# Future Product Development Cost Prediction Model for Integrated Lifecycle Assessment

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Jan Erik Heller[1], Manuel Löwer[1] and Jörg Feldhusen[1]

[1] Institute for Engineering Design (ikt)
RWTH Aachen University, Germany

[1] heller@ikt.rwth-aachen.de

**Abstract.** Beneficial for PLM implementation is the use of data from every product phase for optimising future goods. The objective is to decrease engineering efforts. In order to determine monetary efficiency and its influence on the product's lifecycle, it is essential to anticipate revenues and obtain information about expected costs. Most approaches focus on production expenses as they evoke the major share of costs. Development expenditures are not identifiable reliably. Existing methods premise the availability of accurate values as input. A new approach has been developed, that is based on requirements. Assuming that products with similar indicators cause similar development efforts, databases are set-up to allow for development cost prediction. The model was validated for civil aircraft. A retrospective analysis of existing aircraft and their requirements provided the necessary input. Approach and validation are presented and information about the software demonstrator that was integrated into a lifecycle assessment platform is given.

**Keywords:** Product Lifecycle Management, Development Process Efficiency, Sustainability Analysis, Lifecycle Tool

## 1 Introduction

For new product development projects, it is essential to acquire information about potential revenues as well as anticipated costs in order to predict the economic feasibility of the prospective product. However, the determination of the development costs already at project start is not reliably possible in a grand number of cases. Too many and unquantifiable factors make a forecast inaccurate and lead to mostly unrealistic cost information. Often, predictions are also restricted to an indication of only the expected production and assembly costs neglecting the costs for the product development process and the operating design departments. Numerous methods are known that aim at the estimation of the efforts that are *defined by* engineering departments. Wolfram's FEKIS [1] or Horváth's XKIS [2] may serve as examples. Admittedly, in many cases, production and assembly efforts exceed those for design and development [3]. Nevertheless, as a result of more and more contested market conditions because of globalisation, companies are increasingly forced to also cut their costs for design and development projects besides the reduction of the manufacturing costs [4]. Existing methods for the determination of the development costs are often designed to determine comparably precise values. Therefore, they require correspondingly accurate input values. Some of them incorporate extrapolation techniques, which, for example, implement algorithms to predict the prospective costs based on the number of positions from the bill of materials. Others are based on the precise knowledge of specific parameters of the future product, such as precise masses of individual components. These approaches provide formulas for correlations between those values and the development costs. However, at the beginning of a development project neither the complete bill of materials is known nor are parts designed with their final shape and volume. Thus, the product is not yet sufficiently defined in order to provide the necessary input variables for the existing methods.

In order to still be able to obtain a forecast of the development costs at this stage, despite the prevailing stadium of indeterminateness, it is necessary to develop a method that only relies on few design parameters based on the requirements list.

# 2 Current Cost Estimation Methods and Tools

Methods for the cost estimation and the effort of product development projects that can be applied in early phases are hardly described in the course of conventional methodologies for systematic engineering design. Typical methods are based on estimates of the cost on the basis of experience from previous projects for the development of similar products. For example, it is common practice to estimate the number of necessary drawings and documents and to map them to a comparable number of so-called document square meters. With appropriate in-house experience for the time needed to create one square meter of documents, the actual effort can be concluded. However, this approach requires detailed knowledge of the product structure and in particular the number and type of components to be developed [5]. Thus, this approach is considered unsuitable for a prediction of the anticipated costs prior to or during the early stages of the development process.

Other approaches consider the number of positions from the bill of materials. This number is then used to correlate with company specific effort factors that allow for a prediction of the typical workload for a single position. Often, characteristic figures like engineering hours per position from the bill of materials are implemented. Similar with the previously presented approaches is the necessity to have knowledge about an elaborated bill of materials in order to be able to estimate accurate cost values.

The software business uses methods to estimate the effort that arises during the development phase itself since several decades. In general, a software product invokes design and development costs. Opposed to that, its actual production typically evokes only costs for the manufacturing of the data storage medium and the package. Boehm introduced the Constructive Cost Model (COCOMO) in 1981 [6]. Since then it has been constantly extended. However, the idea and the core remain the same: it is based on a prediction of the effort that is estimated based on the physical size of the program. This is mostly implemented as the number of expected source lines of code.

