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# Modeling of development time for hydroelectric generators using factor and multiple regression analyses

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**Abstract**

The pressure to reduce product development time in today's competitive industrial market has made the need for sound estimation techniques more acute than ever before. This paper reports on work done to construct a parametric model to estimate the time needed to develop future hydroelectric generators. The model uses three factors, namely, product complexity, involvement of partners in the development process, and generator speed. These factors were identified by applying factor analysis, with principal component analysis and varimax rotation to nine candidate factors. The performance of the model was tested in terms of a number of objective criteria. The results indicated that the model has a good accuracy for estimating development time.


*Keywords:* Managing projects; Product development; Time estimation; Factor analysis; Parametric model; Hydroelectric generators

## 1. Introduction

Delivery of products as scheduled is one aspect of measuring the success of development process [1]. Unfortunately, in spite of the significant advances in project management assisted tools and techniques, project managers are still facing the problem of severe schedule overrun and project cost overrun [2–4]. Schedule overrun increases the risk of product obsolescence due to the increased risk of missing the market window [5]. In many cases, this means a project failure. According to Evans [6], delay is deadly. In the auto industry, one study indicates that each day of delay costs an automobile firm over $1 million in lost profits [7]. In most of the cases, the problem of overruns is due to poor estimation [8]. This is because the capabilities of traditional estimation techniques, such as work breakdown structure and network techniques (CPM, PERT), are limited in producing realistic estimates that become the basis of a project plan [9,10].

The existence of such problems in the present era of shrinking product cycle times has made the need for sound estimation techniques more acute than ever before. Improving estimation accuracy is a vital issue not only for the companies that use traditional development approaches, but also for those adopting newer approaches such as concurrent engineering. In other words, reducing the development time of a product is a futile effort without being better able to estimate the required time within acceptable error, and thereby, reduce the probability of overruns in time and cost.

Adopting a metrics approach is one of the promising solutions [9,10]. In a metrics approach, the use of subjective estimation is minimized by assigning quantitative indices to the attributes of product and project entities. These entities are used to construct estimation models. The models, then, can estimate the required time to develop a product. The metrics approach is a more systematic way of overcoming the problem of biased estimation that characterizes most of the available estimation techniques. It has emerged as an effective management tool in disciplines such as software development [11–14].

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## 2. Related research

Several studies have proposed process-oriented mathematical models that are based on the bottom-up estimation approach, i.e., breaking down the projects into activities, then the relationships among these activities are represented mathematically (e.g., see [15–22]). It is beyond the scope of this paper to review these models. Generally, however, because of their computational complexity, these models are usually applicable to small projects or a set of project activities. In addition, they are appropriate and useful at a late stage of project planning.

The focus of this research on the parametric models that relate the time required to complete a project to variables associated with product and project characteristics. This type of models is useful in estimating project duration at the early stages of planning. Very few parametric models have been proposed in the literature. For instance, in Griffin [23], a number of metrics including product complexity, management complexity, amount of change, use of cross-functional teams, and use of a formal process were used to construct multivariable estimation models. The models were developed and tested using data sets gathered from 343 projects from different companies; however, because of the heterogeneity of the projects in the data set, these models only accounted for a small portion of data variation ($R^2$ ranges from 0.15 to 0.30). In Bashir and Thomson [24], a modified Norden's model [25] was used in conjunction with an effort estimation model to derive a quantitative model for estimating project duration. However, due to the limitations of data availability, the performance of the derived model was not tested. Recently, Xu and Yan [26] proposed to use quality function deployment (QFD) and a fuzzy neural network to build a model for estimating product design time. A model was built and tested using data collected from 72 plastic injection mold projects. Although the product was simple, six variables associated with mold characteristics were included in the model. The used characteristics were structure complexity, model difficultly, mold size, and others. The model was built and tested on very small projects (the development times varied from 10 to less than 100 h).

Taking into account the highlighted limitations of previous works, this paper reports on research done to construct a parametric model to estimate the time needed by GE Hydro to develop a complex product, a hydroelectric generator. GE Hydro is a world leader in the design and construction of generators and turbines for hydro-electric power generation. The model attempts to be reasonably accurate, easy to use, and parsimonious.

## 3. Methodology

The methodology involves the following major steps:

- Data collection.
- Factor selection.
- Model construction.
- Model testing.

### 3.1. Data collection

Parametric estimation models use historical data from previously completed projects to establish mathematical relationships capable of generating estimates for future projects. A major step of data collection is to select the sample size. In a very general sense, the best way to ensure predictive power in regression is use a sufficiently large sample size. However, it is extremely difficult to find a company that undertakes a significant number of large projects within a reasonable time. Therefore, in this type of research, since the size of population of interest is small, then the sample size can be relatively small. However, to ensure the generalizability of the model, the ratio of the sample size to the number of variables to be included in the model should not fall below five [27].

In this study, the selection of sample size was based on the most widely used rule-of-thumb, described by Olejnik [28]: "use as many subjects as you can get and you can afford". Using this rule, a sample of 17 projects related to the development of hydroelectric generators was selected. The projects had durations ranging from 14 to 39 months with a mean of 23.6 months. This sample of homogenous projects was considered to be sufficient since it represents more than 90% of the total hydroelectric generators projects carried out by GE Hydro over a 10-year period. The following two criteria were used in selecting the 17 projects:

- Availability of data, i.e. the data required for the analysis were available and reasonably accurate.
- There were no substantial changes in the requirements after feasibility study.

To ensure correctness, completeness, consistency, the data were collected using a special form. This form lists all the required data. It also included a glossary of terms, instructions on filling out the form, and guidelines supported by demonstrative examples on how to perform functional decomposition. Interviews were also conducted to check the data.

### 3.2. Factor selection

Developing a parametric model requires a careful selection of the factors that have predictive relationships to development time. These factors should be identified among the more than one hundred candidate factors, which influence different aspects of development projects [29]. Nevertheless, after reviewing previously published research [9–11,23,29–39], and consulting with design managers from GE Hydro in a brainstorming session, the following candidate factors were considered as possible predictors for project development time: