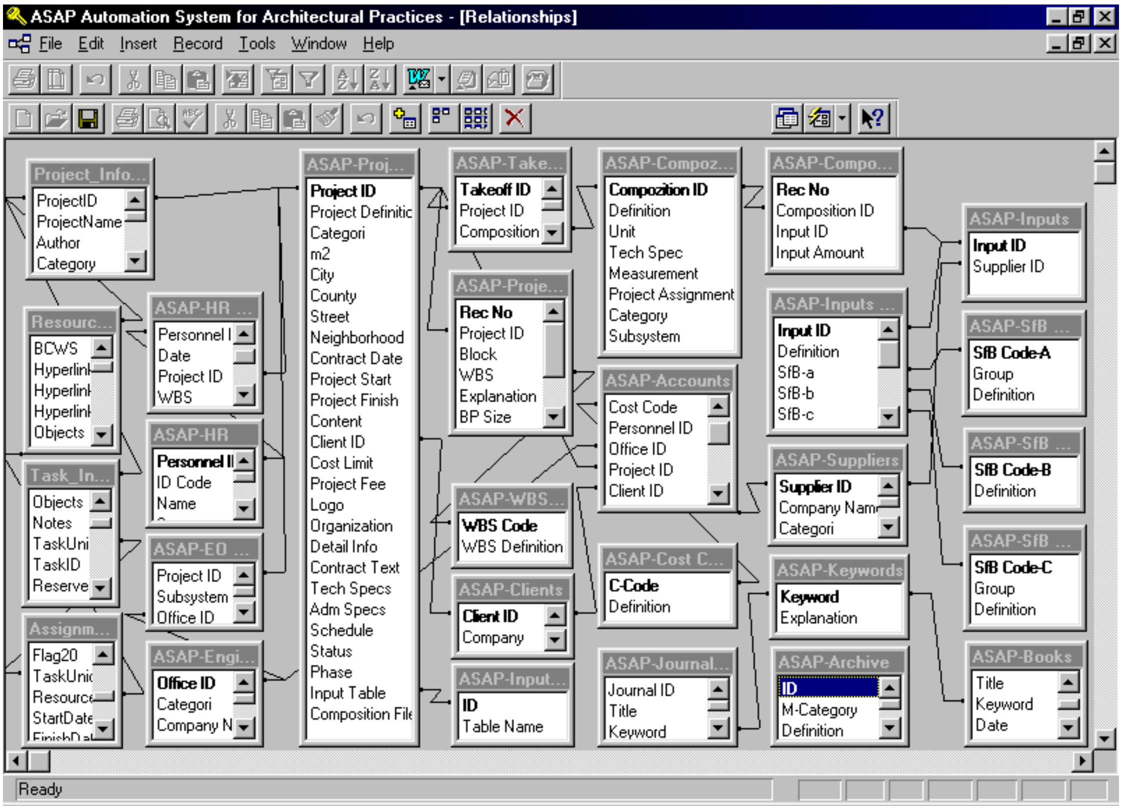

Figure 4 The partial relationships screen of the integration of MS Project and MITOS

Three of the components of MITOS, (i.e., ASAP, ASCC, and MS Project) are essential for the duration estimation process presented in this paper.

ASAP - **A**utomation **S**ystem for **A**rchitectural **P**ractice (Kanoglu and Arditi, 2001), was developed for solving the information handling and management-related problems in architectural offices by taking into consideration a holistic view of the design process (Figure 3). There are few conceptual and practical models developed as a response to the needs in the design stage, the exception being those developed by Platt (1996), and Baldwin *et al*. (1999). However, any comprehensive conceptual or application model designed for architectural offices has not been identified in the literature. All information is organized in the *Projects, Clients, Engineering Offices, Suppliers, Human Resources, Time, Design, Cost, Communication, Quality, Archive*, and the *Library Management* modules.

