"Overloaded, Slow, and Illogical" A Usability Evaluation of Software for Product Manufacturing Processes with a Special Focus on Age and Expertise of CAM Users

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Abstract

Today's manufacturing processes require complex computer-aided planning processes, which are provided by CAM (computer aided manufacturing)-software systems. While the functional capabilities of these systems are constantly extended, less attention was paid to CAM-software usability. Facing the demographic change (cognitively aging users, retiring of experienced CAM experts who are succeeded by inexperienced users), not only usability issues but also user-specific requirements are becoming increasingly important. An online-survey regarding the usability of CAM-software was conducted (n = 76) and - apart from general usability - effects of age and CAM expertise were analyzed. Main usability barriers were program behavior and controllability. For older and inexperienced users, cognitive complexity (menu complexity and information density) was found to affect productivity and satisfaction of CAM-software usage. For younger CAM experts, an improved system support (feedback, search function) in solving CAM problems was identified as important requirement. Recommendations for a user-centered CAM-software usability optimization were derived.

Keywords

Computer-aided engineering software, usability, user diversity

1 INTRODUCTION

Automated product manufacturing processes require complex computer-aided planning processes that are facilitated by CAx-software systems (computer-aided technologies). These software systems are highly complex and place considerable demands on users' domain-specific knowledge and software tool expertise. The increasing complexity of CAM-software systems, on the one side, and the changing structure of the workforce due to the demographic change, on the other, highlight a research issue that has been rarely considered so far: the usability of CAM-software systems and changing requirements of an increasingly diverse workforce.

The invention of computer-aided design (CAD) and computer-aided manufacturing (CAM) systems in the 1950s [1], combined with the computerization of numerical control (CNC) for machine tools, mark the beginning of computer-aided engineering (CAE). While first computer-aided systems were isolated solutions, the logical development led to integrated solutions, since design (CAD) and manufacturing (CAM) are closely connected or even interacting procedures in the CAx process chain [2] (Figure 1).

This trend from traditional to CAE, driven by the improvements in digitalization, processing power, and the invention and mass distribution of the personal computer, triggered the boom of CAD/CAM-software in the late 1980s [3].

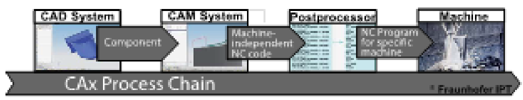

Figure 1 - CAx process chain.

Since then, with increasing requirements to the software by integrating CAD, CAM, computer-aided process planning (CAPP), and several other simulation features like FEM, CFD, etc., the amount of functions has constantly risen, all summed up as CAx [4].

The broad functionalities provided by CAx systems come at a price: the software tools have become highly complex. The increasing number of machine tools and their functions (multiaxle positioning systems, inventions of new milling heads for new and faster machining of more materials, etc.) permanently required software extensions and updates. Even with standardized tools and functions, the complexity of CAD/CAM-software has already risen to a level where only highly trained experts are able to use current CAD/CAM-software. While new production technologies like adaptive manufacturing adopted functionality and user interfaces from established CAD/CAM-software, the development of computer-integrated manufacturing (CIM) - the simulation of the entire production process and organization with fully integrated CAx-features - will boost complexity to an even higher but also inevitable level if manufacturers want to stay competitive [5].

2 CAM-SOFTWARE USABILITY AND USER DIVERSITY

So far, the improvements of CAM-software have mainly focused on technical optimization and compatibility along the workflow [6]. New functionalities were added to the CAM interface without considering a general usability framework. Even though software developers have put a lot of effort into redesigning and optimizing GUI usability of other software products since the mid-1990s [7], along with the development of an industry standard for ergonomic dialogue design (ISO EN9241) [8], usability aspects for CAD/CAM-software have been disregarded so far. Considering the increasing complexity of CAM-software, the quality of interface design, measured by its usability, becomes more and more important as a competitive advantage. The usability of a system is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction" [9]. However, existing UI principles are mostly too generic for complex CAM software, since they are mainly directed on desktop (e.g. text editors) or web applications [10]. Therefore, CAM software requires a refinement of UI principles.

Apart from general CAM system usability, the impact of user diversity factors (e.g. CAM expertise) on a successful CAM-software interaction also needs to be considered. Since CAD/CAM-software can hardly be intuitively used but requires both users' domain-specific knowledge and software tool expertise, novel CAx-users usually receive extensive CAx-software trainings. However, practice shows that CAM novices are not able to successfully handle the CAx-software, which leads to longer training periods and frustration on the users' side and to inefficient allocation of resources, reduced product quality, and delivery delays on the business side. Facing the demographic change and its consequences for the workforce using CAM (cognitively aging users, retiring of well-trained and experienced CAM experts who are succeeded by inexperienced CAM users), future CAM systems should be designed and optimized in a user-centered way to meet the demands of an increasingly heterogeneous user group [11] with differing levels of CAM expertise and cognitive skills. For this reason, the motivation of this study was an evaluation of CAM-system usability as well as a detailed analysis of the effects of age and CAM-expertise on usability barriers of CAM-systems. The following research aims were pursued:

1. Evaluation of general CAM system usability: What are the main usability barriers perceived by users?
2. Evaluation of general CAM system productivity and satisfaction: How do CAM users judge their efficiency while using their CAM-software and how satisfied are they?
3. Impact of user diversity: How do users of different ages or expertise vary in their evaluations and which specific requirements do different user groups have?

3 METHODOLOGY

3.1 The questionnaire

Based on a usability prestudy (interviews with three CAM users) and the analysis of established usability inventories based on DIN EN ISO 9241 [8], the questionnaire was developed. It contained a *demographic section* (age, gender, education, profession) as well as items regarding *CAM expertise* (type of CAM system, usage experience in years, usage frequency, self-ratings of CAM system knowledge and problem-solving competency), CAM system *support*, and used and preferred ways of *CAM knowledge acquisition*. In the *usability evaluation* part, ratings of the efficiency and satisfaction of CAM-software usage as well as key usability criteria (feedback, naming, menu Design, search function, information presentation, icon design, color use, error avoidance, program response) were assessed by using 6-point Likert-scales. Respondents could enter further usability barriers as text comments in comment fields. Usability criteria were selected according to their relevance to CAM usability problems mentioned in the prestudy. Usability criteria scores were calculated by building the means of single usability items. Construct reliability measured by Cronbach's alpha was above 0.7 for all usability criteria.

3.2 The Sample

The online-questionnaire was distributed in several German manufacturing companies and in CAM-related online forums. N = 119 participants took part in the study, but only n = 76 data sets were used for statistical analysis due to incomplete data.

Respondents' age ranged from 23 to 62 (M = 41.1, SD = 10.5), nearly all (97.4%) of the participants were male. Regarding the level of education, 36% held a university degree, 30% completed an apprenticeship, 17% had a secondary school degree, and 14% a technical diploma. Half of the participants (49%) were software developers, 24% technical draftsmen, and 21% were toolmakers. The usage experience was between 2 months and 39 years (M = 8.1 years, SD = 6.9) and the CAM-software was quite frequently used (73% several times a day, 21% several times a week). The majority (43%) worked with Siemens NX, followed by Tebis (8%), CATIA, and SolidCam (both 7%). Since the study focused on a general usability evaluation, no comparisons between different CAM-software solutions were made.

Data was analyzed by MANOVAs, correlations, and regression analyses; the level of significance was set at 5%. The Likert-scale range was transformed to -2.5 (totally disagree) to 2.5 (totally agree) with ratings < 0 indicating negative evaluations and ratings > 0 indicating positive evaluations.

4 RESULTS

First, the results regarding general CAM system usability are reported (5.1), followed by a detailed analysis of user diversity factors (5.2), and a regression analysis (5.3).

