Solution to the Problem of Inaccurate Duration-Estimation: Relational Database Model for Design/Build Organizations

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

Abstract For various participants of projects, accuracy in the estimation of project duration is vital at various stages of the building production process. The importance of the problem has been acknowledged by the industry worldwide, and various models have been proposed in the literature, but all have their limitations. This paper presents a performance-based duration-estimation model that utilizes historical knowledge, in particular information to estimate the worst, best and likely variances of current projects by using the unified structure of an information system developed for design/build organizations. The model allows the estimators to make use of data on past projects. Proposed organizational pattern, design/build, are vital for accessing the as-built schedules and variance information provided by construction groups in a design/build organizational pattern. Our final solution includes an integrated relational database model developed for design/build organizations that provides the integration of satellite software packages, thus eliminating additional efforts for obtaining the data needed in the estimation process.

Introduction

The basic characteristics and purpose of project duration-estimation are unique for the various phases of the building production process. Due to insufficient clarity of information at the design stage, construction duration cannot be suitably estimated to give the necessary accuracy. Current models attempt to solve the problem of estimating duration in the preliminary design stage by using alternative approaches and techniques including simulation, genetic algorithm, regression, neural networks, expert systems and heuristics.

Current scheduling methods using critical path method techniques and others are applicable after the detailed design is completed. The first step of scheduling by using these techniques is project planning that needs determination of the activities and their relationships. In the next step, duration of activities is calculated by using standard productivity values of the crews allocated to each activity in the project. Initial schedules are prepared by considering the relation types, lag and lead times within the activities. Constraints are included in this process, with the exception of those that are resource-related. Resource-related constraints are taken into consideration in the schedule by the resource leveling process in the next step that is mistakenly considered to be the final step of scheduling process commonly applied. However, the estimated project duration may incorporate significant variations due to the effects of unforeseen factors related to the basic parameters of design (e.g., constructability, complexity, etc.) and construction processes (e.g., location of project, weather conditions, etc.). Risk factors and their effects must be taken into account in preparing baseline schedule, as the final step of planning and programming process.

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Problem Statement

Time management is one of the basic functions in construction projects management. The function is located at the core of the project-based management system. Although it gains increasing importance, the time management system fails to function properly and to provide the required accuracy in time schedules due to failures in the estimation of durations in both activity and project levels.

Various models applying alternative techniques were developed for a possible solution to these problems, but the construction industry appears not to recognize and accept these models due to various reasons. Akintoye and MacLeod [1] identified that the reasons for not using such methods were 1) the lack of familiarity with the techniques, 2) the degree of sophistication involved, and 3) doubts regarding the applicability of such techniques to the construction industry. Although these reasons for rejection are plausible, there are additional considerations, such as 4) local or limited characteristics of the models that limits their generalisability, 5) difficulties transition from theoretical solutions appearing to offer success to functional and practical model, 6) the lack of vision in the design of models to consider organizational aspects, that is vital for obtaining valid project-based data, 7) additional efforts needed to collect, record and organize the data required for estimation of project duration, and 8) the lack of the components of solution in organizational, technological (information technology in particular) and individual (human) dimensions that are vital for completeness and applicability of the models.

Regardless of the theoretical underpinning of the computer-based models, the resistance of the construction industry will, arguably, continue due to the fragmented structure of the industry and the lack of support of information technology that does not provide an integrated solution in both theoretical and practical dimensions in this fragmented environment. We would argue that in the current circumstances, efforts to address duration-estimation will continue to fail unless the models consider all aspects of the problem, i.e., theoretical (complexity, accuracy, etc.), practical (versatility, sustainability, customizability, etc.), organizational (confidentiality, accessibility, etc.), human-related (adoption, support, expertise, etc.).

Related Work

The parameters and scope of the problem under investigation are reviewed next so that the conceptual dimensions and practical functionality can be explored.

The modeling tools used in time and cost estimating are classified into four groups by Akintoye and Fitzgerald [2]: namely, 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). 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 reduce the risk associated with estimating to some extent [2]. Dissanayaka and Kumaraswamy [3] reported that multiple linear regression and artificial neural networks were applied in developing such quantitative models for determining time and cost performance; and that neural networks had superior prediction capabilities when compared with linear regession. A model using artificial neural network was developed by Bhokha and Ogunlana [4] to forecast the construction duration of buildings at the pre-design stage. However, it is reported that artificial neural network is not appropriate technique for a small sample size where there were a large number of input variables involved [3].

Other research has addressed the problems associated with project duration by estimating the node point using Monte Carlo simulation [5], Delphi techniques that draw upon the experience of project managers' [6], determining the relationships between value and duration of construction projects [7], and determining the standard times of events, thus total project duration, by time series analysis [8]. Chan and Kumaraswamy [9] analyzed the data of a case through a series of multiple linear regression exercises that assisted in establishing a time prediction model, and so determined a set of significant variables that influence construction duration. Leu and Hung [10] proposed an optimization technique combining genetic algorithm and Monte Carlo simulation modeling to solve scheduling problems under uncertain situations. Chan [11] and Ng *et al*., [12] reported a time-cost model using regression analysis that attempts to verify the validity of Bromilow's [13] time-cost formula in specific cases. The model was developed to provide a quick and quantitative means of estimating project construction time. However, one potential shortcoming of the model is that it fails to consider factors other than cost when establishing the construction time. Several research studies have been carried out to improve the accuracy of the Bromilow's model, yet progress was halted by the occurance of unreasonably high standard errors [12].

The Activity Duration Decision Support System is a practitioner-based computerized model developed by Wu and Hadipriono [14] that uses fuzzy logic to assess the impact of six factor groups on activity duration, by converting the verbal comments into values via a trigonometric system.

An integrated information system model, MITOS – **M**ulti-phase **I**ntegrated Au**to**mation **S**ystem for Design/Build Organizations [15], is a comprehensive model that attempts to solve the integration problem in design/build organizations. The *Time Management Module* of MITOS is an attempt to solve duration estimating problem in particular [16], in theoretical, practical, virtual and organizational dimensions by considering the stated aspects of the problem. However, the detailed approach used increases the number of operations in the estimation process and creates difficulties in the adoption of the model.

A significant consideration is the determination of the risk factors affecting the time performance in building construction projects. Different factors and sub-groups of factors have been suggested by Walker and Vines [17], Mulholland and Christian [18], Dissanayaka and Kumaraswamy [3], Bhokha and Ogunlana [4] and Wu and Hadipriono [14]. These studies propose different factors and classifications of factors affecting time performance in construction.

All of these attempts at addressing a duration-estimation problem have their weak and strong points as indicated in related literature. These critics briefly stated above. Criticicism of these models will not be repeated here in detail since they do not contribute greatly to solving our problem, since they are the output of resident paradigm that reduce the problem and its solution to the success of the computational model. If this perception was realistic enough and sufficient to solve the problem, then these models would be more widely applied and it would be possible to minimize time overruns in construction projects. Therefore, the current paradigm should be reviewed again instead of addressing same aspect of the solution by applying various computational models. With increased competition in the construction industry, the essence of forecasting, therefore, emphasises not only its accuracy but also attempts to minimize the associated effort [4]. Arguably, this is a trade-off that needs to be solved by considering the accuracy of estimation, against the complexity and the number of operations in both gathering the data required and estimating the duration. None of the above stated models attempt to provide a holistic approach that is required to solve the duration-estimation problem.

Principles and Components of the Conceptual Model

The studies stated above perceive and define the problem from the point of view of an accuracy concept and they try to increase the accuracy of estimation by focusing only the computational part of the solution. The authors' claim is that the problem with these attempts is not related to the computational models used in their solutions but their perception and definition of the character of the problem. Whereas, a duration-estimation problem should be perceived as a trade-off problem as much as an accuracy problem. The construction industry needs accuracy of duration-estimation to some extent. Yet, it also needs practical models that do not create resistance in construction professionals and can easily be implemented. The most accurate computational model may not be applicable, and any model that is not applicable to practice is controversial if not having proven validity.

Taking due consideration of the effects of these critics, the authors claim that the baseline schedule must be prepared as the final step, with considering the completion date stated in the contract, and also an earlier date that yields the contract date when duration-variance that is inavoidable in most projects, is added. (Figure 1). The estimation model suggested in this study is based on the hypothesis stated above.

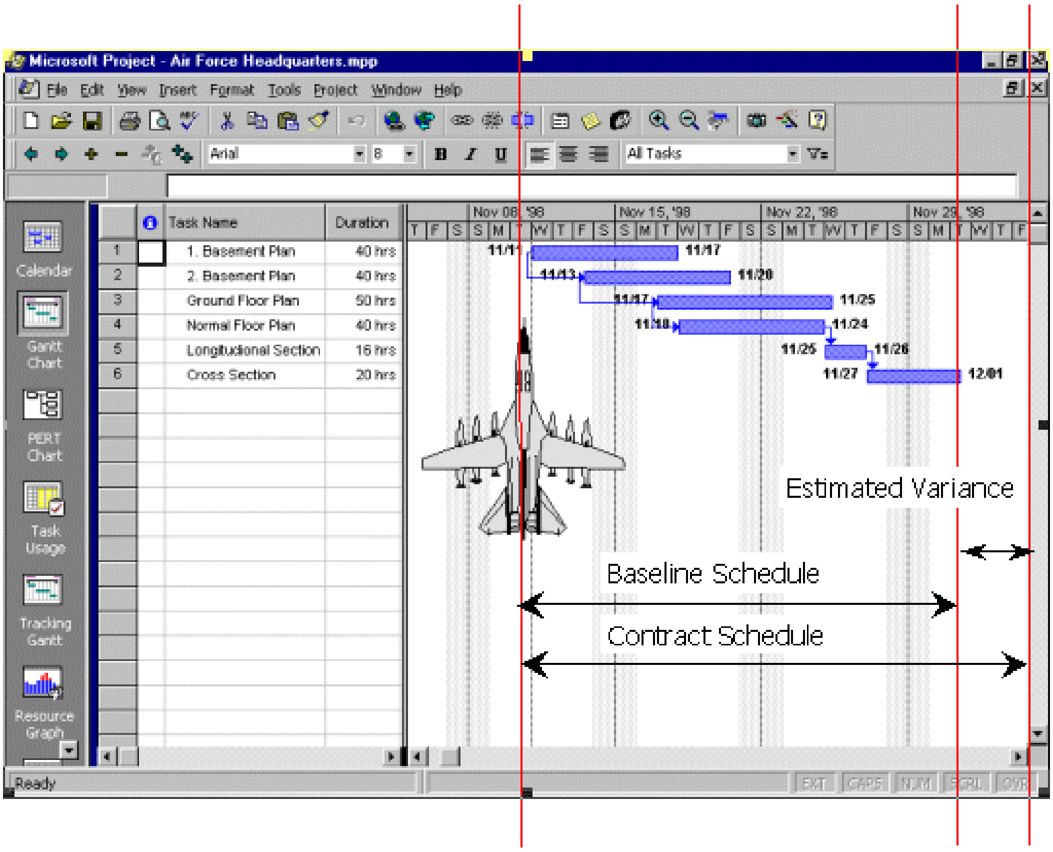

Figure 1 Calculation of T_1 point that yields project completion time T_S defined in contract when added to estimated variance

Resulting from the evaluations above, the outline of the model proposed in this study is structured as follows:

- Duration estimating models should take into consideration the factors affecting team, activity and project level performance values in the *construction* phase (i.e., labor productivity, weather conditions, organizational effectiveness, etc.) and the *design* characteristics (i.e., maturity level of design, number of stories, constructability, etc.) to allow more accurate estimation in the design stage of any given project. Searching a solution for the duration-estimation problem by models proposing use of limited physical parameters, such as number of stories, total construction area, etc., and discarding the factors affecting the duration of activities, the productivity of crews and the performance of project directly is imprecise.

- The theoretical model should have generalisability and be valid for any kind of project, no matter the type of building, location of project etc., or it should allow information filtering and use of relevant data in terms of the selected parameters. Thus, it will be possible to apply models by analyzing the empirical data of a limited number of projects for certain types of buildings.

- The accuracy of duration-estimation depends on the completeness of design information. In pre-design, preliminary design, detailed design and tendering phases estimators have different levels of details in terms of the design information affecting the accuracy of estimation. The models should allow these details to be included in estimation process where available.

