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Product Cost Estimation in the early Development Phases – The Case of Powertrain Systems and Battery Packs

Simon Röhrenbacher[1], Oliver Moerth-Teo[1,*], Lukas Schwarz[1], Hans Schnöll[1], Christian Ramsauer[1]

[1]*Institue of Innovation and Industrial Management, Graz University of Technology, Austria*
[*]*Corresponding author. Email: oliver.moerth@tugraz.at*

In the automotive industry, high competition, volatile markets and short development cycles are commonplace. In addition, the transition to new drive technologies brings further challenges and complexity for car manufacturers. Improved product cost estimation especially during the early development phases enhances design decisions to better address this situation. Due to the lack of data availability in this stage, exact calculations are very difficult and require a lot of experience. Even though various methods to estimate the product cost already exist, they usually vary greatly in accuracy and applicability. Therefore, the focus of this paper is to investigate different qualitative and quantitative product cost estimation methods in the early development phases.
First, a literature review provides the fundamental understanding about existing cost estimation methods. Aiming for a data triangulation, documents were collected, experts interviewed and a survey conducted, all at one engineering company dealing with powertrain development. Based on these three sources, two empirical studies were performed (study A: documents and interviews; study B: survey). A subsequent comparison allowed statements about the applicability of qualitative and quantitative cost estimation methods in the early development phases. Finally, two of these methods (case based and fuzzy logic) were applied at two different points in the early stage of battery pack development. In order to represent the increasing data availability when progressing in the development process, different parameters were included. While the reference data for the product cost estimation came from literature, the case company provided the input data for six battery packs of existing electric vehicles. This allowed a comparison of the estimated cost to the actual cost, whereas the calculation of derivations built the basis to evaluate the accuracy of the methods at both points.

1. Introduction

Estimating the product cost accurately represents a difficult challenge in general, but even more in case only little data is available as in the early development stage. Improving decision making, an appropriate product cost estimation is essential to deal with increasing market competition, shortening development cycles and general market volatility. This is especially true in the automotive industry, typically characterised by large and complex projects. However, with the shift to new eco-friendly technologies and a great attention of customers on topics such as sustainability, estimating the future vehicle cost has become more challenging for car manufacturers. While cars with internal combustion engines have been produced for many decades, new automotive trends such as electrification appeared rather suddenly and caused a quick shift to new technologies, resulting in a lack of experience and a lot of uncertainties [1, 2].

Product cost comprises all financial resources used for development, production and distribution. Important decisions need to be made during the development phase, whereas future production and distribution cost should be considered. The high relevance of these early decisions is illustrated in Figure 1. While decisions during product development already cause high cost commitments, most of the actual costs are incurred much later. Therefore, Ehrlenspiel and Meerkamm (2013) express the significance of systematic development approaches to effectively realize benefits such as product cost minimization [3]. An appropriate pre-calculation of the product cost in the early development phase is consequently highly relevant.