4.1 CAM system usability

The general CAM system perception was positive. CAM users reported a high work efficiency (M = 0.95, SD = 1.23), a high ease of use (0.93, SD = 1.18), and satisfaction (M = 0.81, SD = 1.08) in using their CAM-system.

Looking at general CAM system usability, the majority of criteria was positively rated (Figure 2).

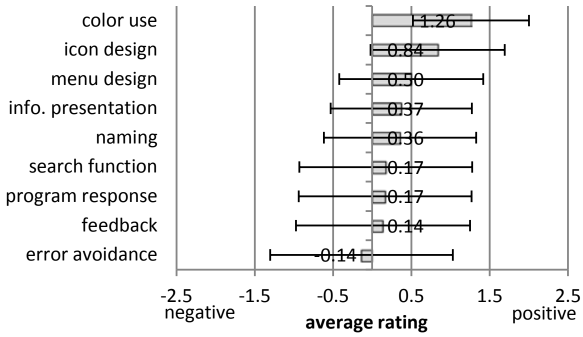

Figure 2 - Mean CAM usability criteria scores (n = 76).

The use of colors in CAM-software was mostly positively evaluated (M = 1.26, SD = 0.74), followed by icon design (M = 0.84, SD = 0.86), menu design (M = 0.5, SD = 0.92), information presentation (M = 0.37, SD = 0.9), naming (M = 0.36, SD = 0.97), search function (M = 0.17, SD = 1.10), program response (M = 0.17, SD = 1.10), feedback (M = 0.14, SD = 1.11), and error avoidance (M = -0.14, SD = 1.17). However, only two criteria ("color use" and "icon design") received on average affirmative ratings (> .8); the evaluations of the other usability criteria were only slightly positive (> 0.5) or even negative for the criteria "error avoidance." Moreover, the usability criteria evaluations show high standard deviations (between 0.74 to 1.17), which implies that CAM users strongly differed in their perception of CAM system usability. Therefore, the following section focuses on the effects of user diversity, i.e., CAM users' age and expertise, to explain discrepancies in usability evaluations.

4.2 User diversity: effects of age and expertise

To analyze effects of age and expertise, the sample was divided into different subgroups according to age (young = 23-34 years, middle = 35-45 years, old = 46-62 years) and expertise. To quantify expertise, an expertise score was calculated based on the multiplication of subjective ratings of "CAM knowledge" and "problem-solving competency" (M = 1.94, SD = 2.18, min = -6.25, max = 6.25). Two expertise groups were derived: *novices* with an expertise score < 0 and *experts* with an expertise score > 3.75. Novices had on average M=6.2 years (SD=5.4) and experts M=9.6 years (SD = 7.8) of CAM usage experience. A longer duration of CAM usage in years was associated with higher expertise levels (r=.24; p < 0.05). Age and expertise (measured by the expertise score) were not correlated (r =.19; p>.1), which indicates that age and CAM expertise were independent from each other.

A 2x2 (age x expertise) MANOVA of ratings of efficiency and satisfaction revealed a highly significant main effect of expertise ($F(2,36) = 14.18$; $p < 0.000$) and an interaction between age and expertise ($F(4,74) = 3.67$; $p < 0.01$; Figure 3).

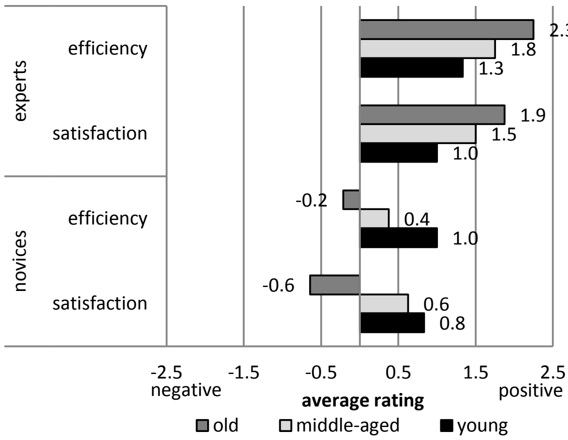

Figure 3 - CAM efficiency and satisfaction ratings for different age- and expertise groups.

