Cost Calculation of Dies and Molds: Challenges, Developments and Future Trends

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Abstract
The degree of accuracy in generation quotations has a direct impact on the die and mold manufacturer's profitability. Die and mold manufacturers use their experience and expertise and often guess the price with varying success. Numerous tests have shown that the quotations for a die or mold can vary by more than 100% under the same circumstances. Due to modern information technologies cost calculation of dies and molds can be supported in each phase. In this paper, challenges, problems and the state-of-the-art technology of cost calculation of dies and molds will be discussed. Developments and future trends of cost calculation systems will be presented on the experience and knowledge base of the author in development of die and mold cost calculation systems.

Keywords:
Costs of die and mold, decision making regarding cost, manufacturing of dies and molds

1 INTRODUCTION

The German dies and molds-manufacturing industry enjoys a worldwide reputation and is still highly relevant to the country's economic performance. Many of the firms involved heavily depend on the work they do for the

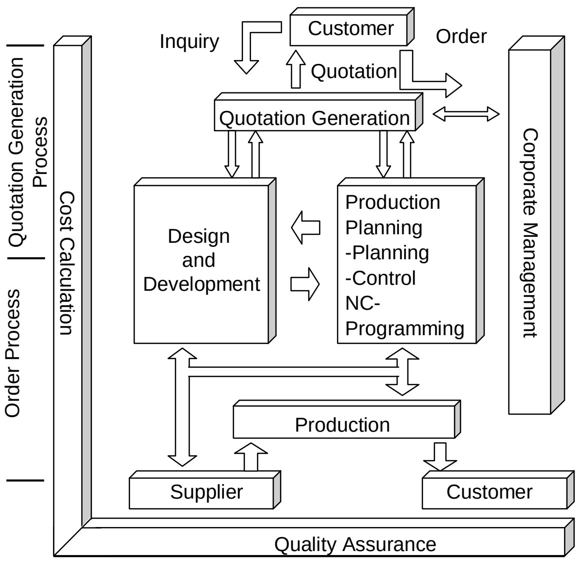

Figure 1: Quotation generation based on customer specific orders.

German car manufacturers, e.g. Audi, BMW, Daimler-Chrysler, Porsche or Volkswagen. Most firms are small and medium-sized enterprises and in today's times of hyper competition they have to fight for every contract more than ever before. As most German car manufacturers are facing increased competitive pressures they try to mitigate the pressure by passing it on to their suppliers. Thus, the competitive pressure for the molds and dies industry has increased. Because of the increasing dynamics of influence factors regarding technological and economic growth, die and mold manufacturing industries have to constantly re-orientate their quotation generation, taking into consideration recent and future technical and economic changes [1, 2]. The organizational relationship between quotation generation for customer specific orders and their completion in the organization of an enterprise is illustrated in Figure 1.

The accuracy of the cost calculation without a computer-aided cost calculation system is around +/- 30 percent, provided there is no existing die or mold drawing as a ground for calculation. Although making an accurate estimation of the real costs is no guarantee to really obtain the order, it is important to the firms' economic survival. Orders normally are at the level of several hundred thousand Euros. When the estimated costs turned out to be lower than the actual costs, the die and mold manufacturers suffer financially. Accumulated losses finally will lead the firm into bankruptcy. On the other hand, when the estimated costs are too high the contract would be lost out to a competitor [3]. Thus, achieving costing accuracy and reducing the time and expense entailed in preparing quotations are important for survival (Figure 2).

It is essential for the development and implementation of computer-aided quotation calculation systems to consider the challenges of computer-integrated data processing. In particular, the requirement of interfaces of all CA-Systems within an enterprise between quotation calculation, die and mold design, process planning and control and scheduling should be taken into account [4].

The necessary information for quotation generation is especially available in the die and mold design and production planning process. Since the quotation generation is the first step of a long row of activities within the company which is not predictable in detail, the accuracy of the cost estimation has a special significance [5, 6].

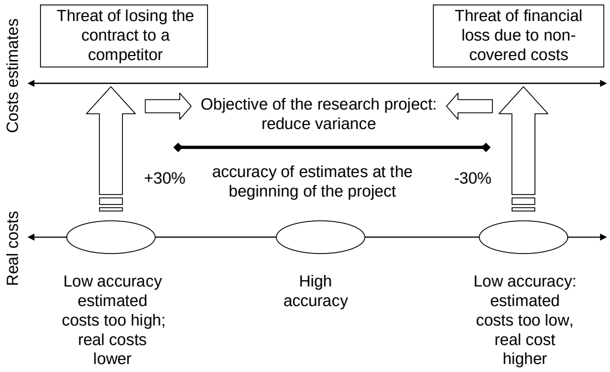

Figure 2: The importance of accurate cost calculation for receiving orders and economic survival.

The customer input data for a new die or mold is mostly in form of product drawings or even prototypes. This makes the accuracy of cost calculation more difficult. Although geometrical and technological descriptions of the die or mold do not yet exist at this early stage, manufacturing costs must be specified as accurately as possible. The general procedure of the quotation calculation is shown in Figure 3.

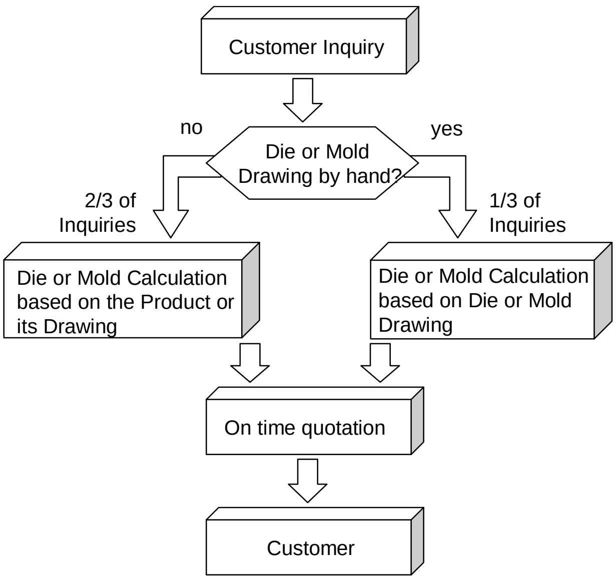

Figure 3: General procedure for cost calculation of dies and molds.

Injection molds, pressure-die casting molds, pressing and forging tools can be summarized under the common term "hollow form tools", since their geometry and technology are similar [2]. This tool group is the subject of the cost calculation method presented here.

The tasks of the computer-aided quotation calculation in die and mold manufacturing are represented in Figure 4. The important task of a computer-aided quotation calculation system is the determination of the manufacturing time for the required product based on the previous experiences with regards to similar parts of dies and molds manufactured [7].

The objective of the computer-aided quotation calculation in die and mold manufacturing is to make a precise statement about geometry, technology and costs of the finished tool. The prerequisite of the development of such a calculation system is the ability of it to find the required algorithms for the individual calculation activities and decisions.

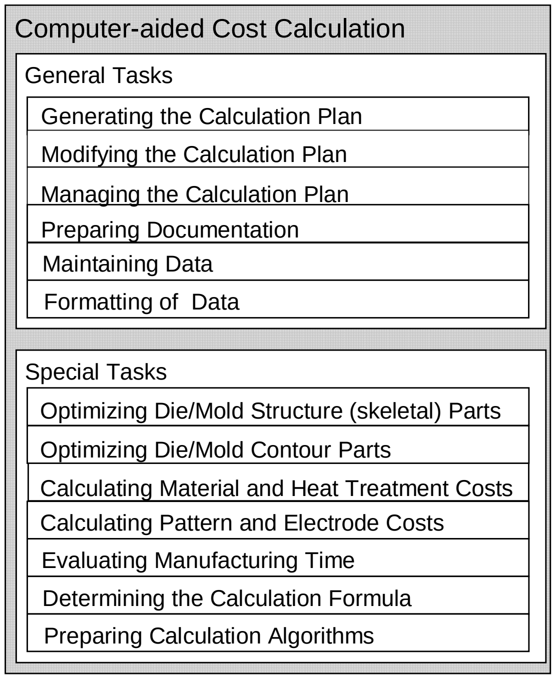

Figure 4: Tasks of computer-aided quotation calculation.