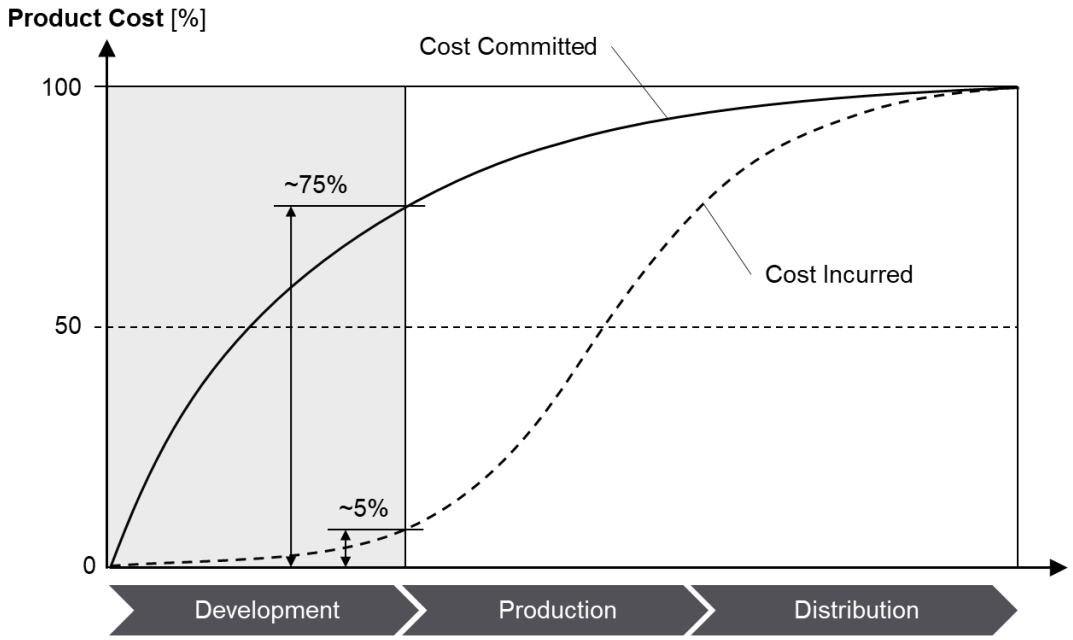

Figure 1: Impact on Product Cost [adapted from 3]

Schlink (2015) stated different principles for preliminary cost calculations during the development process. The basic approach of each method is identifying the main cost influencing factors. For example, the predicted used materials or the predicted weight of the product. Another approach is to identify certain performance parameters of the future product. The appropriate selection of a method depends on three aspects: the properties of the project, the experience of the developing company and the time of the project [4]. Lindemann et al. (2014) summarized the problem of early cost recognition such as that a company already wants to know the future cost when hardly having information about the product. They suggest a cost tracking on basis of the whole product or on single systems and elements. While some of the elements are purchased from suppliers, other parts might be produced in-house. Sometimes, the costs can also be derived from reference projects. The decisive factor for the accuracy of a calculation mainly depends on its purpose. In case of a quotation costing, the result must be very accurate. If the price is set too high, the customer will not order the product and if it is too low, the company will lose money. On the other hand, for a comparison of variants, the results simply need to be accurate enough to enable clear decisions and selections between them. Any higher accuracy only means an unnecessary use of resources [5, 6].

The previous statements underline that an appropriate product cost estimation in the early development phases might be crucial for a company to remain competitive. The literature provides several different qualitative and quantitative methods for such product cost estimations, whereas a specific group is investigated in the next section of this paper. On the basis of a powertrain development process, the applicability of different product cost estimation methods in the early development phases is subsequently evaluated. Finally, two of these methods are applied at two different points in the early stage of battery pack development.

2. Theoretical Basis

Based on the purpose of building a common base to different actors, a product development process also enables continuous tracking of the progress, detecting deviations from chosen targets and avoiding mistakes by integrating the lessons learned of previous projects. Developing a powertrain system, it is crucial to consider all interfaces between the involved systems, upwards to the whole vehicle and downwards to the elements. An entire vehicle can be divided into several systems, such as a powertrain or chassis, whereas these systems consist again of many elements, such as a battery pack or transmission [7]. Typically, a powertrain development process is structured in phases, Q-gates and milestones, starting with innovation or concept activities and ending with the start of production (SOP) [8].

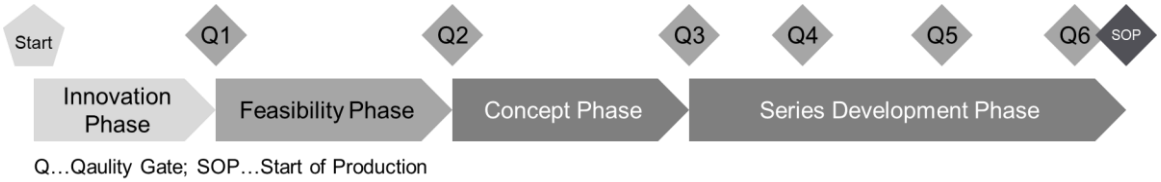

Figure 2: General Powertrain Development Process with Example Quality Gates [adapted from 7]

Figure 2 shows a general powertrain development process, whereas the innovation, feasibility and concept phase are part of the early stage [7]. The product cost is mainly set during the development by aspects like the product design, the production processes and the production location [4].