Novices reported to be significantly less efficient and satisfied when using their CAM-software (efficiency: $M_{experts} = 1.8$, SD = 0.94; $M_{novices} = 0.36$, SD = 1.0; satisfaction: $M_{experts} = 1.5$, SD = 0.7; $M_{novices} = 0.26$, SD = 1.1). Looking at the interaction between age and expertise, reported satisfaction and efficiency was extremely low (or even negative) among older novices and extremely high for older experts.

A similar pattern was found for CAM usability criteria ratings. Novices gave lower CAM usability ratings than experts ($F(1,38) = 2.69$; $p < 0.05$). The criteria naming, menu design, icon design, error avoidance, program response, and info presentation were evaluated as less user-friendly (Figure 4). Severe usability barriers for novices (indicated by negative evaluations) were error avoidance, program response, and search function. No age differences were found for CAM usability evaluations.

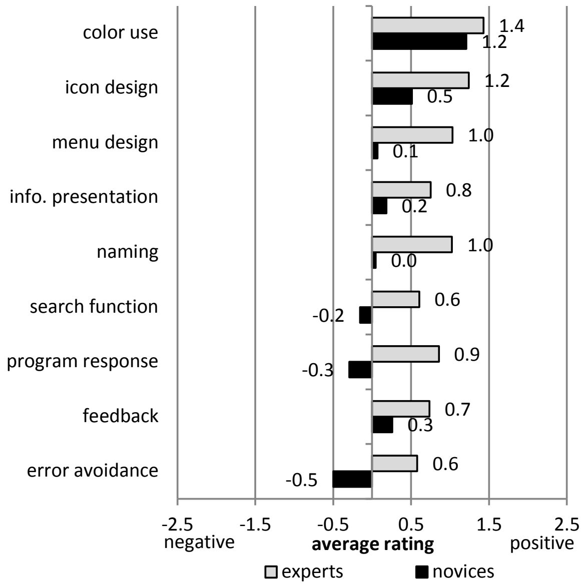

Figure 4 - CAM usability criteria ratings for CAM experts and novices.

The interaction between age and expertise ($F(18,44) = 1.9$; $p < 0.05$) indicated that especially older CAM novices perceived a lower usability of their CAM-software, except for the criteria "icon design" and "error avoidance", where the evaluations of the age- and expertise groups did not differ (Figure 5).

The most noteworthy results of the age x expertise interaction will be outlined here: Except for color use, older novices evaluated all usability criteria negatively, especially program response and menu design. Interestingly, search functions were evaluated more negatively by younger novices. In contrast, especially young CAM experts complained about bad system feedback and middle-aged experts negatively evaluated the search functions.

4.3 Regression analysis

So far, results showed that user factors strongly affect CAM-efficiency, -satisfaction, and usability perceptions. To investigate the relationship of these variables, multivariate regression analyses were conducted. Regression analysis is a statistical tool for the investigation of relationships between variables. To analyze which CAM usability criteria predict perceived efficiency and satisfaction among CAM users, stepwise age-specific regression analyses were run. Condition indices < 10 showed that regression models were not biased by effects of multicollinearity due to interrelated predictor variables.