- The variance data, in terms of activities, crews and project performance can be obtained from historical projects. Yet, reflecting the estimated variance to activities one by one increases the complexity of the models and the number of transactions that must be completed by the estimators. This could be a reason there is resistance to using such models. Instead, determination of project level duration variances and the variance rates obtained from various scenarios, such as best, worst and likely situations, diminishes the efforts to reach a reasonable solution.

- Since fully automated models lead to deterministic approaches and patterns, the contribution of estimators should be allowed during the estimation process. This can be achieved by allowing the experts to set their scenarios that are meaningful for the given project. The lack of expert professionals is a potential weakness. Arguably, this aspect is a criticism of the construction industry compared with the other industrial sections, and therefore worthy of "rethinking construction". After all, duration-estimation is not the function of site management but of headquarters and design or construction organizations may have this service from internal or external sources without introducing difficulties.
- Any additional effort to collect, record and organize the data for performance of past projects creates difficulties in adoption and use of the models. The model should be designed in a way that uses the records that are already organized by the other functional components, such as time management, change management, etc., modules of an integrated information system. Consequently, this has been the rationale for developing an integrated computer application that will allow integration of commercially available software.
- Since duration-estimation is essential in every phase of the building production process, for various participants that have various objectives, the model should provide access to these professionals. Unless a suitable organizational pattern is adopted the model will fail due to confidential issues when accessing data. The opportunity exists for such models to be applied to 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.

In sum, the model should propose a solution in a holistic way for duration-estimation in four basic dimensions:

- **Component - I**: A *computational* model (algorithmic) in *conceptual* terms, that is successful in solving estimation problems theoretically,
- **Component - II**: A *computer* model in *practical* terms, that conveys the theoretical model for professional practice,
- **Component - III**: An *organizational* model in *physical* terms to provide a cooperative environment between design and construction groups,
- **Component - IV**: An *integrative* model in *virtual* terms for design and construction groups to provide an access to each other's data via their information systems.

With reference to the conceptual structure, the model proposed in this study comprises four complementary components stated above (i.e., an *experience-based* estimation model in conceptual dimension, a *relational database* model in practical dimension, *design/build* as an organizational model in physical dimension, and an integration model of information systems of design and construction firms in virtual dimension). The computational part of the model is only one of these components. Yet, unlike the other attempts in the literature, the model developed in this study does not focus on proposing a powerfull computational model that aims to increase the accuracy of the estimation to solve the problem. It aims to contribute to the solution of the problem by suggesting an alternative perception that emphasise focusing on the practical aspect of a solution when considering the other aspects of the problem, i.e., defragmentation in organizational and virtual dimensions, by integrating the information systems of project participants as explained above. This approach accepts an approximate accuracy in estimation of project duration that is sufficient to prepare a baseline schedule by considering probable risk factors and their effects on construction duration and increases the applicability of the model proposed by providing an integrated tool that make it possible to organize and access the data needed for duration-estimation process without any additional effort.

The Computational Model Proposed for Duration-Estimation: An Experience-Based Approach

The model presented in this paper is applied within the domain of experience-based models defined in Akintoye and Fitzgerald's study [2]. Figure 2 explains basic steps of the conceptual model of duration-estimation process proposed for the model developed.