There are different characteristics of cost models. The applicability characteristic describes the state of the system. While predicting future cost is usually the aim in the early project phase, the estimation of already incurred cost might be the focus of a later stage. In contrast, the granularity level characterizes the “direction” of the cost model. The third characteristic relates to two approach types: qualitative and quantitative [9]. These qualitative and the quantitative methods can be further divided as illustrated in Figure 3. The included methods for estimating the cost of a new product can also be structured in four levels. Differing between qualitative and quantitative approaches represents the first level. In the second level, they can be further split into intuitive, analogical, parametric and analytical techniques. The third level already provides specific methods, whereas only decision support techniques also include a fourth level [10].

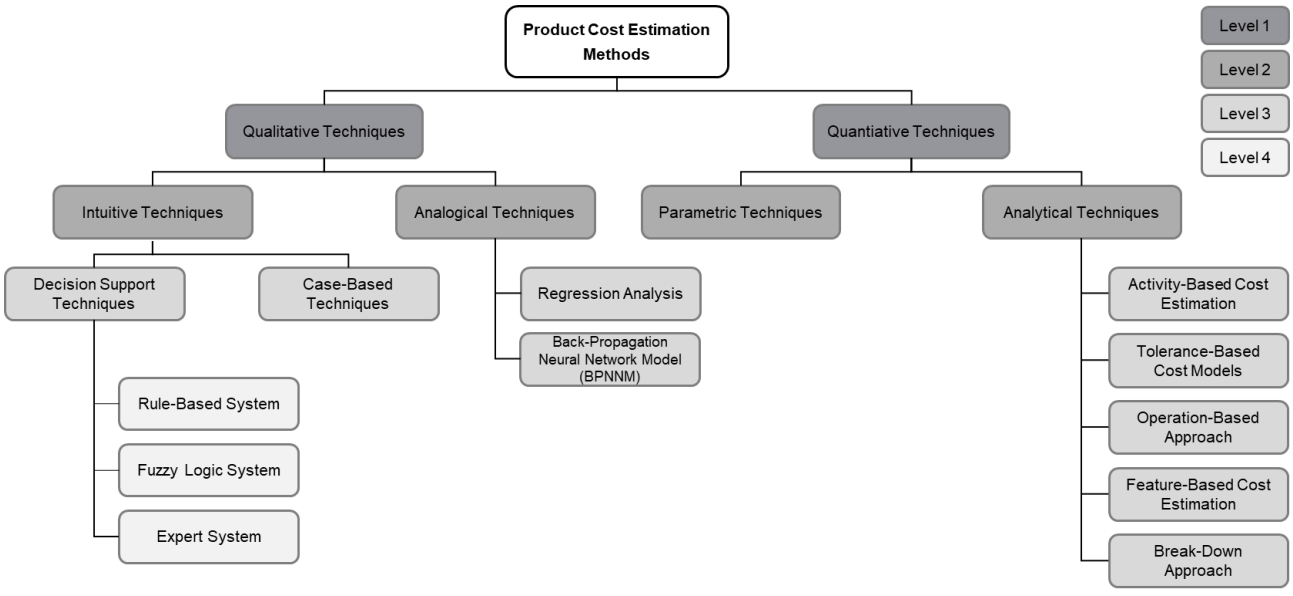

Figure 3: Classification of Product Cost Estimation methods [adapted from 10]

Table 1 provides brief descriptions of each product cost estimation method from Figure 3.

Table 1: Descriptions of available Product Cost Estimation methods [10]

#	Title	Description
1	Rule Based System	Based on design/manufacturing constraints which are reflected as IF-THEN rules
2	Fuzzy Logic System	Based on a decision table with IF-THEN rules. Handles uncertainties of variables through linguistic expressions (low/med/high)
3	Expert System	Based on experts' knowledge to a specific topic that is transferred through a rule-based programming into a knowledge database
4	Case Based Technique	Based on the idea that similar product characteristics cause similar cost
5	Regression Analysis Model	Based on historical cost data, aiming to establish a linear relationship between cost of past and current values of design variables
6	Neural Networks	A neural network is a type of artificial intelligence which is able to processes big data amounts to extract valuable information
7	Parametric Techniques	Based on applying statistical methodologies, aiming to express product cost as a function of its main cost drivers
8	Activity Based Approach	Based on performed activities to manufacture a product
9	Operation Based Approach	Based on the sum of the cost associated with production times, non-productive times and setup times
10	Tolerance Based Approach	Based on design tolerances. Different design variables are linked to manufacturing processes and further to costs
11	Feature Based Approach	Based on identifying the product´s cost driving features for determining their associated costs. (design, process planning, manufacturing processes)
12	Break Down Approach	All cost that arise during a product lifecycle are summed up. Comparable with Lifecycle Costing