Besides that measure, Boehm has included another seventeen parameters that are required to be estimated before the approach can be used for effort prediction. Amongst others, characteristic figures describing the complexity of the product and the similarity with previous projects as well as indicators for the collaborative capabilities of the team are implemented [7]. A transformation of the COCOMO method to the needs of mechanical engineering design processes has already been undertaken by the author [8]. The seventeen factors of the COCOMO II model have been adapted to meet the specific needs of the discipline and combined into a total of seven parameters. For example, the degree of innovation in the sense of the expected novelty of the product is measurable both in software development and in conventional mechanical product development [9]. This parameter could directly be applied. However, some of the seventeen original parameters do not have a direct correspondent. Thus, additional factors like the distribution of the engineering team over several sites have been included. Although many of the required factors are known in advance or their determination often can be achieved regardless of the product to be developed, yet the knowledge of the *size* (which can be considered the counterpart of the source lines of code, for example the number of positions in the bill of materials) of the product is essential. Thus, this method also does not provide itself as useful to adequately predict the development costs in advance with the use of only the design parameters.

Other methods exist, that are specially designed to be used for commercial and military aircraft development. They are characteristically focussing on the determination of lifecycle costs of aircraft. In particular, development costs are addressed as well.

Cost estimation relationships are a typical tool to predict development costs. For example, Raymer suggests a formula for the estimation of necessary engineering hours. Parameters like the mass of the aircraft, the maximum speed and the overall size of the vehicle are used. With company-determined factors, the resulting engineering hours can then be converted to the expected efforts [10]. The drawback is that Raymer's equations are only valid for aircraft with vessel and wings made from aluminium. A simple adaption for current aircraft, that are to a large extent made from fibre reinforced plastics and metals, is unmanageable. Moreover, an adaption of the method for industrial sectors other than aerospace seems to be impossible without completely revising the formulas. Another approach that is presented by Raymer tries to anticipate development costs as a fraction of production expenses [10]. However, this approach requires that the costs of production are well known. Typically, assessments are only available towards the end or even only after the development phase so that a prediction of the development costs in the early stages is difficult.

Also specific to aircraft development is the model presented by Roskam. It determines the development costs as a function of weights of individual key components of the aircraft to be designed. For example, it is necessary to know the empty weight of the aircraft as well as individual weights for wheels, brakes, engines, batteries, aviation systems, climate control systems, fire extinguishment systems and the auxiliary power unit before a cost estimate can be conducted [11]. In general, these detailed weight distributions are not known at the beginning of a new development project. As not all products can be considered new product development projects, Raymer's prediction approach cannot be utilised for follow-up designs. He suggests a difficulty factor that has to be incorporated on company-specific discretion [11]. Existing approaches allow for a prediction of the effort for development projects. However, the different methods require precise input values that generally are not accessible prior to or during the early phase. As a consequence, their application is restricted to advanced phases of the development process.

# 3 Methodology for Product Development Cost Prediction

A new methodology that intends to enable the prediction of development costs has to be conceptualised in order to improve this unsatisfying situation. The methodology has to be usable with only basic design parameters as input values. Another requirement is that the cost prediction must be enabled already during or even prior to the early phases of development process.

## 3.1 Setup of the Methodology

The methodology is set up by two methods. The first of which is aiming at building up and qualifying a data model that is used to store and supply lifecycle data for the second one. This method is applied when an actual cost prediction is conducted. The second method requires a working and validated data model. Thus, the first method has to be successfully executed at least one time prior to the first prediction runs.

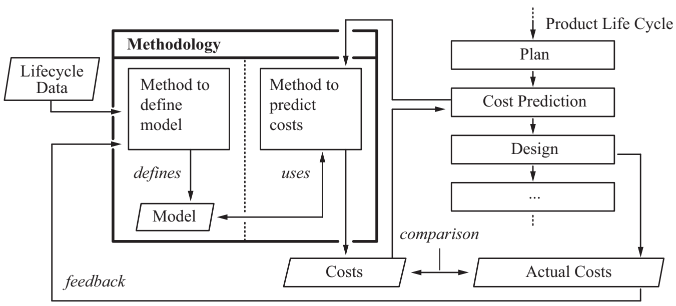


**Fig. 1.** Structure of the cost prediction methodology

An overview of the structure of the methodology is given in Fig. 1. On the right side the general procedure for a product development process embedded in the product lifecycle is displayed including the coupling point for the cost prediction methodology that is comprised of the two basic methods. Two hypotheses are introduced: the fundamental one postulates that products can be described by physical parameters, for example by their mass or their volume. Moreover, correlations can be deducted between these parameters and the factors that economically determine lifecycle phases (e.g. the development phase). In addition to that, a similarity condition is established postulating products with similar parameters will evoke similar costs. Typically, three different kinds of correlations can be distinguished: economies of scales, statistical models or equation-based mathematical relations [12]. The last one will be implemented here. The second hypothesis is that the cost of the development project depends on the year in which it is performed. Due to technological progress, it is inferable that the development of a product in a specific year evokes less effort, compared to the development of the same product if it had taken place some years earlier.