Normally it is argued that the computer cannot be used for creative decision activities in the planning process. However, if the sequences of the quotation calculation procedure are analyzed, then it is obvious that many of the occurring activities are schematic and recurrent, so that they can be algorithmized and be processed by the computer. The adoption of the computer into the routine activities enlarges the space for creative thinking processes for the quotation calculation which also increases its accuracy.

In the computer-aided quotation process an efficient sharing of tasks between the user and the computer is paramount. Due to the complexity of assignments in die and mold manufacturing, the experience and associative thinking abilities of a quotation calculating expert can not be disregarded in today's state of the art. During the interactive process between the calculating expert and the computer, sharing of tasks can be realized in such a way that the non-algorithmic decisions can be made by the calculator and repetitive decisions will be taken over by the computer. The technological expertise of the quotation calculating expert is replaced in this early stage, the missing accuracy and logic of the die and mold manufacturing. This expertise includes geometry, production process sequences, manufacturing times and also manufacturing and material costs of formerly manufactured dies and molds.

2 HOW TO DEVELOP A COMPUTER-AIDED QUOTATION CALCULATION SYSTEM?

In order to gather the production process data within the product range of an enterprise, actual production time of representative dies and molds and their components calculated in the past must be analyzed. Because of the abundance of the data, application of data processing is necessary. Such analysis of product structure must be performed in continuous intervals. Therefore it is essential to develop and regularly update the specific software for an enterprise.

In most cases it is appropriate to develop cost calculation systems individually for each die and mold type such as injection molds, die casts etc. The parts of dies and molds causing major expenditure in manufacturing can only be specified by thorough analysis, based on the computer-aided quotation calculation system.

The computer-aided quotation calculation system requires a computer-internal part classification key, based on group technology. The aim of this classification key is to specify the computer internal tool data, which concerns both, die and mold type and also their organizational and technical production flow. Consequently, this classification key offers a transparent knowledge base for quotation generation, cost calculation, dies and mold design, production planning and manufacturing [2, 5].

An analysis of existing classification systems shows that due to their broad application purposes, these systems cannot be used for the specific demand of die and mold manufacturing or they are developed for a certain range of application that cannot be adopted here. Therefore a particular classification key for die and mold manufacturing should be developed and integrated into the computer-aided quotation calculation system.

Molds and dies consist of *external structure (skeletal) components* and of the *internal workpiece-contour shaping parts*. External structure components, such as clamping plates, ejector pins etc. have no direct contact with the workpiece to be produced. These parts can in principle be standardized or already are. For the quotation calculation of the external structure components of dies and molds, a functional relation between several influencing variables such as the number of bore holes, the material removal rate, and a particular target value, such as manufacturing time, must be defined. For these purposes, the multiple regression analysis is specifically suitable to identify relevant cost functions [2, 7].

Internal workpiece-contour shaping parts of a die or mold are the intrinsic form giving components consisting of several free-formed surfaces.

Statistical methods can only provide the determination of manufacturing time of mainly homogeneous objects. But in die and mold manufacturing this homogeneity can be found only in the external structure components. In case of the internal workpiece-contour shaping parts, an analytical method is to be developed which can describe geometry and the associated manufacturing technology for each contour, which is basically inhomogeneous due to its direct workpiece-contour dependence.

Usually, the workpiece-contour can be described by geometrically basic elements. It has to be taken into account that the workpiece-contour parts of dies and molds consist of a fixed and a moving component. As the fixed component generally contains the concave shape of the workpiece contour, the moving element describes the convex workpiece-contour. Hence it is crucial to develop a workpiece-contour describing system which includes standard elements for the concave and convex shape.