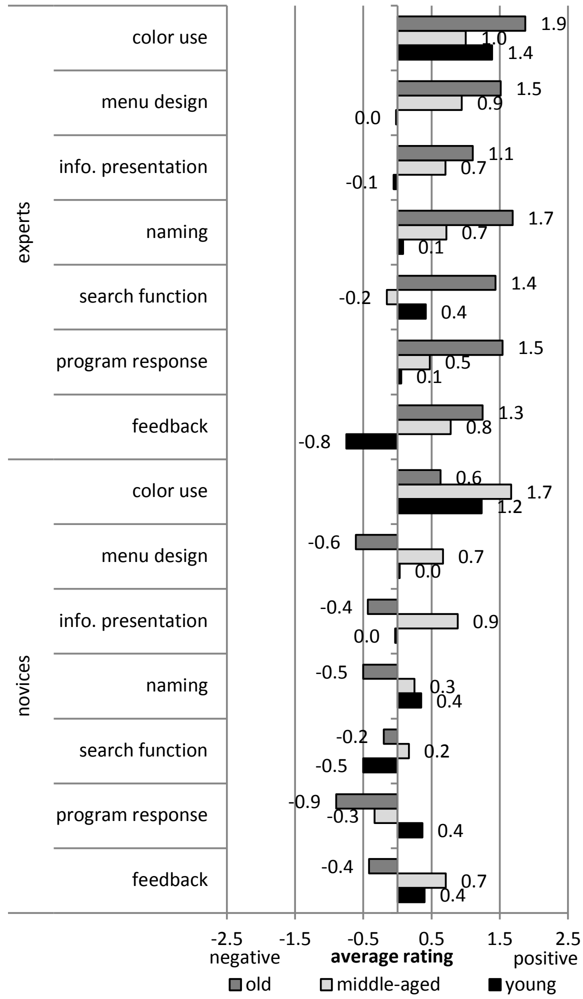

Figure 5 - CAM usability criteria ratings for different age- and expertise groups.

The regression models for predicting *efficiency* of CAM-software usage with usability criteria as dependent variables showed that the criterion "program response" was the only predictor, which explained CAM efficiency ratings in young (ß=.54) and middle-old users (ß=.69). For young CAM users, the proportion of explained variance (R^2) for CAM efficiency was only 25%, for middle-aged CAM users it was 44%. For older CAM users, a different pattern was found: not only "program response" (ß=.8) but also "information presentation" (ß=.86) and "menu design" (ß=.73) explained 89% of CAM efficiency ratings in older CAM users (Figure 6). This shows that perceived efficiency in older users is not only determined by program response issues but also by aspects of cognitive complexity, i.e., menu complexity and information density of CAM-software design.

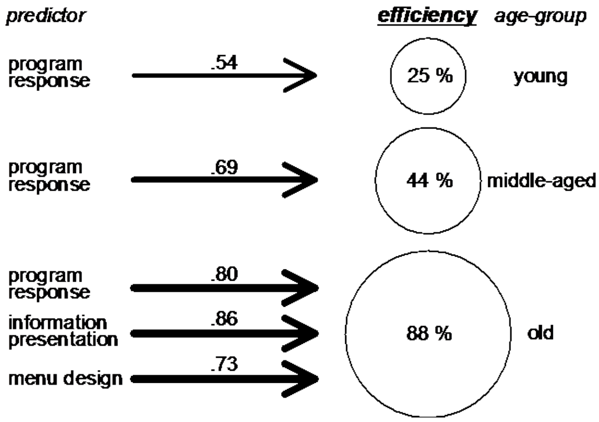

Figure 6 - Age-specific stepwise regression analysis on efficiency (R^2 in % circles, ß-coefficients above arrows).

A comparable pattern was found for the prediction of CAM-*satisfaction* ratings. CAM satisfaction in younger and middle-aged users could only partly be explained by usability criteria (R^2=21% for young users and R^2 = 25% for middle-aged users), namely by color use (young group, ß=.51) or program response (middle-aged group, ß=.54). For older users, satisfaction was strongly affected by usability criteria (R^2=89%), i.e., by program response (ß=.89), information presentation (ß=.84), menu design (ß=.61), and search function (ß=.35, Figure 7).