### 3.2 Method 1: Lifecycle Data Modelling

Before the second method for the cost prediction can be applied, it is essential to perform the lifecycle data modelling and set up the mathematical relationships between parameters and economic data. The steps that are necessary for this approach can be taken from Fig. 2.

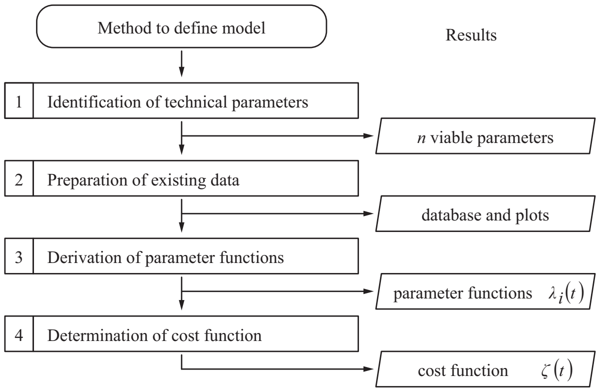


**Fig. 2.** Method for model qualification: steps and results

The identification of a set of suitable parameters forms the first step of the method. It is important to identify the parameters in a way that they unambiguously define the prospective product. In addition, the parameters must have a substantial influence on the development costs. The colour of a product is not as useful as the allowed mass. In most cases, colour does only have a low influence on the development costs.

Forming combinations of several single parameters is helpful in order to achieve indicators of a higher quality. Exemplarily, the length of the landing field that is necessary for an aircraft already is a good indicator for the effort. Vehicles that can operate with a short landing field generally are more difficult to develop. But, if the landing field length is divided by the maximum weight of the aircraft, the effect of the indicator is increased as it is more difficult to develop a vehicle that has a huge weight and operates with a short landing field length at the same time. Concluding, it is possible to choose any design parameter and any combination of them for the modelling step. However, the performance and the quality of the model are significantly increased with more meaningful parameters. The method analyses data ranging from lifecycles of already existing products and its predecessors in addition to data that is incorporated from similar competitor products. Thus, a sufficient amount of data has to be researched, estimated and prepared for the qualification of the model, before it is ready to be used by the second method. The second step of the method therefore addresses the preparation of data. The model has to be fed with characteristic values for the identified parameters from already conducted development projects. For all parameters that have been selected values have to be retrieved and put in context with temporal information, i.e. the year, in which the original development project has taken place. After that, the parameter functions $\lambda_i(t)$ can be established for every identified parameter in the third step. This is achieved with the help of parameter value charts. An example is given in Fig. 3. The mathematical function is conceived by entering all pairs of parameter values and the corresponding year into the chart. Then, the maxima or minima for a defined time period are computed depending on the industrial sector or the type of the product. The length of the period can be chosen individually based on the typical duration of development projects in the industrial sector under consideration.

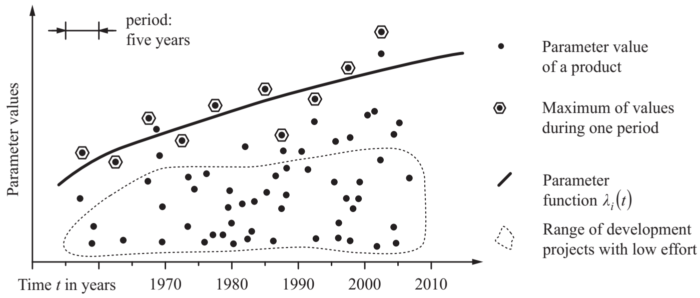


**Fig. 3.** Exemplary parameter value chart with parameter value function

For the example in Fig. 3, the maxima approach has been chosen. Thus, higher development costs are related to a higher parameter value. A line of best fit is derived and referred to as the parameter function $\lambda$. This parameter function can be interpreted as the average border of the technological progress of the respective parameters in the specific year in case enough and representative development projects are included in the chart. As a consequence, there are no other development projects surpassing this border significantly. For every identified parameter this step has to be performed. Finally, the fourth step serves to derive the mathematical representation of the development cost function. Similar to the parameter functions the cost function $\zeta$ is derived based on the same data. Likewise, a chart is conceived that contains all pairs of cost values and related years. A linear regression curve is estimated with the maxima. In order to allow for comparisons between the different results, all cost values have to be harmonised regarding inflation. The results of the first method are a number of parameter functions and the corresponding cost function with the according charts.