ASCC - Automation System for Construction Companies is the outcome of a research project (Kanoglu, 1999) with the aim to develop a management information system for construction contractors. The model contains the *Projects, Clients, Subcontractors, Suppliers, Human Resources, Time, Design, Materials, Equipment, Cost, Communication, Quality*, and the *Procurement Management* modules organizing various parts of information required by related management functions.

MITOS calls on MS Project – Project Planning and Programming System, not only for planning and programming purposes but also for the time and cost estimating processes. The relational database file that is created and saved in mdb format by MS Project consists of several tables, of which four, project, task, resource, and resource assignment tables, are essential for the integration of ASAP and MS Project. The inter-relationships of the database objects (i.e., tables) are seen in Figure 4.

The complementary components of the model, SIS - The **S**uppliers **I**nformation **S**ystem organizes the information of the supplier companies, input items supplied by these companies and their unit prices. ASCE – **A**utomation **S**ystem for **C**ost **E**stimation comprises four modules (i.e., input table composition, unit price composition, quantity takeoff, and cost estimation modules). Codes and regulations, construction specifications, and standards relating to

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construction are organized in QIS - **Q**uality **I**nformation **S**ystem. Nemetschek CAD software was integrated with MITOS to extract the quantities of building components from the design and export these values in a format that can be recognized by ASCE.

Performance-Based Duration Estimation Model

Basic concepts relating to the model

The model presented in this paper takes place within the domain of experience-based models defined in Akintoye and Fitzgerald's (2000) study. Their model suggests the use of productivity information and team performances of the completed projects that are similar to this writer's model in terms of particular parameters (e.g., type, size, total cost, location, climate conditions, etc.). The team's productivity is revised by the coefficients that represents the effects of site-based factors at different levels. These coefficients are explained below:

- *Project Level Productivity Coefficient* (PJC): The factors that do not affect the teams individually but the whole project are represented by PJC.
- *Team Group Level Productivity Coefficient* (TGPC): If certain teams in a given trade are affected by similar factors the effect of these factors is represented by TGPC instead of using TPC for each team in this trade.
- *Team Level Productivity Coefficient* (TPC): If any team is affected by a specific factor, (e.g., experience) the effect of the factor is represented by TPC.
- *Production Item Productivity Coefficient* (PIPC): The effects of some factors that are not related to teams but production items are represented by PIPC.
- *Final Productivity Coefficient of a Team* (F-COEF): This coefficient is calculated in Equation 1 as:

$$\mathbf{F\text{-}COEF}_{TEAM\text{-}A,\ PRJ\text{-}Z} = (\mathbf{PJC}_{PRJ\text{-}Z}) \times (\mathbf{TPC}_{TEAM\text{-}A,\ PRJ\text{-}Z}) \times (\mathbf{TGPC}_{TEAMGRP\text{-}TRADE\text{-}I,\ PRJ\text{-}Z}) \quad \text{.........................(1)}$$

The Revised Productivity Value (RPV) is calculated in Equation 2 as:

$$\mathbf{RPV}_{TEAM\text{-}A,\ PRJ\text{-}Z} = (\mathbf{SPV}_{TEAM\text{-}A}) \times (\mathbf{F\text{-}COEF}_{TEAM\text{-}A,\ PRJ\text{-}Z}) \quad \text{.........................(2)}$$

The duration of activity (AD) is calculated in

Equation 3 as:

$$\mathbf{AD} = (\mathbf{AP}_{ACT\text{-}A,\ PRJ\text{-}Z}) \ / \ (\mathbf{RPV}_{TEAM\text{-}A,\ PRJ\text{-}Z}) \quad \text{..........(3)}$$

Revised duration of activities (RAD) are calculated in Equation 4 as:

$$\mathbf{RAD} = (\mathbf{AP}_{ACT\text{-}A,\ PRJ\text{-}Z}) \ / \ (\mathbf{RPV}_{TEAM\text{-}A,\ PRJ\text{-}Z}) \times (\mathbf{TMNR}_{ACT\text{-}A,\ PRJ\text{-}Z}) \times (\mathbf{PIPC}_{ACT\text{-}A,\ PRJ\text{-}Z}) \quad \text{...........(4)}$$