With the input from the calculation experts a catalogue of 44 contour elements and standard form elements was created by the author with experts from cost calculation and manufacturing. Figure 5 contains an excerpt from this basic geometry elements catalogue developed for this special purpose. Those 44 elements are sufficient to allow to the experts work more efficiently in terms of time required for the calculation as well as the accuracy of the cost estimates for the shaping part of a die or mold. The cost calculation of the parts surrounding the shaping parts of the die or mold can be deduced from standard part cost models developed with regression analysis [2, 5].

In order to calculate the manufacturing time for the internal workpiece-contour shaping parts of a die or mold, in addition to the analytic description of the contour geometry, the associated manufacturing process sequences of the individual geometrical basic elements must be specified. Thereby, the volume-oriented (milling)

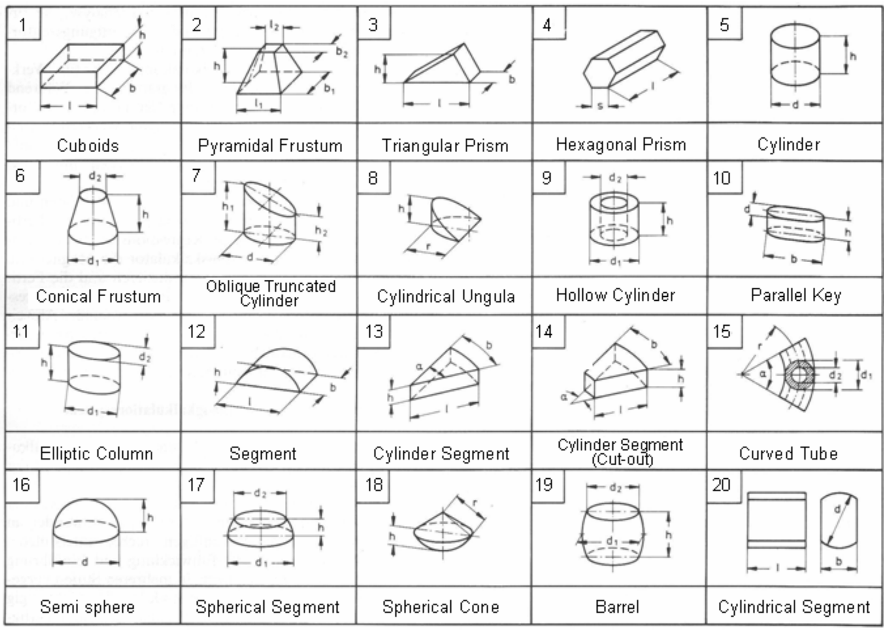

Figure 5: Excerpts from the contour and standard elements catalogue.

and surface-oriented (grinding) manufacturing methods are to be differentiated. The allocation of manufacturing methods to geometrically basic elements should be prepared specifically for each individual enterprise and in relation to their technical equipment and manufacturing methods. Because of the variety of the manufacturing methods and their combination options, the clarity of the allocation is problematic. Therefore, it is advisable to combine the frequently occurring manufacturing methods and process sequences and assign them to geometrically basic elements of the contour of a mold or die. The manufacturing time calculations were backed up by various experiments on cutting material and its appropriate tools, cutting time and also the manufacturing process.

Figure 6 shows the analytical procedure in the form of a flow diagram to calculate the manufacturing time of a particular volume element (convex or concave) or a surface element (Spherical segment is taken as an example in this case). Subsequent to the calculation of the manufacturing time of the individual basic geometrical elements, manufacturing time will be multiplied by the average hourly machining rate of appropriate machine groups. Afterwards the manufacturing costs per basic geometry element and its manufacturing method will be determined. Thus the total manufacturing costs of a die and mold contour shaping part is gradually deduced element by element. Manufacturing time and cost for each element were calculated for each type of relevant manufacturing process like milling, drilling, grinding etc. with a formula determined via statistical methods.

Since manufacturing costs of the components of a die or mold can be determined according to statistical and analytical methods, the remaining tool costs must be added as a supplementary cost (in percentage) to these manufacturing costs.

