PAPER REF: 7196

ADAPTING KANO´S THEORY FOR WEIGHTING AND IMPLEMENTING CUSTOMER REQUIREMENTS ON A SOFTWARE TOOL FOR ASSESSING HUMAN RELIABILITY IN MANUAL ASSEMBLY

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ABSTRACT

The following paper illustrates the conception of an Excel-based software tool developed to predict human error probabilities in manual assembly lines. In this regard, the paper clearifies how reliable risk analyses of manual work tasks can be carried out with the help of a software tool. Furthermore, to initiate a high user-friendliness, a high acceptance and a high level of dissemination, this paper deals with a Kano survey concerning customer requirements on the developed software tool. As a result, it will be examined how customer requirements on a software tool for the automated evaluation of human errors in manual assembly can be subdivided into basic requirements, performance requirements and enthusiasm requirements. The paper concludes with an approach to widen Kano`s theory by suggesting a quantitative method to find out the weighted significance of costumers' requirements.

Keywords: manual assembly operations, human error probability, software-based evaluation, customer requirements, customer satisfaction, Kano`s theory.

INTRODUCTION

Manual assembly operations are the endmost place of the production process and represent a melting pot for organizational, time-related, and qualitative errors of manufacturing. The quality standard of manual assembly operations resulting of this business matter is considerably influenced by employee qualification, by the exclusion of error-privileged situations, and by the complexity of the assembly task. Currently, there is a trend for manufacturers to increase the number of variants with a simultaneous reduction of product life time to assert their market position against the growing competition on the world market (Hu, 2011). In spite of the progressing automation of manufacturing processes, a considerable proportion of the arising assembly tasks are still carried out by humans (Krüger, 2009). Since competitive advantages are increasingly determined in the manual assembly, the creation of economical and reliable work steps is of fundamental importance for future business success (Lotter, 2012). Therefore, it is worth striving to quantitatively determine the occurrence of errors of the persons operating in the production system.

As the occurrence of staff errors so far has been taken into account insufficiently, the development of robust and efficient manual assembly processes often fails. Especially during the start-up phase of an assembly line, unstable processes often effect variations of quality which cause high quality-related costs. That is why a method for planning assembly processes is desirable, which considers the dynamically developing factors of industrial production and simultaneously generates risk analysis at the planning stage. Thus, the department of the

authors has developed a procedure called MTQM (methods time and quality measurement) to use the knowledge of established concepts of Human Reliability Analysis (HRA, cf. (Swain, 1983), (Brauser, 1990), (Sträter, 2012), (Haase, 2015)) to create a computer supported expert system that allows to predict human error probabilities of manual assembly operations. In this context, the paper also introduces the conception and practical application of an Excel-based software tool that allows an automated creation of reliable time and risk analysis of manual work tasks with little effort.

Developing products and services suitable for customers and providing them with a high level of customer service, it is mandatory to identify and analyze explicit expressed customer requirements, as well as non-expressed, but latent existing requirements. In recent years, the Kano model of customer satisfaction (cf. (Kano, 1984)) increasingly achieved reputation in both, research and practical application (cf. (Turisova, 2015), (Lo, 2016), (Madzik, 2016)) for structuring, classifying and valuating customer requirements. Additionally, to initiate a high level of dissemination of the software tool this paper illustrates a structured Kano survey taking 22 customer requirements into account with regard to the software-based evaluation of human reliability during the execution of manual assembly operations.

As part of the addressed Kano-project and in connection with the industry partners of the corresponding research project it will be examined how customer requirements can be subdivided into basic requirements, performance requirements and enthusiasm requirements. Hence, during the evaluation it will be pointed out which scope of services should be included in the software tool and which design elements must be implemented in the user interface in order to arouse the greatest possible customer interest. Moreover, it is shown how existing modes to analyse Kano-projects can support the process of prioritizing measures and how they enable the user to deduce configuration principles and recommended procedures for the development of products suitable for many customers.