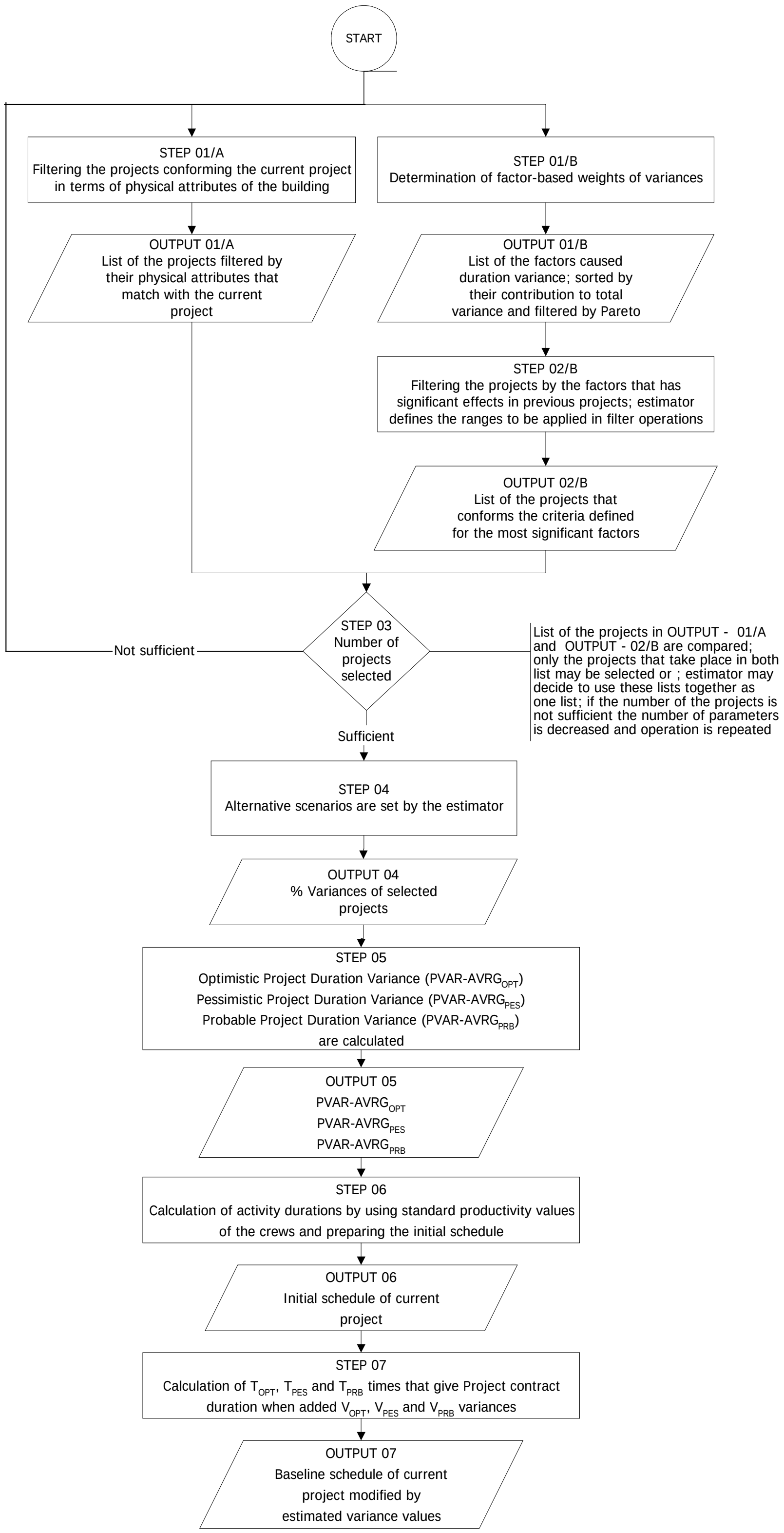

Figure 2 The algorithm of the computational model

The Computer Model Developed for Duration-Estimation: SPIDER

After the conceptual model was formulated, it was converted into a relational database software called **SPIDER** – **S**olution for the **P**roblem of **I**naccurate **D**uration-**E**stimation: **R**elational Database Model for Design/Build Organizations in *MS Access 2000*. The software provides multi-user architecture with secure access rights to the database. The algorithm of the duration-estimation model requires that the basic steps to be performed in three consecutive phases.

Phase – 0: Pre-operations fulfilled by the other external/internal functional modules

Step – 00: Information related to projects, crews and their associated productivity values, take-off items, and factors affecting duration performance is defined in *Project*, *Human Resources*, *Cost* and *Time Management* modules. Information related to duration variances of past projects, is imported from MS Project software first, and recorded in the *Change Management Module*, with additional data such as cause of variance, factors affecting the variance, the participant responsible from variance etc.

Each variance record contains the factor causing the variance on time and cost and the activity affected by variance. Since these factors are categorized in three basic groups, i.e., *crew*, *activity*, and *project level* factors, it is possible to summarize their cost and time effects in the module (Figure 3).

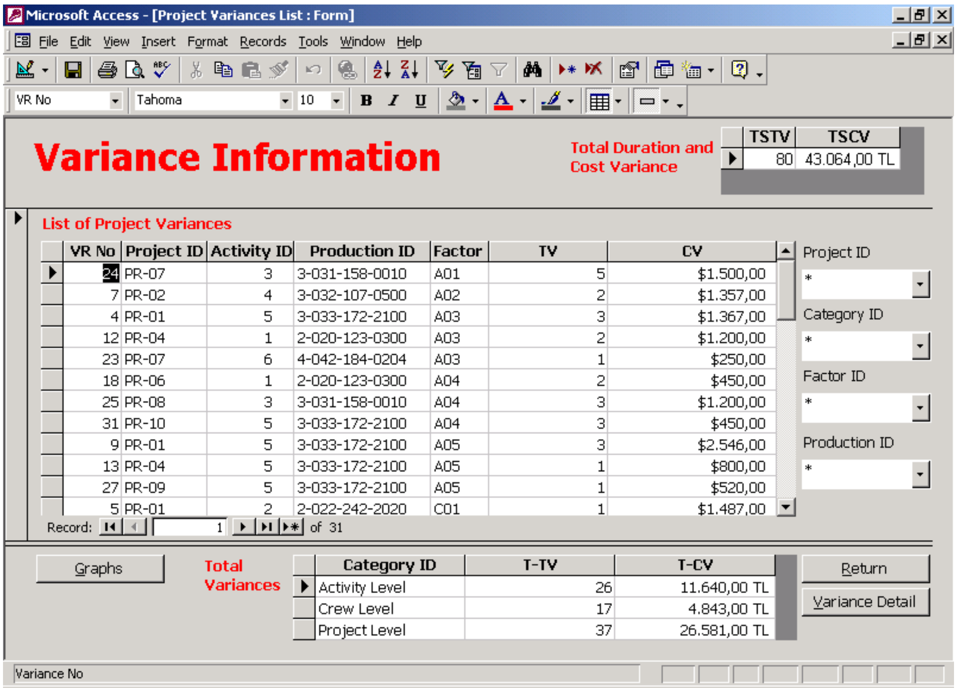

Figure 3 Interface of duration variances

The *Change Management Module* can also organize variance data to reveal the significant factors among others, and displays the output in both graphical and tabular format (Figure 4).

Phase – I: Operations fulfilled by SPIDER

In this step, the operations needed to set the scenarios to be applied for the duration-estimation process take place. There are three basic steps that can be fulfilled by accessing the related interfaces.

Step – 01/A: The projects matching the current project in terms of their physical attributes, such as number of stories, construction area, type of building, etc., are filtered.