### 3.3 Method 2: Development Cost Prediction

After the successful execution of the first method, the model is qualified with lifecycle data of existing development projects. The second method which is used for the actual prediction of the effort for the development of future products can be performed. The required steps and the related results are given in Fig. 4. During the first step, the values of the design parameters for the new product have to be identified. These values are the key input for the method. The year in which the design project is undertaken is required as well. Typically, it is the current year. However, the method is capable of predicting effort for projects in the past as well as in the future, as long as the year value remains inside the specified system boundaries.

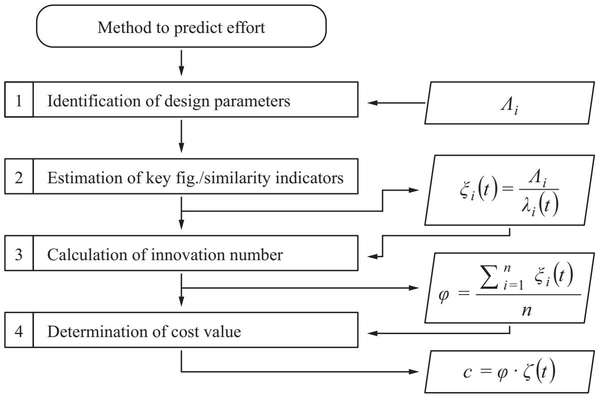


**Fig. 4.** Method for effort prediction: steps and results

The estimation of key figures based on the parameters is conducted in the second step. Key figures are implemented in order to investigate similarities between existing data points and the current development. The similarity indicators $\xi_i$ are calculated dividing the value $\Lambda_i$ of the design parameter by the value of the corresponding parameter value function $\lambda_i$ at the defined time. Each key figure locates the prospective product in relation to a theoretical product that resides on the border of the technological progress at a given time $t$. An innovation number $\varphi$ is calculated in the third step. In the current implementation, $\varphi$ is determined by the arithmetical average of all key figures $\xi_i$. However, it is possible to train the model with a weighted emphasis on specific indicators if this enables a model of higher quality. The decision to opt for a weighted mean has to be carried out within the first method. The weighted mean can be advantageous compared to the arithmetic mean, in case the identified design parameters are describing similar technological difficulties. In this case, the forming of groups of similarity indicators that are weakened by appropriate weighting factors can be beneficial in order to maintain a balanced representation of the prospective product. The fourth step of the method for the prediction of the effort is defined by the determination of the actual cost value for the prospective development project. By multiplying the dimensionless innovation number $\varphi$ with the year-dependent value of the cost function of the model $\zeta$, the cost value can be predicted.

### 3.4 Product Lifecycle Engineering Platform Integration

Typically, within engineering departments, the application of this methodology is not limited to a *prediction* of product development costs. Apparently, the majority of products for which the prediction has been performed will be realised after the design phase is completed. It is possible to then effectively determine the actual costs and compare them with the initially predicted costs. This brings with it two advantages: the feedback that is collected on this way can be used to verify if the model that has been set up with the first method is capable of reliable cost predictions. In addition to that, the feedback information can also be used to add new data points to the parameter value and cost charts aiming at a further refinement of the data base. With an increasing amount and extensiveness of interpolation points, the predictions gain accuracy. Fig. 1 also shows the established verification and feedback loops. When it is intended to permanently integrate this methodology in the product emergence process of a business it is necessary to continuously include new data points. Else the model would be out-of-date and thus unable to predict current project costs accurately.

A large scale lifecycle assessment project whose goal was the extensive investigation of the complete lifecycle of civil aircraft formed the framework for the methodology presented here [13]. In the course of the project, a lifecycle engineering platform has been implemented that allows for an assessment of different preliminary aircraft designs and their impacts on production, operation and end-of-life phases.

# 4 Application for Civil Aircraft Design and Development

Section 3 presented a model for the cost prediction of future products with a surrounding methodology. A prototypical application of both model and methodology has been undertaken as a part of design and development processes for civil aircraft that have a capacity of more than 100 passengers. Both the process steps for method 1 (for the qualification of the model) and for method 2 (for the actual cost prediction) have been conducted. A software demonstrator has been conceptualised to support the data handling. It has been designed to interact with the lifecycle engineering and assessment platform which has been addressed in the previous section.