The process of duration estimation

When implementing the model, the functions related to design and construction phases are performed by the design and construction groups respectively in a preset order. The conceptual structure of the relationships is presented in Figure 5. The process is defined step by step below:

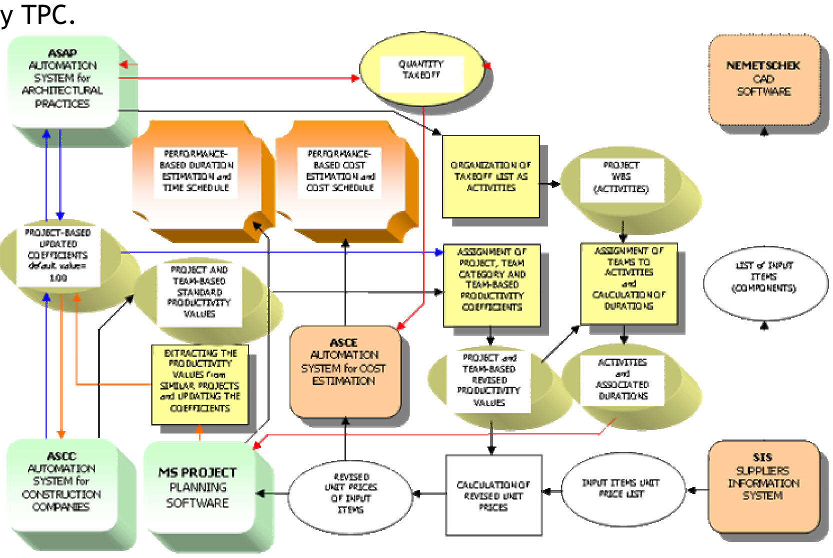

Figure 5 Conceptual structure for the integration of performance-based cost and duration estimating systems

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The construction group records the standard productivity values for each team in the *Human Resources Management Module* in ASCC. The values are obtained from work and time studies for each type of production (Figure 6).

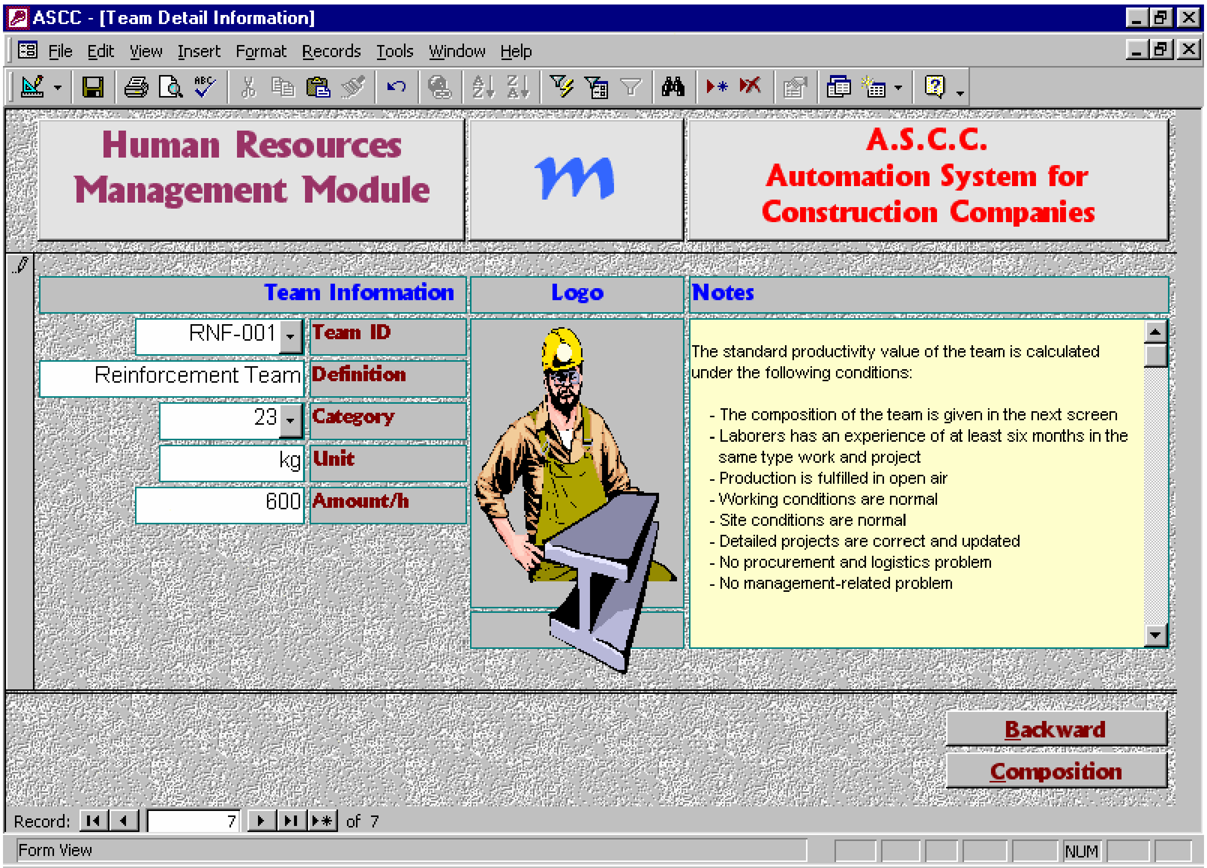

Figure 6 Standard productivity information for the teams

- The design group defines the design projects in ASAP; stores and maintains detailed information in the different functional modules (described earlier).
- Information related to production items in projects are imported from the CAD software or defined manually by the design group in ASCE.
- The design group prepares the initial project schedule by using the project take-off list and default coefficients for project, team group, and team level performances.
- The construction group defines the *construction projects* in ASCC; stores and maintains detailed information in different functional modules described earlier. Information related to the use of planned and actual resources is recorded and maintained in MS Project.
- The construction group performs the final evaluations for the completed projects in ASCC. The *Time Management Module* retrieves actual team-based quantities and durations for each activity from MS Project; groups the data and calculates the actual performances for each team. The averages of the team-level actual productivity values are divided by the standard team-based productivity values to calculate the productivity coefficients of the teams in the project.
- The same process is repeated to calculate the "team group" level coefficients by calculating the averages of the productivity coefficients of the teams categorized in the same group.
- The project level productivity coefficients, the effects of the factors are quantified by the construction group at the site as percentages by using the information of *duration variances* (D-VAR) provided by MS Project software. After importing this information from MS Project summarized and *total values of duration variances* (TD-VAR) can be obtained as seen in Figure 7 by using *group codes of the factors* (CH-GR).