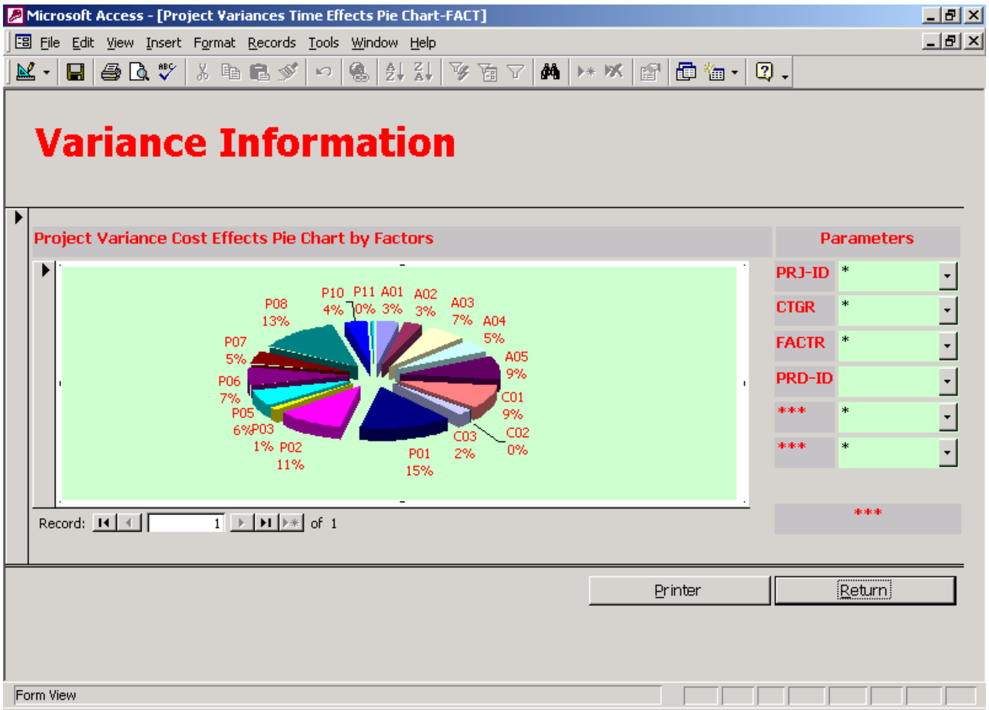

Figure 4 Graphical interfaces of duration variances by weights of activity, crew and project level factors

Step – 01/B: Factor-based variance totals are calculated by taking into consideration all projects and all records related to duration variance. Variance totals are divided by total variance of the virtual project including the data of all projects in the database to calculate the percentage of contribution of each factor to the variance total. Thus the most significant factors are determined to be used in scenarios that will be set for the duration-estimation process in the next step. The threshold value of the variance rate is determined by the estimation professionals using the Pareto rule (Figure 5).

Step – 02/B: The projects that have the approximate variance rates with regard to the significant factors are filtered. The low and high limits of ranges for each factor are decided by the estimator after considering the average values determined in the previous step (Figure 6). Thus, the projects that are affected by identical factors in a like manner are determined (Figure 7). Only the data related to these projects is taken into consideration in the next step.

Step – 03: List of projects defined in OUTPUT - 01/A and OUTPUT - 02/B in Figure 2 are compared and the number of projects are checked to determine if a significant number of projects are filtered to allow further analyses (Figure 8).

Step – 04: The sets of scenarios including different parameters are prepared by the estimator. Data related to duration variance are filtered by beginning with the first scenario. In the final stage duration variances in selected projects are divided by the total project durations and project-based variance rates and the average variance rate of selected projects are determined (Figure 9).

Step – 05: Three of the scenarios that have the highest, the lowest and medium probability of occurrence are selected by the estimator. The duration variance rates are recorded by relating these scenarios as follows:

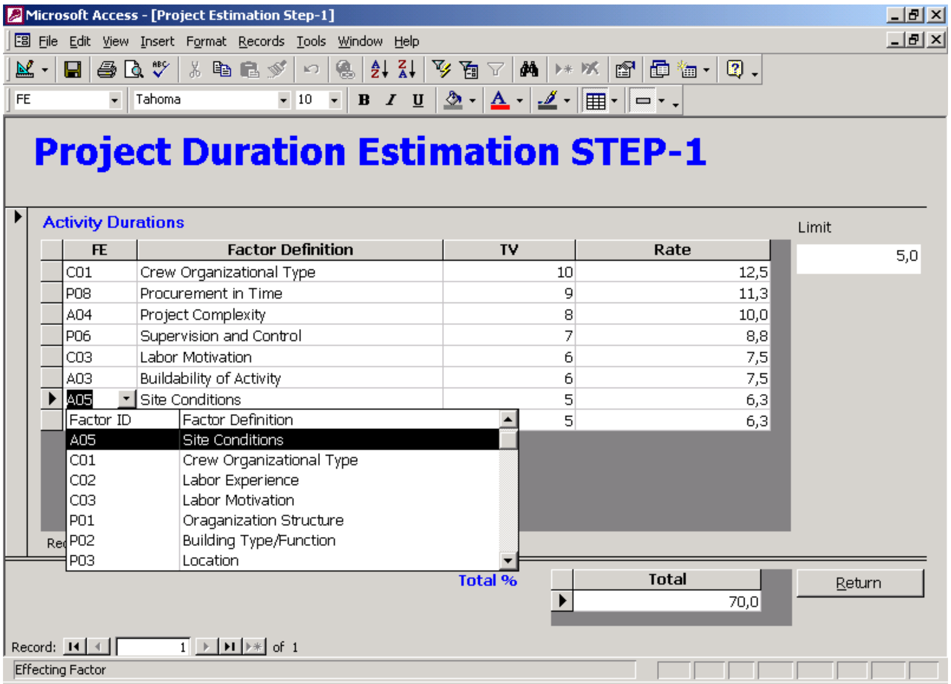

Figure 5 Determination of the factors to be considered by Pareto rule

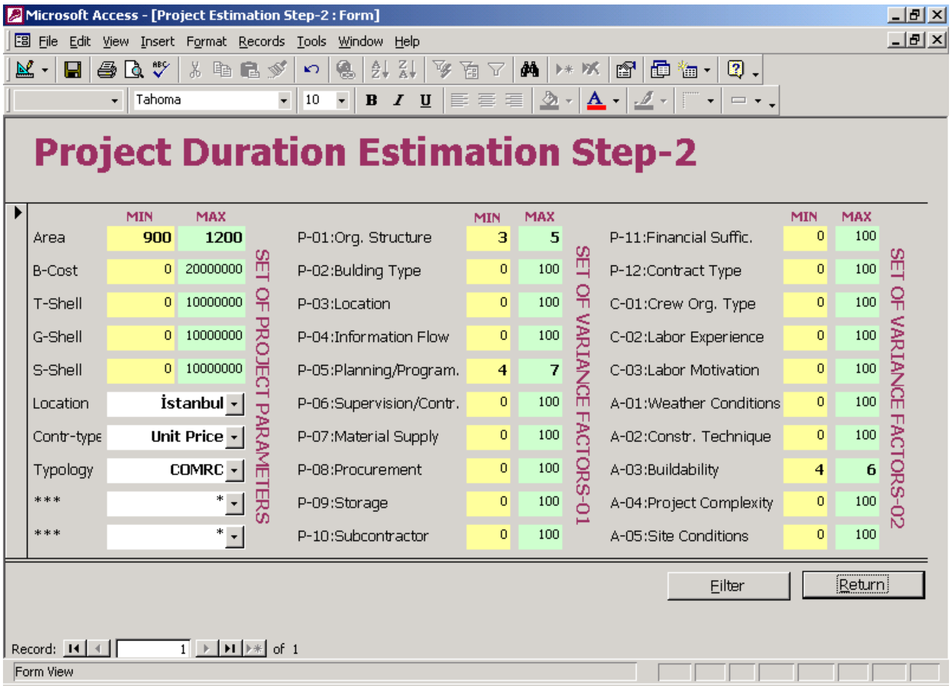

Figure 6 The interface for definition of the factors and their ranges

P-VAR$_{AVRG\text{-}BST}$ – Estimated Best Average of Duration Variances of Past Projects