Conventionally, the key concept requirements in preliminary aircraft design are defined and referred to as TLAR (Top Level Aircraft Requirements) [14]. In general, the TLAR are defined prior to the beginning of the actual design and development phase. For aircraft that are available on the market at present, the parameters constituting the TLAR can be determined from literature and manuals of manufacturers. Thus, it can be made sure that a set of suitable data is available. In the application example, the design parameters that are used for the model in method 1 have been taken from the set of TLAR. However, an adequate set of design parameters had to be extracted from the list of all top level requirements. After that, each parameter and every group of parameters had to be tested regarding the applicability for the intended cost prediction. The parameters that have been chosen for the implementation are displayed in Tab. 1. An exemplary discussion demonstrates the impacts: the maximum take-off weight has a huge impact on the costs, as expected. But to only rely on this design parameter did not produce satisfying prediction results. Although key factors in the aerospace sector are masses, other parameters do have significant impact on the development costs as well. Thus, more parameters are necessary in order to express the technological feasibility by the parameter value functions. Other design parameters that have been investigated did not have significant or unambiguous impact on the development costs at all. The allowed noise emission of an aircraft has a notable effect on the design of the geometry of the wings and the engines. But with the available data no feasible parameter function could be conceived.

**Tab. 1.** Overview of implemented parameter values and parameter functions

| Parameter | Description | TLAR |
|---|---|---|
| $\lambda_1$, $\Lambda_1$ and $\xi_1$ | Max. Takeoff Weight | MTOW |
| $\lambda_2$, $\Lambda_2$ and $\xi_2$ | $\frac{\text{Max. Landing Weight}}{\text{Landing Field Length}}$ | $\frac{\text{MLW}}{\text{LFL}}$ |
| $\lambda_3$, $\Lambda_3$ and $\xi_3$ | Number of seats · Range | Seats · R |
| $\lambda_4$, $\Lambda_4$ and $\xi_4$ | $\frac{\text{Number of seats}}{\text{Operating Weight Empty}}$ | $\frac{\text{Seats}}{\text{OWE}}$ |
| $\lambda_5$, $\Lambda_5$ and $\xi_5$ | $\frac{\text{Max. Payload} \cdot \text{Range}}{\text{Sea Level Static Thrust}}$ | $\frac{\text{Max. Payload} \cdot \text{R}}{\text{SLST}}$ |

Eventually, five parameters have been identified which have a notable impact on the development costs. Both single parameters and combinations of several values have been implemented in a software demonstrator. Fig. 5 displays the prototype that has been established with Excel. In addition, an xml interface was set up for the connection with the existing lifecycle assessment platform [15].

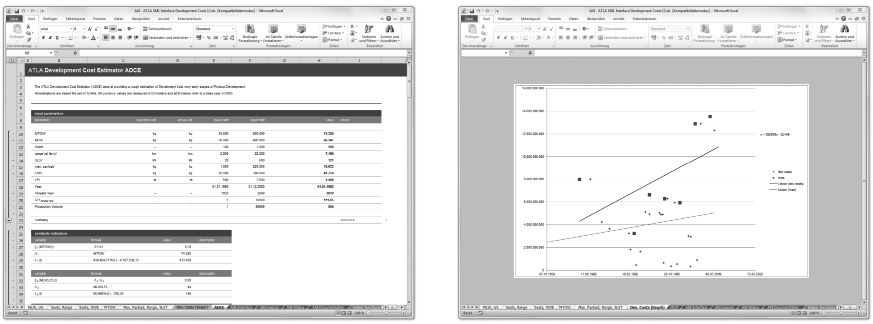

**Fig. 5.** Software demonstrator implementing the methodology with cost function chart

Actual aircraft development projects have been used for a verification of the method. The set of projects included in the verification contained both projects being used for the model qualification and projects that have been left out on purpose. In our tests, the average deviation between predicted and actual costs was not exceeding 22 %. Thus, the initially postulated hypotheses can be considered true.

## 5 Conclusion and Prospects

This paper introduced one approach to predict the development efforts and accordingly the development expenses. The presented methodology relies only on a small number of available technical requirements that are already defined at or even before the start of the related development project. Because of its structure which separates data model and prediction method, the methodology is generally applicable in any industrial sector or for any specific product groups. Lifecycle assessment data from similar products is incorporated to allow for a prediction of the lifecycle impacts of future products. In order to validate the applicability of the methodology, investigations for the sector of civil aircraft design have been presented. In addition to that, a software demonstrator that enables the integration of the predicted data into a lifecycle engineering platform has been addressed in the last section.

The methodology presented here is subject to current research at RWTH Aachen University. Further research will be conducted regarding the generalisation of its application. The investigations will include the research for suitable sets of design parameters being largely valid for other industrial sectors. Moreover, it is intended to extend the validation of the underlying methods with other application examples.

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