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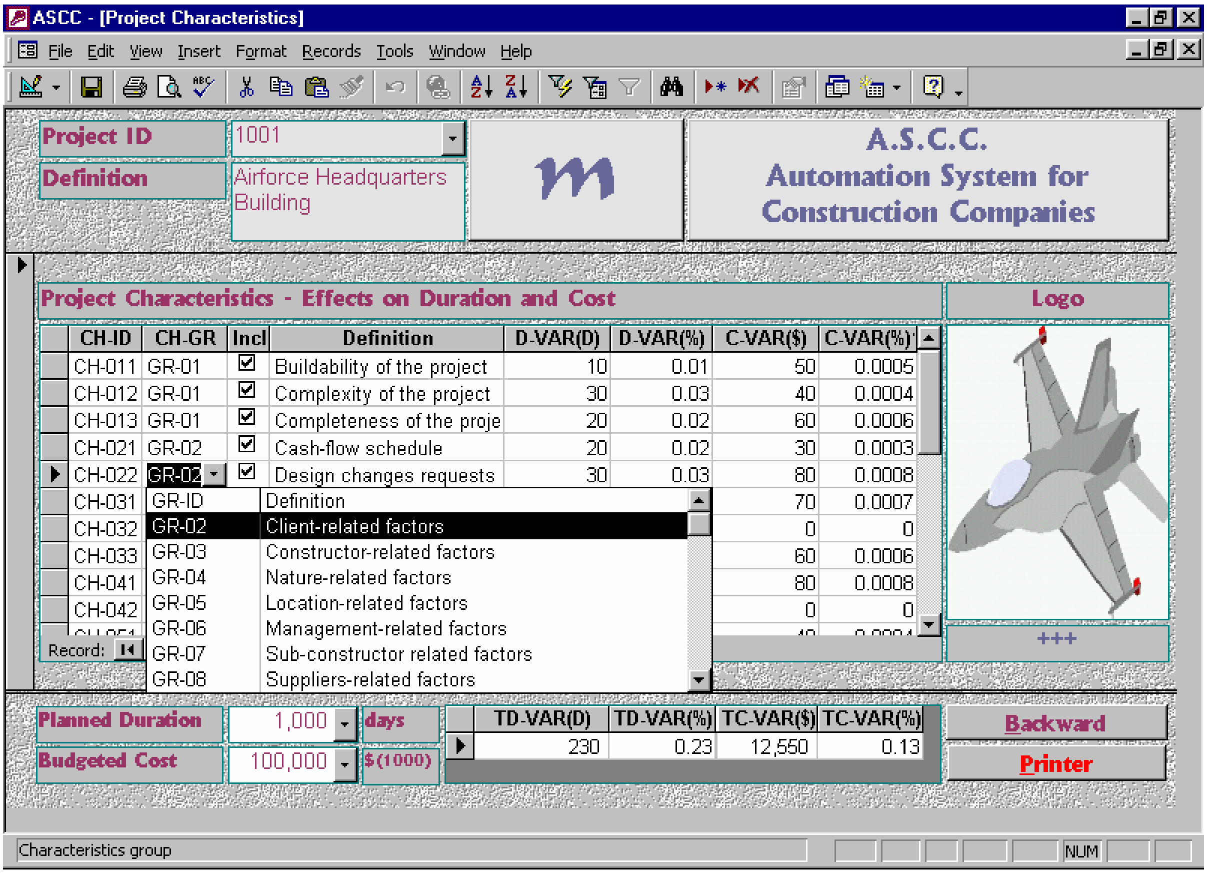

Figure 7 Project characteristics and their effects on duration (and cost)

- The design group determines the parameters and criteria to be applied to filter the similar projects from the construction projects database in ASCC and performs the filtering operation. Averages of the coefficients of filtered projects are calculated and replaced with the default values.
- The project level productivity coefficient can also be modified manually considering the special conditions for the current project (Figure 8).
- The design group prepares the revised project schedule by using the quantity takeoff list and revised coefficients for project, team group, and team level performances.
- The model revises the durations of activities by applying the *project*, *team group*, and *team level performance coefficients*. As seen in Figure 8, the *project performance coefficient*, the *team group performance coefficient* and the *team performance coefficient* are applied to the team productivity values. Revised durations of the activities are calculated by using the final coefficient.
- The teams are assigned to these activities. The durations of activities are automatically calculated and updated by the revised productivity values of the teams (Figure 9). In addition to the *production item performance coefficient* (PIPC), one more parameter, *number of teams* (TMNR) assigned to perform the activity is included in calculating the durations of activities.