3. Empirical Studies

The data acquisition is based on an engineering company dealing with the development, simulation and testing of powertrain systems for different kinds of vehicles. A single case design was chosen due to the uniqueness of the case [11] as well as the opportunity for a greater depth of investigation [12]. Aiming for a data triangulation [13], the first step was collecting documents. The typically used powertrain and battery development processes provided information about data availability in the different early phases. Subsequently, four semi-structured interviews with individual experts of the case company were conducted to gain practical knowledge. Merging the extracted data from the documents with the expert knowledge from the interviews represents study A. Based on the information from these two sources, the authors qualitatively assessed the applicability of the twelve qualitative and quantitative product cost estimation methods in the early development phases. Additionally, a survey was conducted in the department "Production & Cost Engineering" of the partner company, representing study B. The aim was to assess the costing approaches regarding their complexity and accuracy in the same early phases of powertrain and battery development. The seven participants therefore rated the complexity and accuracy of each cost estimation method separately from one to four, whereas "one" stood for high complexity or low accuracy, and "four" for low complexity or high accuracy. The applicability value was calculated through Formula 1, and in case it was greater than the threshold value of 2, the product cost estimation method was assumed to be applicable.

$$Applicability = \frac{Accuracy}{Complexity}$$

Formula 1: Calculation of the Applicability Value in Study B

Comparison of Study A & B

In the following section, the results of the two studies A & B are compared. Table 2 shows the applicability of each method in the three defined early development phases. While a letter "A" indicates an applicability according to study A, a letter "B" means the same for study B. "A & B" represents an assumed applicability in both studies, whereas "NA" means that it was neither in study A nor in study B seen applicable.

Table 2: Applicability of the Product Cost Estimation methods based on Study A & B

			Early Development Phases		
			Innovation Phase	Feasibility Phase	Concept Phase
Product Cost Estimation Methods	**Qualitative Methods**	Rule Based	A	A	A & B
		Fuzzy Logic	A	A	A
		Expert	A & B	A & B	A & B
		Case Based	A & B	A & B	A & B
		Regression Analysis	A & B	A & B	A & B
		Neural Networks	A & B	A & B	A & B
	Quantitative Methods	Parametric	B	B	B
		Activity Based	NA	B	B
		Operation Based	NA	B	NA
		Tolerance Based	A	A	A
		Feature Based	A	A	A
		Break Down	B	B	B

Starting with the innovation phase, qualitative methods are mainly rated applicable in both studies. On the other hand, quantitative methods are only partially applicable with limitations, for example on specific components. The results for qualitative methods are identic in the feasibility phase, while the results of the quantitative methods also show only a partial applicability. The manufacturing related methods such as the operation based and break down method are not favourable due to the lack of information caused by a low project maturity. Moving to the concept phase, qualitative approaches still show the highest applicability and manufacturing related methods the lowest. The results indicate that the maturity of quantitative methods provides little applicability during the early development phases, whereas the lack of required input data can be stated as reasonable explanation. Furthermore, the results of study A and study B demonstrate big differences within the group of quantitative methods. On the other hand, qualitative methods that strongly rely on experience and need less quantitative data mainly show a rather high applicability throughout the entire early stage.

4. Practical Application

Two of the investigated qualitative methods, case based and fuzzy logic, were also applied to estimate the product cost of the powertrain element "battery back". They were selected due to their high relevance mentioned in literature. On the other hand, the battery pack was chosen as this technology is rather new and shows high relevance in the future of the automotive industry [2]. Furthermore, sufficient reference and input data is available. As seen in Figure 4, the methods were applied at two points in the early stage of the development process to enable a comparison.