THE MTQM PROCEDURE: SHORT OVERVIEW AND REFERENCES

Although the early recognition of quality-critical manual work tasks constitutes a key element of creating stable and efficient production processes for cross-sectoral manufacturing companies, the prospective examination of human reliability in the assembly process has been neglected in both, research and business practice in the recent past. In order to counter this situation, the developed assembly planning method contains the three successive fields of error analysis, reliability analysis and comparison of alternatives and has been developed in cooperation with several industry partners e.g. the automotive and electronics industry with the examples of typical manual assembly tasks from series production (fitting a brake piston, fitting a valve, connecting a control unit etc.). With it, the developed procedure is based on a reliability model, according to which human reliability depends not only on the work task itself, but on the personnel performance prerequisites of the operator and the circumstances of the work system (cf. (Wang, 2013)). In order to meet the requirements of the selected reliability model, the reliability analysis is based on the Expert System for Task Taxonomy (ESAT), an established HRA (Human Reliability Analysis) method for quantifying human reliability of safety-critical control and surveillance tasks (cf. (Brauser, 1990)). In the course of method development, the ESAT method was combined with the MTM procedure (Methods Time Measurement), an established system of predetermined motion times for creating work-analytical time and motion surveys. Furthermore, the ESAT method was adapted to the scope of manual assembly (cf. (Kern, 2015a), (Kern, 2016)) by modifications within the stress vector and by the ongoing expansion of the risk prognosis database. Figure 1 illustrates the

substantial elements of the developed MTQM method and gives an overview of both, needed inputs, as well as outcomes resulting from method application.
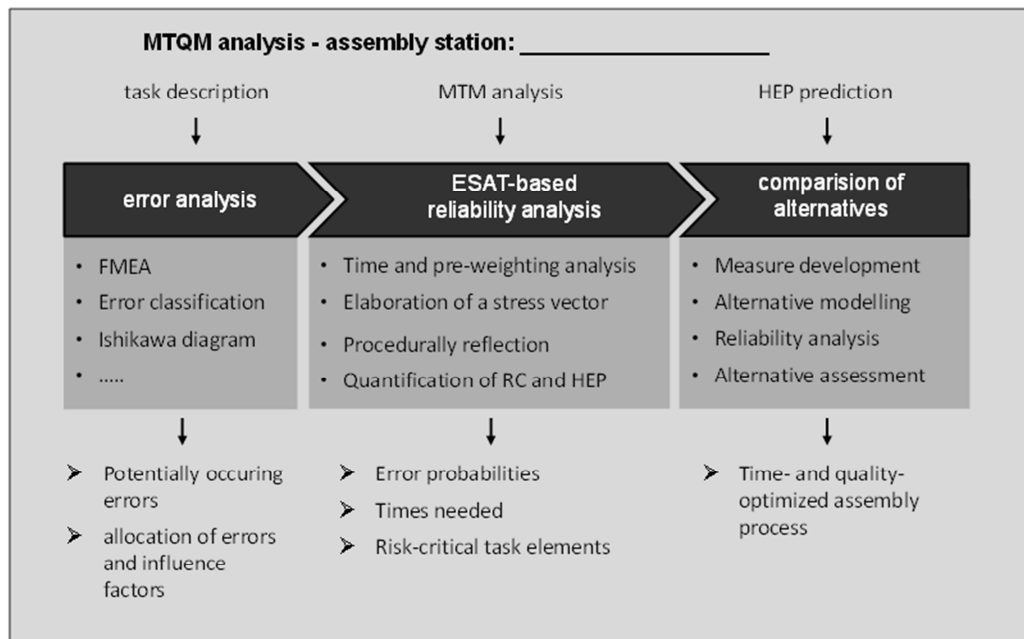

Fig. 1 - Elements and process steps of the MTQM procedure

The testing and validation of the MTQM method took place based on numerous case studies from several business partners from the automobile industry, heaters technology, as well as drive and control technology. While testing and validating, only those manual assembly operations were analyzed for which retrospective error data existed. Furthermore, when selecting the case studies, it was ensured that the considered assembly operations clearly differed from each other in their work content, their execution time and their task complexity. The case studies for applying the method in the industry have been published at several scientific conferences (cf. (Kern, 2014), (Kern, 2015b), (Refflinghaus, 2013), (Refflinghaus 2014)). As a result, the developed procedure was applied for the prediction of human error probabilities for assembly profiles of different volume that consist of ten to hundred task items. The evaluation of the analysis results showed that although the predicted HEP values in absolute height deviated from actual error rates (depending on the input data's level of detail and the analysis scope, two to thirty times too high prediction values resulted) the order of assembly stations' forecast error susceptibility in all cases tallied with companies' practices. With it, the established reliability values enable an unambiguous prioritization for the development of process optimization measurements. By prospective determining of human reliability in the assembly process, the production planner is able to both, recognize and transfer necessary system adaptions before putting the assembly system into service, so that cost-intensive rearrangements in the ongoing process can be reduced.