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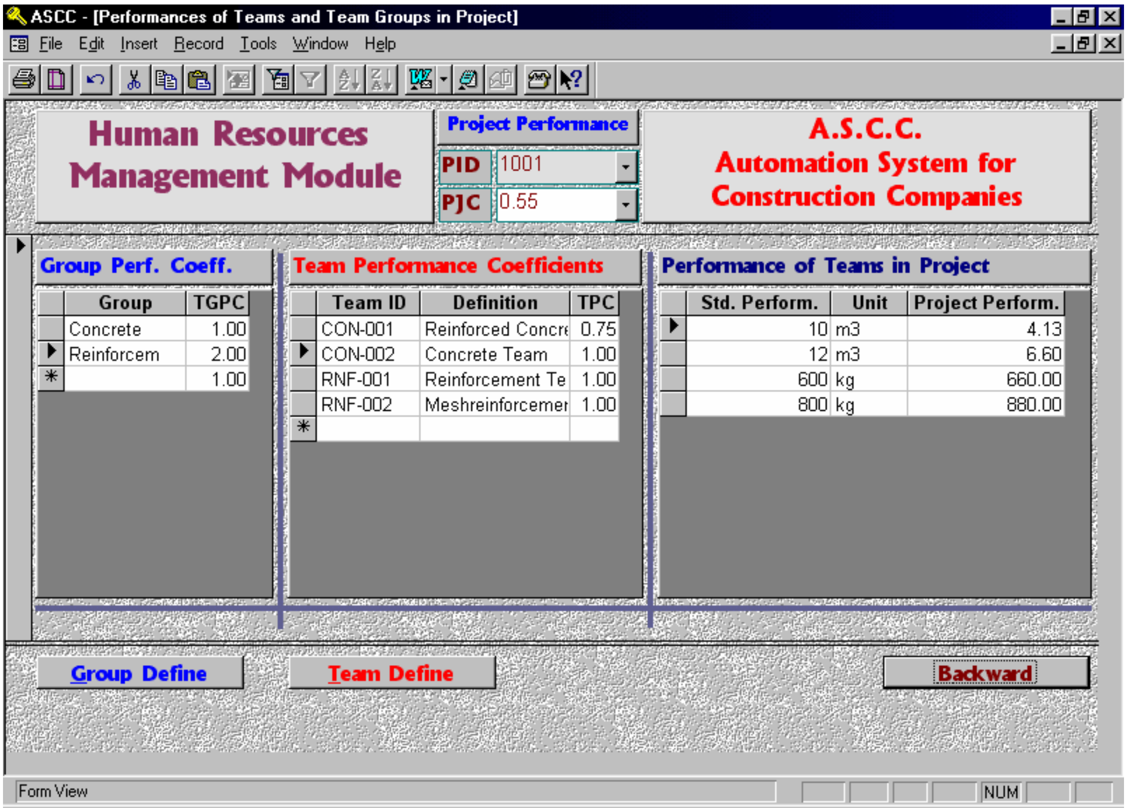

Figure 8 Assignment of coefficients and calculation of revised productivity values