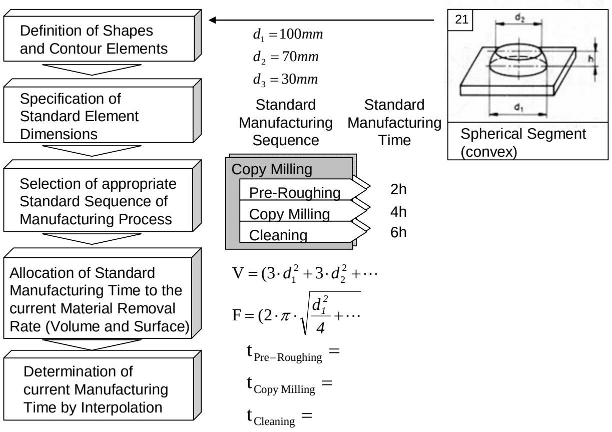

Figure 6: Flow diagram to calculate the manufacturing time of a particular volume element (convex or concave) or a surface element.

3 STRUCTURE OF A COMPUTER-AIDED QUOTATION CALCULATION SYSTEM

With the computer aided quotation calculation system for the die and mold manufacturing, the quotation calculation expert should be able to determine the manufacturing costs of a die or mold not only from an associated die or mold drawing, and since it may not normally exist in this early stage, but even from a workpiece drawing or from the workpiece itself.

Figure 7 represents a schematic diagram of a die and mold cost calculation system. This system is designed in a way that apart from the quotation calculation of the individual components of the die and mold, it also enables the analysis of manufacturing time of die and mold components, the determination of supplementary costs (in percentage) of manufacturing cost and also the development of mathematical formulas of manufacturing time through further interactive software modules.

The computer-aided calculation system for external structure parts of a die and mold contains two software modules. The software module "FORMULA" enables the derivation of the mathematical formulas from the manufacturing time of formerly manufactured components of dies and molds, the software module "STRUCTCALC" determines the manufacturing costs from these manufacturing time formulae.

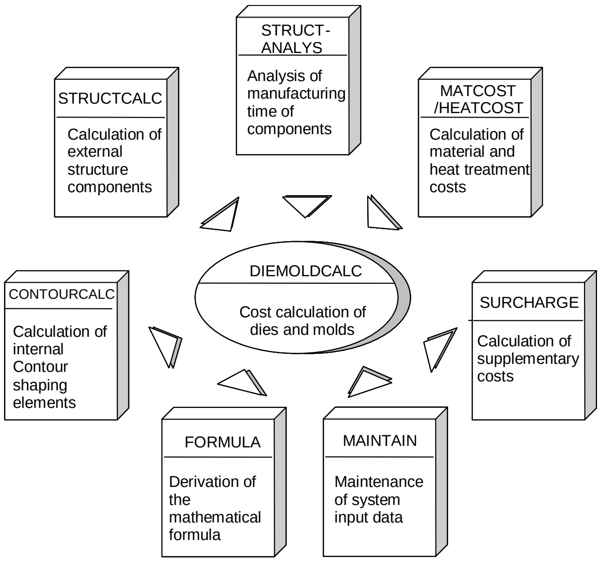

Figure 7: Structure of a cost calculation system.

The acquired data and influencing variables accumulated for a component family will be converted by the regression analysis software into regression functions for determination of the manufacturing time. Thereby, the quotation calculation expert has the possibility to gradually reduce the influencing variables and to optimize the manufacturing time formula. The evaluation of the regression function takes place via certainty and discrepancy analysis and initial and remainder variance analysis. The estimation of the influencing variables is obtained from analysis of standard deviations, covariance and correlation.

4 HOW TO MAKE EXPLICIT KNOWLEDGE OUT OF TACIT KNOWLEDGE – EXPERIENCES WITH THE DEVELOPMENT AND IMPLEMENTATION OF CALCULATION SYSTEMS FOR DIES AND MOLDS

In a project on the development and implementation of a die and mold calculation system conducted by the author in a medium-sized German die and mold enterprise, the work of the cost calculation experts involved was closely observed in order to improve the performance of the cost calculation process. A computer-aided quotation calculation system requires the acceptance and self identification of the future users. The motivation does not derive from guidance instructions, but results from the participation and the positive cooperation of the users during the development of their future computer-aided tools.