Figure 4: Application of two Product Cost Estimation methods at Point A and B

In order to represent the lack of available input data at point A (innovation phase), only information about the two parameters "annual pack production" (strongly determining production resources), and the "vehicle range" (correlating with total battery pack energy capacity), was included. As the available data increases with progressing in the development process, at point B (feasibility phase) was also information about two the additional parameters "total pack mass" (correlating with amount of used materials) and the "number of cells" (affecting the battery power and used electrode materials) included. The output variable was stated as "Total Battery Pack Cost to OEM in €". The reference data used in the methods came from the report "BatPaC – modelling the performance and costs of lithium-ion batteries for electric-drive vehicles", which was created by the Argonne National Laboratory [14]. In contrast, the case company provided the input data for six battery packs of existing electric vehicles to perform six cost estimations. Additionally, also the cost of these six battery packs calculated by the engineering company were provided. As these calculations are based on highly detailed data from benchmark studies, their results were assumed as actual costs. The comparison of the six estimated battery pack costs in the early development stage with the related actual costs enabled the calculation of derivations, building the basis to evaluate the accuracy of the two methods at point A and B.

Application of the Case Based Method

The purpose of this method is to compare a new "case" with existing reference "cases" to find similarities, based on the idea that similar product characteristics cause similar cost [10]. Therefore, it is important to systematically arrange the relevant information of the reference cases in a database. Even though this sounds quiet obvious, in practice it is often not executed appropriately and consistently enough. Such databases need continuous maintenance and must be regularly updated. However, this effort ideally results in a quite strong support for cost engineering departments [9]. For this paper, the gathered data from the "BatPaC" was arranged into seven cases using a "Microsoft Office Excel" document as database. An input mask for the four chosen parameter was also created. In order to ensure a quick and simple application of the tool, the best fitting cases were highlighted. Therefore, cost engineers can directly see the cases with the closest values and decide which one to choose as final reference for the new project.

Application of the Fuzzy Logic Method

Its purpose is to handle uncertain knowledge with linguistic expressions by connecting input variables to output variables through IF-THEN rules. For this application, the two input variables of point A and the four input variables of point B were connected to the single output variable. An actual tool was created using the "Fuzzy Logic Designer" provided by Mathworks Matlab. Having identified all input and output variables as first step, the next includes the creation of membership functions (MFs) to all variables. A MF defines the fuzziness of the variables and outlines the degree of membership, and therefore describes the belonging of a value to a function. In general, every variable is described through linguistic expressions. An example would be, "if the tomato is red, it is ripe". But what if the tomato is not totally red and still has some green spots? In cases a decision with 0 or 1 is not fully clear or possible, the application of a fuzzy logic system is preferred as it is able to describe such situations [15]. There are many different ways to create membership functions. After intensive investigations of the topic "fuzzy logic systems", the authors decided to take an "Intuition" approach using triangular MF. This decision was mainly based on the little data available, as most of

the other approaches need bigger datasets. Furthermore, it is also easier to use by non-experts compared to the others. It was assumed that the variables have a linear relation, hence the triangular shape [16, 17]. For the actually created fuzzy logic system, a base of 81 IF-THEN rules was created to connect the input variables with the output variable.

Comparison of Results

In general, the bigger the reference database for case-based cost estimations, the higher the probability to obtain more accurate results. Using only two input parameters resulted in an average deviation of around 30% at point A. Increasing the number of included parameters to four at point B also caused a reduction of the deviation to around 12%. As expected, the small database comprising only seven reference cases and the low amount of input parameters provided a rather low accuracy of the product cost estimation. Nevertheless, the values at point B could already be used by cost engineers for a quick and simple project evaluation. Taking a look at the fuzzy logic system, achieving very accurate results also needs much more reference and input data as well as deeper expert knowledge and experience regarding the single variables. In point A, the average deviation of the cost was around 16%. This could already be used for a first assessment of the project. In point B, the deviation shows results similar to the case based cost estimation with around 12%.

Comparing both methods at both points, it is obvious that more input data also led to more accurate results. While both methods show a similar deviation at point B, the results of the fuzzy logic cost estimation provided a much higher accuracy at point A. However, realizing a fuzzy logic system also requires more effort. It can be concluded that for an accurate product cost estimation of complex systems such as a powertrain or battery pack, broader reference data and more than just four input parameters are greatly required. Nevertheless, the applications showed their potential and provided also with less data acceptable results. Therefore, both methods are assumed to be a supportive tool for cost engineers in the early phases of developing a powertrain or related elements.