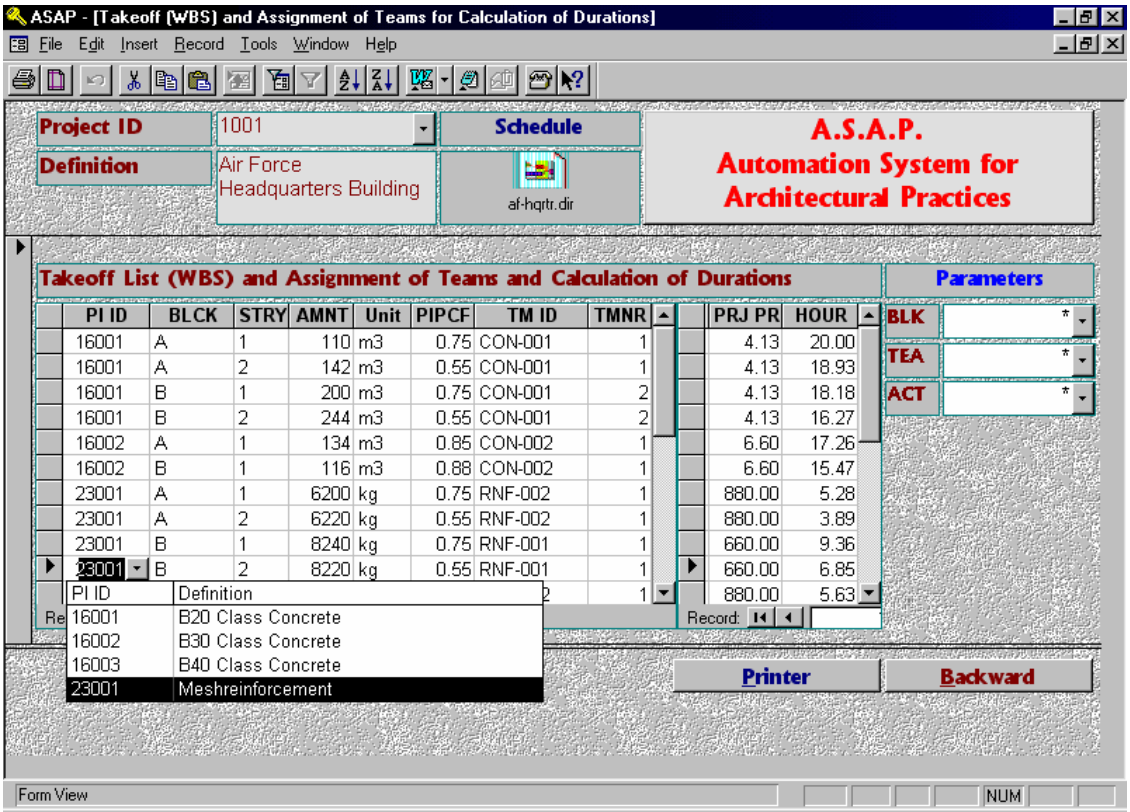

Figure 9 Assignment of teams to project activities and calculation of durations

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Conclusions

Design/build contracts combine design and construction under a single entity and it has gained the attention of the industry in the last decade and is expected to become the dominant project delivery system in the near future. This growth is justified by the reported benefits of the system, including faster delivery and lower cost. It is now time to have a management information system in place in design/build organizations that could facilitate the management of this delivery system. Such a system would facilitate the interactions of the members of the D/B team, but it would be particularly useful if the team members belong to different organizational cultures.

Although it has the stated advantages the D&B procurement route does not always achieve its claimed advantages. One aspect of this is the emphasis discussed in this paper on integration, a claimed advantage of D&B. The suggestion of an automated system for D&B integration is worthy of examination. Such a support provided by an integrated information system will provide various advantages. One of these advantages is the ability of accessing the data related to the performance values of the past projects in terms of duration and cost as well as team productivities.

MITOS was developed in response to the need expressed by a large design/build firm in Istanbul, Turkey. The firm is a well-established firm that undertakes international projects in cooperation with international partners. The team that contributed to the development of the model was composed of experienced professionals including architects, civil engineers and construction managers. The complete model is being used by one design/build firm, while some components are being used by several firms on an experimental basis. The model does not need any additional information for duration estimation, only the data that is already recorded by MS Project software and the other functional modules of the system. This will reduce the resistance of the construction professionals towards the complex and separate models that need additional efforts to organize the required information for estimation. Moreover, the computational model integrates the estimation processes of duration and cost since the same information is needed for the both processes (Figure 5). The details of the cost estimation process are explained elsewhere (Kanoglu, 2003).

The accuracy of the estimate will help to reduce the number of claims and disputes during the construction phase even if traditional project delivery systems are preferred over those of design/build. The importance of an accurate estimation of construction duration is understood very well in the context of the low markup values, bonuses of early completion and penalties due to delays. The model reflects the organizational structures of design/build firms compared with other project delivery systems, since design and construction groups are part of the same organization and typically cooperate to complete the project within the cost, time and quality limitations.

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