The people that were involved in the process of offer calculation were experienced technical experts who had been with the company for many years. Losing any of these experts and their knowledge meant a tremendous loss to the firm. During the assessment of their work practices, it was observed that they often took hints from former projects where a certain shape of a mold or die had already been manufactured before. Often, however, they lacked the information where and when such a shape already had been calculated or produced before. While the estimates of cost calculation experts normally were quite precise in situations which were based on experiences of their earlier work, it became clear that errors could mainly be attributed to those parts where the experts had to do "educated guesses". That was the case when a contour shaping element of the actual part of a die or mold had to be calculated for the first time or when calculations were not done by themselves earlier.

The calculation experts were convinced that the objective of the project was to create a computer-based explicit knowledge model that would allow them to do more cost calculations of higher accuracy in lesser time. Thus it was a typical win/win-situation for the employees and the firm.

While traditional craftsmanship offered the apprentices to observe the master and to construct a mental model based on the master's well perceived actions, cognitive processes of experienced knowledge workers (in our case: cost calculation experts of die and mold) cannot be observed from the outside. Therefore, sharing and transferring tacit knowledge is inherently difficult and because of its complexity and normally requires a close interaction between the source and the recipient [8].

As the engineers' and experts' knowledge and ability to create new knowledge has become core to the firms' competitiveness, technology-based firms like die and mold manufacturers are facing a new challenge: they do not own the most important factor of production because knowledge is in the people's heads and thus can – if at all – only be rented [9]. Every day, after finishing their work, expert workers leave their firms and – in the worst case – do not come back. When they leave, their knowledge goes too.

Knowledge – or generally: a factor of production – that is in the heads of employees and not the hands of the firms is a frightening experience for firms [10].

Tacit knowledge allows individuals to claim appropriate rents due to hold-up situations based on monopolistic knowledge. There is ample evidence that knowledgeable people do not prefer to share knowledge (that has rent-generating potential; [11, 12]). Knowledge (even when its creation was paid by the company people work for) is considered as a personal property and insurance for employment [13]. Thus while every firm has incentives enough to externalize tacit knowledge it might be hindered by the employees' unwillingness to cooperate.

Another driver of knowledge externalization is the need to grow knowledge by sharing it [14, 15]. Knowledge grows when it is shared [16, 17]. Sharing knowledge is easier when it is externalized because externalized knowledge can much easier be multiplied/communicated. Knowledge that is tacit and restricted to an individual is unlikely to get shared. The use of knowledge in an explicit form – e.g. an algorithm, a formula, etc. – is not restricted to an individual [9, 18]. While tacit knowledge is difficult to leverage (as it demands closer interaction between the source and the recipient of knowledge), explicit knowledge can be much easier and much more efficiently leveraged. As a result of such leverage a firm can increase its competitiveness compared to its competitors where knowledge is tacit and difficult to leverage. Thus, while tacit knowledge is located in the heads of people, a firm has every incentive to externalize it in order not only to reduce the dependency on the employees but also to improve this knowledge [19].

Further more, the holders of tacit knowledge may benefit from making it explicit themselves. This is especially true when the work which is based on tacit knowledge is rather routine-based like in cost calculation of dies and molds. When such work gets automated or the underlying knowledge is made explicit the work can be delegated to other people and the experts can focus on non-routine work or complex projects. From a company perspective, some issues regarding the benefits of making tacit knowledge explicit have already been mentioned. Explicit knowledge reduces the rent-seeking potential of employees because it reduces knowledge monopolies [20, 21, 22].

In the 18-months development process of a computer-aided cost calculation system of dies and molds, explicit database based on experts' experiences and knowledge was created. It was done in close cooperation and with ample support from the cost calculation experts as they saw computer-aided cost calculation system as an instrument to make their work more effective and efficient. Based on this experience we can delineate the procedure shown in Figure 8 for making a tacit body of knowledge explicit. Based on the role model's visible actions and outputs an observer or team of observers tries to create a theory or hypothesis how certain outputs can be achieved with certain actions [23]. This is a typical black box situation with the role model's knowledge representing the black box. Based on the visible inputs (actions) and outcome, a knowledge model (theory about input – output – relationships) is developed. The process of refining the knowledge model and modifying it until it reaches the necessary level of performance corresponds to a reflective trial-and-error process. It is called a reflective process because all assumptions on why something works or not has to be openly discussed and documented. Eventually, the process yields a knowledge model that reaches the performance expected or even exceeds the tacit knowledge's performance.