Table 2: Comparison of Case Based & Fuzzy Logic System

	Point A			**Point B**		
	Average	Max	Min	Average	Max	Min
Case Based System	+/-30 %	-54 %	+28 %	+/-12 %	-38 %	-8 %
Fuzzy Logic Sstem	+/-16 %	+40 %	-18 %	+/-12 %	-27 %	-6 %

5. Discussion and Conclusion

An appropriate product cost estimation in the early development phases is essential for automotive companies to remain competitive. While the literature already provides several qualitative and quantitative methods, the applicability of twelve was evaluated in the innovation, feasibility and concept phase. Based on data from one engineering company, two empirical studies were therefore performed (study A: documents and interviews; study B: survey). The results indicate that the maturity of quantitative methods provides little applicability, whereas the lack of required input data can be stated as reasonable explanation. On the other hand, qualitative methods that strongly rely on experience mainly show a rather high applicability throughout all early development phases. The application of a hybrid approach could allow combining the advantages of both types. However, only assumptions can be mentioned at this point and further research for a clear statement is still necessary.

Finally, two of these methods (case based and fuzzy logic) were applied at two different points in the early stage of battery pack development. While the reference data came from literature, the case company provided the input data for six battery packs of existing electric vehicles. This allowed a comparison of the estimated cost to the actual cost. Basically it can be stated that more input data also led to more accurate results. Even though the outcomes provided a broad range of deviations, some might be already acceptable for quick and simple project evaluations. Therefore, both methods are

assumed to be a supportive tool for cost engineers in the early phases of developing a powertrain system or related elements such as battery packs.

This work represents a basis for future investigations into the topic of product cost estimation in the early development phases. Further research regarding main cost drivers is essential to simplify the process while increase the accuracy of its results. This should always happen in accordance to data availability to ensure the applicability of methods in the early development stage.

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References

1. S. Volker, G. Prostean, Research of Automotive Change Management and Combined Management Models, 13th International Symposium in Management, 2015, pp. 395-396.
2. Roland Berger & Lazard, Global Automotive Supplier Study 2018, 2017, available at https://www.rolandberger.com/en/Insights/Publications/Global-Automotive-Supplier-Study-2018.html.
3. K. Ehrlenspiel, H. Meerkamm, Integrierte Produktentwicklung - Denkabläufe, Methodeneinsatz, Zusammenarbeit, Carl Hanser Verlag, Germany, 2013.
4. H. Schlink, Wirtschaftlichkeitsrechnung für Ingenieure, Springer, Germany, 2015.
5. U. Lindemann, K. Ehrlenspiel, A. Kiewert, M. Mörtl, Kostengünstig Entwickeln und Konstruieren – Kostenmanagement bei der integrierten Produktentwicklung, Springer, Germany, 2014.
6. U. Lindemann, Handbuch Produktentwicklung, Carl Hanser Verlag, Germany, 2016.
7. P. Kranabittl, M. Bajzek, M. Atzwanger, D. Schenk, H. Hick, Automotive Development Process - Systems Engineering for Automotive Powertrain Development, Springer, Switzerland, 2020.
8. P. Fietkau, B. Kistner, J. Munier, Virtual Powertrain development, Journal of Automobile Engineering, 2020, pp. 3288-3301.
9. A. Salmi, A review of cost estimation models for determining assembly automation level, Computer & Industrial Engineering 98, 2016, pp. 246-259.
10. A. Niazi, Product Cost Estimation - Technique Classification and Methodology Review, Journal of Manufacturing Science and Engineering 128(2), 2006, pp, 563-575.
11. R.K. Yin, Case study research - Design and methods, Sage Publications, United States of America, 2009.
12. C. Karlsson, Research methods for operations management, Routledge, United States of America, 2016.
13. J. Freeman, T. Chen, Green supplier selection using an AHP – Entropy-TOPSIS framework, Supply Chain Management: An International Journal (20), 2015, pp. 327-340.
14. Argonne National Laboratory, BatPaC Model Software, 2020, available at https://www.anl.gov/cse/batpac-model-software.
15. A. J. O´Brien, FLIHI: Fuzzy Logic Implemented Hill-based Model, Washington, 2018.
16. T. J. Ross, Fuzzy Logic – With Engineering Applications, John Wiley & Sons, United States of America, 2010.
17. H. Unbehauen, Regelungstechnik 1 – Klassische Verfahren zur Analyse und Synthese linearer kontinuierlicher Regelsysteme, Fuzzy Regelsysteme (Bd. 15), Vieweg + Teubner, Germany, 2008.