P-VAR$_{AVRG\text{-}WRS}$ – Estimated Worst Average of Duration Variances of Past Projects

P-VAR$_{AVRG\text{-}LKY}$ – Estimated Likely Average of Duration Variances of Past Projects

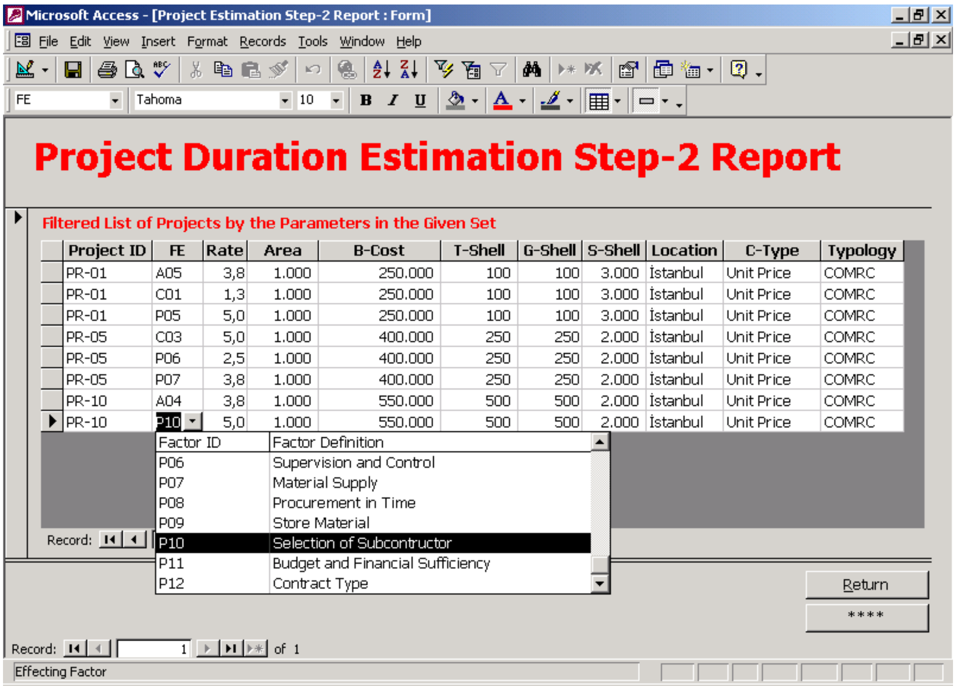

Figure 7 Output of filtering for determining the projects that conform to the set of parameters in the scenario selected

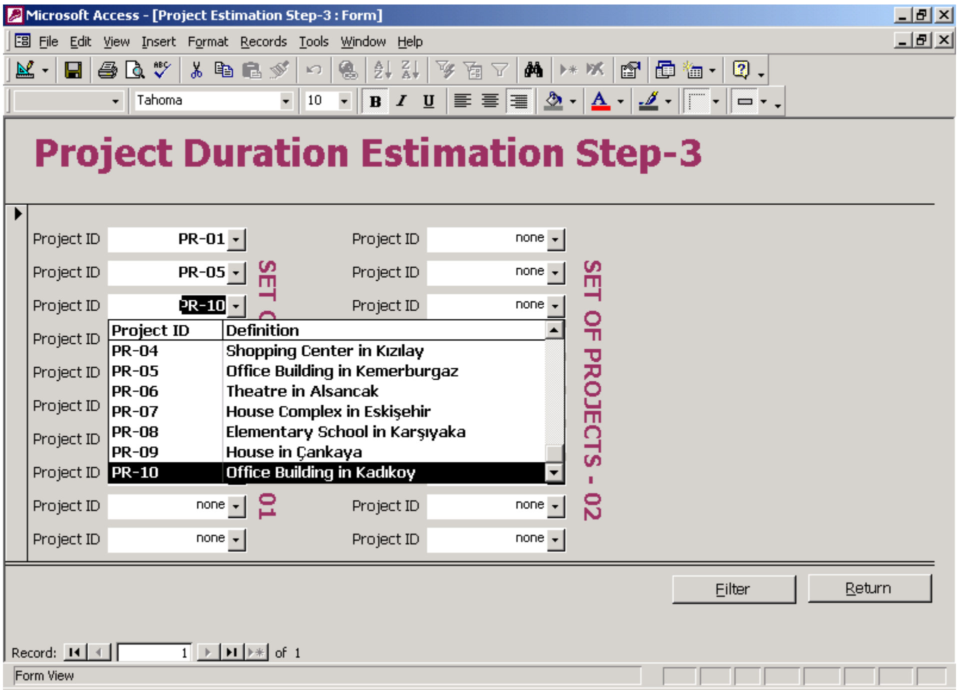

Figure 8 List of projects that conforms to the set of parameters in the scenario selected