It is important to note here that there is no silver bullet to success. To succeed heavily depends on the involved persons' absorptive capacity which is necessary to be able to identify the important patterns in the behaviour of the role model and then to use those recognized patterns to develop the explicit knowledge model. The more cooperative the role model, the greater the chances are for the knowledge constructors to succeed. The lesser cooperative the role model, the more difficult it becomes to recognize the patterns of the role model that leads to success. A knowledge-sharing supportive culture is beneficial to a firm's attempts of codification – although it is no guarantee for success.

This methodology was successfully used to convert tacit

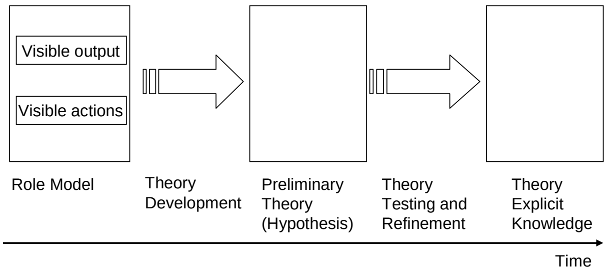

Figure 8: Explicit knowledge development process (based on a tacit knowledge role model).

knowledge of cost calculation experts into explicit knowledge in form of algorithms which were transformed into computer programs as a ground for the computer-aided cost calculation system. Involvement of the cost calculation experts were deep because the individual software program modules, which are functionally independent from each other, were implemented for users one by one after their completion. Thus the future users and the system designers had the opportunity to reduce the long implementation and test phase of the system to a minimum.

Therefore development and implementation of a die and mold cost calculation system should be carried out in several stages.

An investigation of different die and mold manufacturing enterprises revealed that the accuracy of the determined manufacturing time with a conventional quotation calculation (without computer aid), but with existing die or mold drawings, has an average accuracy of ± 15 %. This turned out after the post calculation of the die and mold had been completed. In case of a conventional quotation calculation (without computer aid), without existing die or mold drawings (only a product drawing), the inaccuracy of the determined manufacturing times doubled to a value of ± 30%. In contrast to this, the accuracy between the real manufacturing costs according to post calculation determined from the production planning and the actual manufacturing time is only ± 10 %.

From the very beginning the computer-aided cost calculation system performed extremely well – and much better than the cost calculation experts' implicit models of their previous experiences. Instead of variances in the area of 30 percent, the program's variance was just 10 percent. Furthermore, after having the explicit model, improvements to the knowledge (model) itself became possible (or easier to do). The cost calculation experts welcomed the computer-supported explicit knowledge model as it helped them making their work easier, quicker and more accurate. And they did not lose their status as experts because there were still in the situations where they could not rely on a computer-aided cost calculation system but had to do their own guesses. Furthermore the new knowledge based cost calculation system enabled them to improve their work and their knowledge and to update the system continuously with their newly gained experiences.

5 INTEGRATION CONCEPT OF A DIE AND MOLD COST CALCULATION SYSTEM AND DEVELOPMENT TRENDS

Besides the technical data such as geometry and technology data of a die or mold, quotation generation of die and mold manufacturing also requires economical data such as machinery costs. Because of the linking function between the technical and the economical information level, the quotation calculation can be named a techno-economical system.

For a systematic quotation generation, the information of different working areas is necessary. So far, this information is provided discretely and at different times by the different areas. The need for information could be optimally satisfied by computer integration [24].

An important step for the integrated data processing in the die and mold manufacturing is the interfacing of the quotation calculation with the CAD systems of die and mold design and with the computer-aided process planning system. With this integration, the quality and the quantity of the input information increase, thus the accuracy of the decision in the quotation phase is improved.