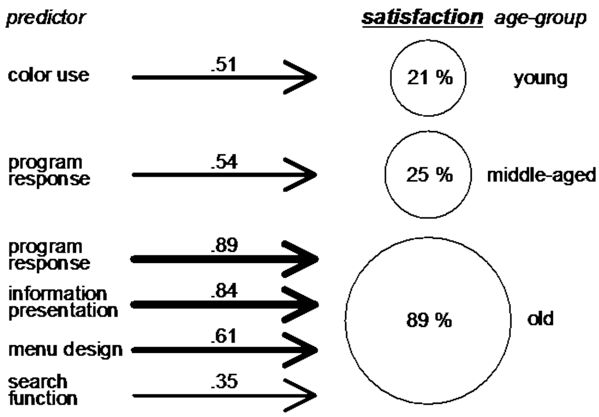

Figure 7 - Age-specific stepwise regression analysis on satisfaction (R^2 in % circles, ß-coefficients above arrows).

5 DISCUSSION

Today's manufacturing processes require complex computer-aided planning processes. While the functional capabilities of CAM-systems are constantly extended, less attention has been paid to their usability. Facing the demographic change, not only usability issues but also user-specific requirements should be considered. Therefore, a survey regarding the usability of CAM-software was conducted (n=76) and –apart from general usability-effects of user age and CAM expertise were analyzed.

5.1 General usability considerations and recommendations for CAM-software

Although the usability evaluations of CAM-software were positive and users reported to be generally satisfied and productive with their CAM-software, a deeper look at specific usability criteria revealed main starting points for an optimization of CAM-software. Hence, optimization activities should be directed on aspects of *error avoidance* (automatic caching, explicit warnings prior to important events, going back to previous steps without losing data entries), *feedback* (reliable, comprehensive, and timely feedback), *program response* (knowledge if the program is still running or has crashed, having full control over every step in the procedure), and the *search function* (context-sensitive search, clear presentation of search results). In contrast, graphical design aspects of CAM-software interfaces such as color use or icon design were not perceived as relevant barriers. Accordingly, CAM-software optimization activities should not be directed on "cosmetic GUI improvements" of color, font size, etc., but they should focus on program behavior and controllability. Moreover, the integration of user diversity factors yielded further recommendations for CAM-software optimization.

5.2 User-specific requirements for CAM usability

The user-centered analysis in this study revealed that two main future CAM user groups, i.e., older and/or inexperienced users, have specific requirements regarding CAM-software usability. As the regression analysis for *older CAM users* showed, not only aspects of program behavior but also aspects of cognitive complexity, i.e., menu complexity and information density, affect satisfaction and productivity of CAM usage among older users. The interactions between age and expertise imply that cognitive complexity affects most older novices. Human factors research [11], [12] suggests that cognitive complexity in GUI design can no longer be compensated by the cognitive system of the aging user. Accordingly, CAM systems should be designed in such a way that cognitive complexity is reduced, e.g., by simplifying menu structures and using users' mental models for designing task procedures [13].

The user group that needs the most consideration and support was the group of older *novices*, i.e., older users with low CAM expertise. Accordingly, not only the CAM GUI but also knowledge support such as training, software-immanent tutorials, or online knowledge communities should be improved and established in order to avoid longer training periods and frustration for the user and inefficient resource allocation on the business side. The negative evaluation of search functions by younger novices suggests that younger novices could also benefit from an improved CAM-software immanent knowledge support. In contrast, the findings for the group of *older experts* showed that expertise can moderate age effects with regard to perceived usability barriers, satisfaction, and efficiency of Cam-software usage. Companies should therefore systematically use this valuable CAM-knowledge source of older users and establish knowledge transfer structures in which experts accompany the "onboarding process" of novel CAM users by giving support in CAM-knowledge acquisition and problem-solving.

5.3 Limitations and future research questions

The present study should be replicated with a larger sample, which allows for a more detailed analysis of age- and expertise subgroups as well as a benchmark study with regard to different CAM-software systems. Future research activities should also be directed on a GUI redesign and evaluation – especially focusing on cognitive ergonomics of CAM-software – under consideration of age- and expertise-specific user requirements.

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