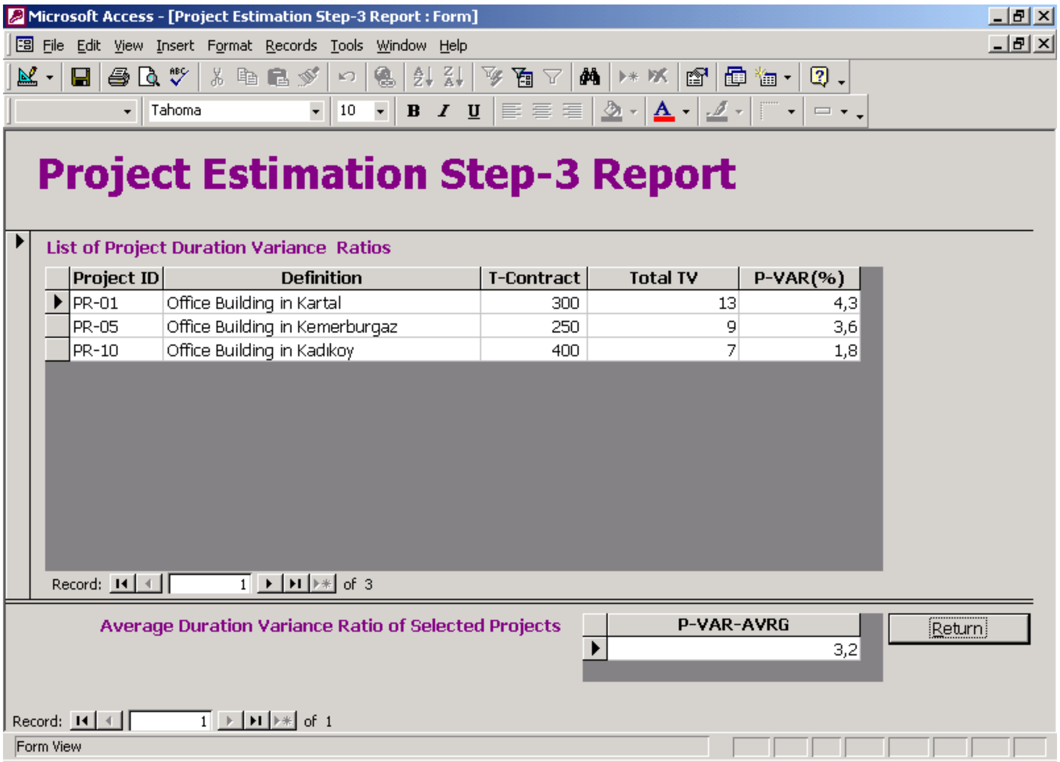

Figure 9 Determination of duration variances of the projects that are similar to current project with regard to the set of parameters in the scenario selected

Phase – II: Post-operations fulfilled by the other functional modules

Step – 06: Calculation of activity durations, by using standard productivity values of the crews, are performed and the initial schedule is prepared. Duration of activities are automatically calculated in the *Time Management Module* when the related crews are assigned (Figure 10).

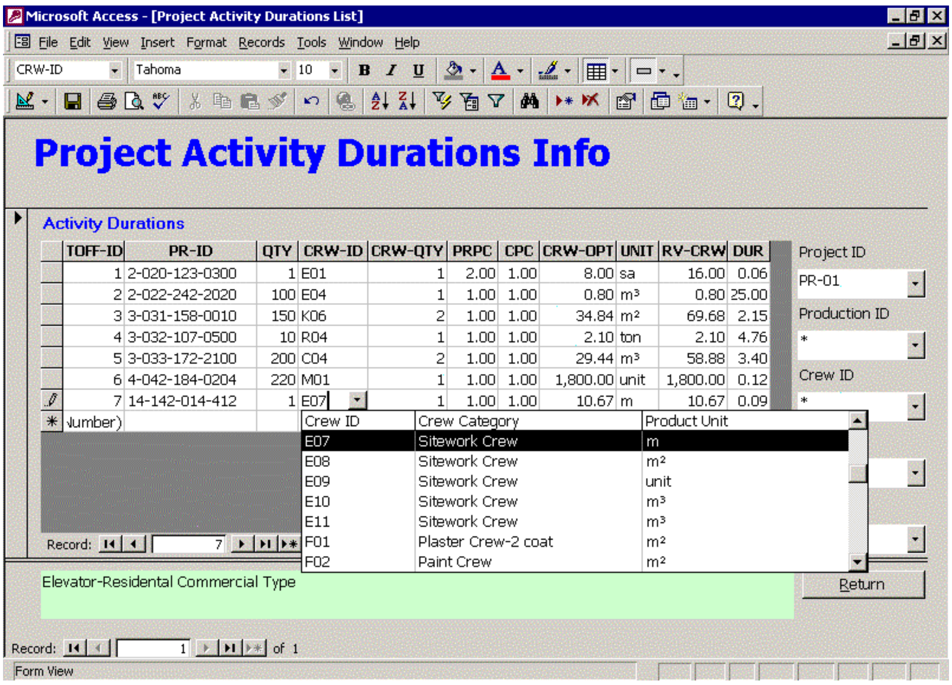

Figure 10 Calculation of activity durations by assigning related crews

Step – 07: Time points $\mathbf{T}_{1\text{-BST}}$, $\mathbf{T}_{1\text{-WRS}}$ and $\mathbf{T}_{1\text{-LKY}}$ that gives to contract time $\mathbf{T}_S$ as indicated previously in Figure 1 when added $\mathbf{P\text{-}VAR}_{AVRG}$ values obtained from each of the three scenarios, i.e., best, worst, and likely scenarios are determined. Modifications are performed to revise the schedule by considering the calculated probable variances.

The Organizational Model Proposed for Solving the Fragmentation Problem: Design/Build

Design/Build is considered as one of the most suitable organizational patterns for solution of the fragmentation problem in construction projects. It is sometimes conducted by a company that has design and construction capabilities or by a joint venture between a design firm and a construction company. 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.

Although it has these stated advantages, this procurement route does not always achieve its claimed advantages. The suggestion of an automated system for design/build 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. That is why design/build is preferred as the organizational pattern in physical dimension that makes the proposed model applicable.

The Integration of Duration-Estimation Model with a Comprehensive Information System: Integration of SPIDER and MITOS

As an organizational pattern, design/build may help to solve fragmentation problems in the construction projects. Yet, it must be supported by the integration of computer-based information systems of the project participants. Accessibility of the as-built schedules of past projects without spending any additional effort is one of the basic requirements of an applicable duration-estimation model. Integration of information systems make it easier and faster to have an access to the data in construction firm's database whilst design/build provides an organizational reliability between the project participants. That is why any application model developed for duration-estimation should be considered first during the conceptual modeling process of integrated information systems.