The problem of the interfaces between the stand alone computer-aided systems is to find different fields for different CAD systems application, which communicate information with each other. The variety of the assigned CAD systems is caused by the diversity of their performance and design tasks in the enterprises.

In the quotation generation phase, it can be mostly assumed that the product description mostly and in rare cases the supplied die and mold design have been provided on different CAD systems of the customer. If in the quotation generation of a mold or die, interfacing with the die and mold cost calculation system is to be reached, then the CAD system of the die and mold manufacturing enterprises must be able to gather and process the CAD data of the customer with the standardized interfaces [6]. The product and the die and mold design data should be procured by the customer into the CAD system of the die and mold manufacturing enterprise as an internal computer product model, which contains geometry, technology and method data. A standardized interface is a prerequisite for the processing of these data. Planning data such as determination of the production process, cost data such as manufacturing costs and method data such as shrinkage determination of a mold or die in the quotation calculation can be calculated by this supplementary product model.

Figure 9 represents the time schedule of implementation of a computer-aided cost calculation system for die and mold manufacturing. With the implemented cost calculation system, up to 30% reduction of the calculation time and shortening of a cycle time in the quotation generation is achieved.

By the interfacing of the computer-aided cost calculation system with the computer-aided determination of work plan, an additional shortening of the cycle time is reached because of the possibility to re-use of calculation information already entered in the work plan preparation. Interfacing the cost calculation system with a CAD system will lead to fulfilling the quotation calculation by a CAD technical designer parallel to the draft procedure of the product.

This integration of CAX systems requires the central storage of the obtained information in data bases [25]. Due to the high information volume and the large database as well as due to the various modeling concepts of the individual CAX systems; the usage of a central data base system becomes more complex. Therefore, it is crucial to aim at a distributed data management which supports the CAX systems that can be integrated well-directed and effectively.

The first step towards calculation expert system such as quotation calculation, systematization and an algorithmizing of the specialized knowledge of the quotation generation are made with the die and mold cost calculation system [1, 25]. The factors, coefficients and formulas should be controlled by the knowledge management system. Thus, the rules and the formulas about calculation of cost positions arise from structuring the data. The objective is to generate a calculation structure which requires just few steps for calculation. The number of steps surely depends on complexity of the tool types and the possible variance.

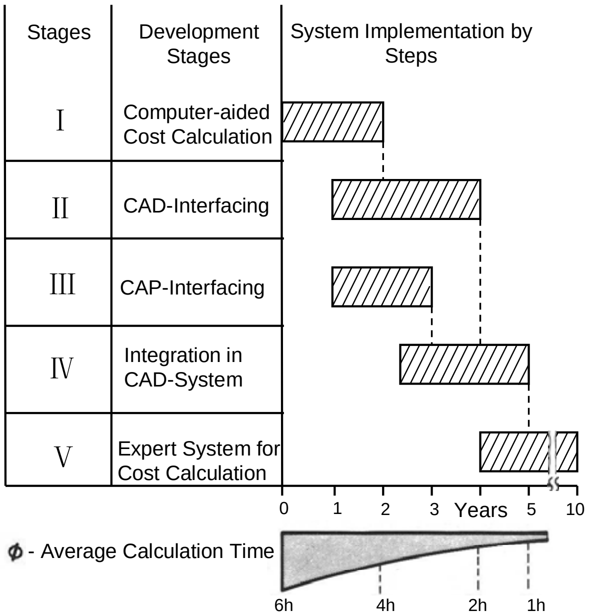

Figure 9: Time schedule of implementation of a computer-aided cost calculation system.

It is reasonable to think about the recent recognizable future trends, such as the integration of design and calculation processes and respectively with the CAD and the cost calculation software [2, 7, 25], calculation on mobile devices like Notebook or PDA, with or without the access to the own enterprise network and further step could be calculating costs on Internet.

The experiences with cost calculation software are different because every company that calculates die and mold costs has a different approach and philosophy. Therefore, a more or less fixed solution which is not possible to customize is easily. As the development of cost calculation systems for dies and molds continues, the situation will improve.

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