Current information modeling for the A/E/C industry includes *product*, *process*, and *project* models [19, 20]. Froese introduces several versions of core conceptual models (reference models) of construction processes from a variety of research projects associated with computer-integrated construction [21]. The idea of managing efficiently the functional components of a construction company or a design firm by means of computer applications is not new. Various studies that attempt to solve the integration problem can be located in the literature [20, 22, 23].

There are few conceptual and practical models developed as a response to the needs in the design stage, such as those developed by Platt [24], and Baldwin *et al*. [25]. However, except ASAP [26], any *comprehensive* conceptual or application model especially designed for architectural offices could not be located in the literature.

The model proposed in this study was designed as a stand-alone computer model that can also be integrated into comprehensive information systems such as MITOS [15] for design and construction firms (Figure 11).

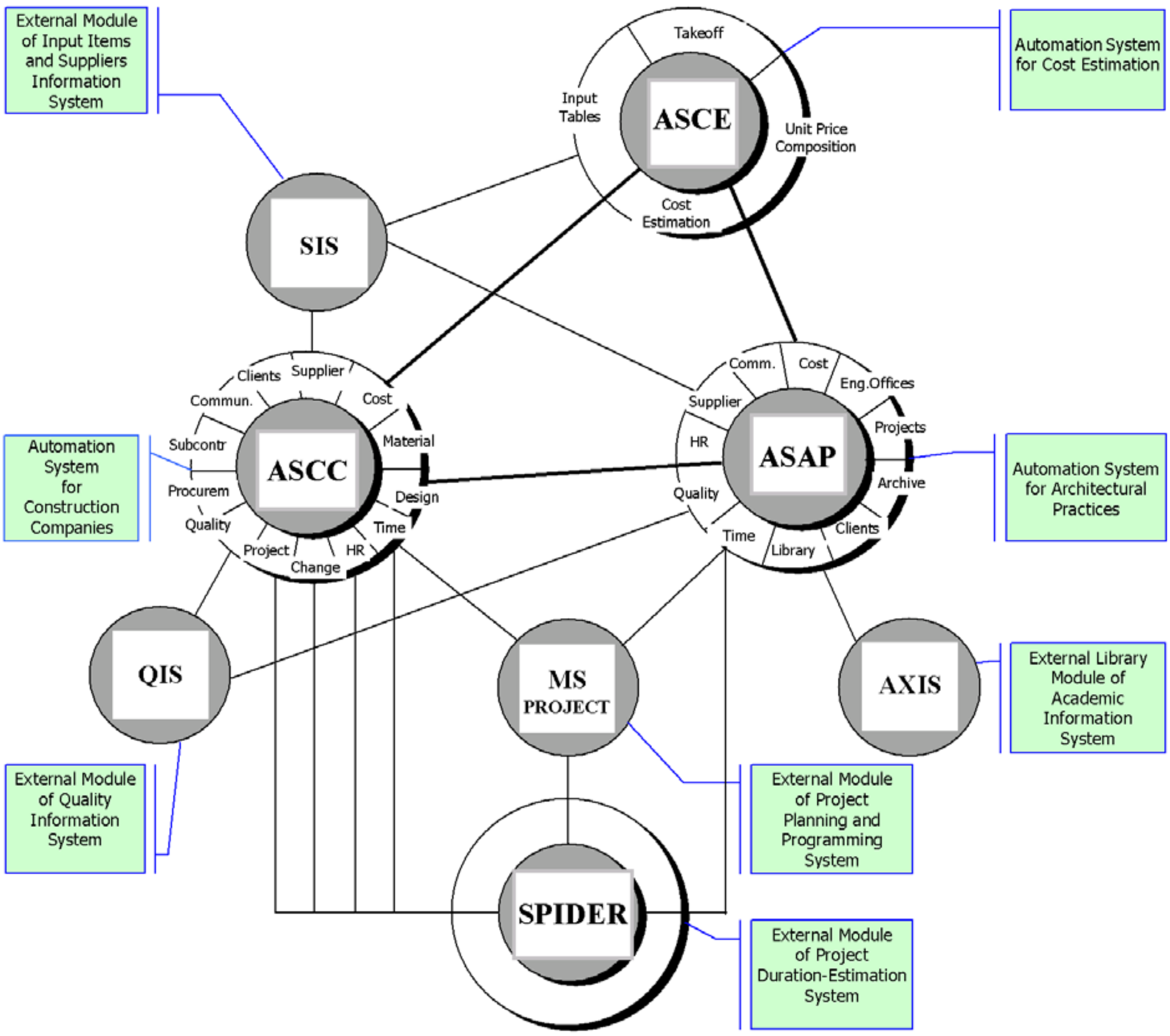

Figure 11 Integration of SPIDER and MITOS

Conclusions

The importance of an accurate estimation of construction duration is acknowledged in the context of the low markup values, bonuses of early completion and penalties due to delays. 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.

SPIDER, the model developed in this study, emphasizes that duration deviations are the reality of construction projects and that is why baseline schedules must be prepared by not only considering the completion time stated in the contract but also by using an earlier date that yields to this date when estimated duration variance is added. In order to be able to find out this point of time estimation of best, worst and likley variances for the current project is essential. These values can only be estimated by using “similar” past projects. The task of the theoretical model is to determine the parameters that are the best set of parameters for the current project and the ranges that must be associated to these parameters. The parameters and ranges vary for each project, and the responsibility of proposing scenarios, including best, worst and likely scenarios, including suitable parameters and ranges, does not automated but carried out by the estimator.

The computational part of the model developed within a theoretical dimension, provides a simple structure that eliminates resistance from the estimation professionals. The software supporting the theoretical solution, allows integration to a comprehensive information system that includes various modules that organize the data required by duration-estimation process proposed. Finally, the organizational model, design/build, allows the integration of information systems of project participants. This aspect is the basic component underpinning the solution developed in this study. Furthermore, the model adopts an approach that assigns the computational processes to the computer and the expert-related processes to the estimation professionals.

Arguably, experience-based duration-estimation models need the data of significant number of projects to be able to provide more accuracy in estimation and the accuracy of estimation increases by the number of projects that conforms with the project that is currently analyzed. Since the data from a limited number of projects decreases the reliability of the validation process it was decided to validate the model during the implementation phase of the model by integrating it to the information systems of nine design/build organizations currently using MITOS, the integrated information system previously discussed above.

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