MTQM SOFTWARE TOOL: CONCEPTION AND REQUIREMENTS

Applying the MTQM method requires an in-depth knowledge of established procedures of human reliability analysis. This affected, that until now, companies that have no experience with those procedures have difficulties applying the MTQM method. Due to high needs of time and personnel, the MTQM method is designed for the optimization of assembly

processes in large series production and is mainly used in major companies so far. Since the necessary method knowledge in small and medium-sized companies is often inadequate, a systematic planning of manual assembly operations can currently only be conducted on high financial and temporal (training) expenditure or with the help of an external consultant in these companies. Enabling small and medium-sized companies to analyze manual assembly operations under time and risk aspects, an Excel-based software tool is currently being developed at the department of the authors (cf. (Kern, 2017), (Refflinghaus, 2018)). The software tool allows to evaluate typical, frequently occurring assembly operations with a standardized description and to automatically determine all input variables that are necessary for the following risk analysis. Thereby, the software tool combines aspects of work planning for the time-optimized interpretation of manual assembly tasks with aspects of quality planning for the assessment, evaluation and reduction of quality risks caused by human error handlings. As a result, the developed software tool enables the user to perform a prospective evaluation of human errors that potentially could occur while executing typical manual assembly operations. By this new base, it is possible to identify error-prone assembly steps, portray them quantitatively, and assess their risk monetarily. Figure 2 illustrates the conception of the developed MTQM software tool.
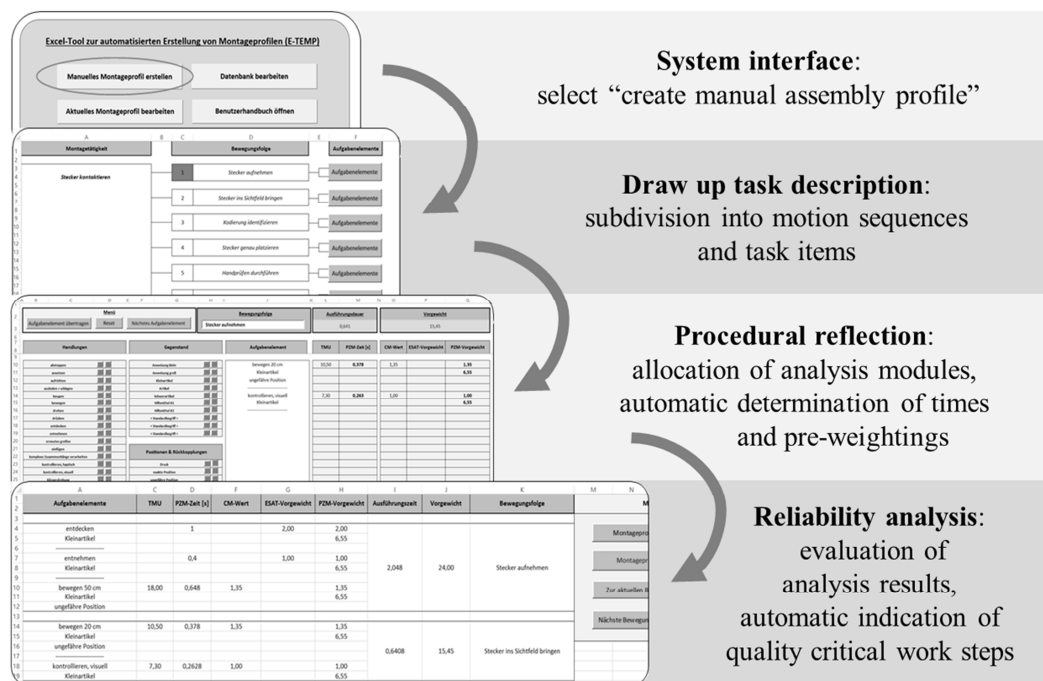

Fig. 2 - Elements and process steps of the MTQM software tool

Since the program modules are based on each other (e.g. task description, procedural reflection, reliability analysis, time prediction, risk prediction) and with the help of the integrated method knowledge and the visualization of work operations, the user is conducted through the analysis step by step. When using the analysis modules stored in the software`s database the user will be able to evaluate not only complete work tasks, but single process steps of a manual assembly operation under time and risk aspects on less expenditure. As a result, by visualizing the MTQM method, inclusive required method knowledge risk analysis for evaluating human failure in manual assembly will be carried out automatically and can also be conducted in companies having limited method knowledge, restricted financial devices and small workforce.

As mentioned before, it is necessary to identify and exactly evaluate customers' needs and their requirements concerning the product in order to develop products and services that are suitable for several customers. On the one hand, customer requirements for a computer-aided analysis tool result from the methodology of the developed procedure for the assessment of human failure in manual assembly, on the other hand, they are determined by the planned application field of the analysis tool. Figure 3 illustrates a selection of customer requirements subdivided into the categories' software, user and methodology.
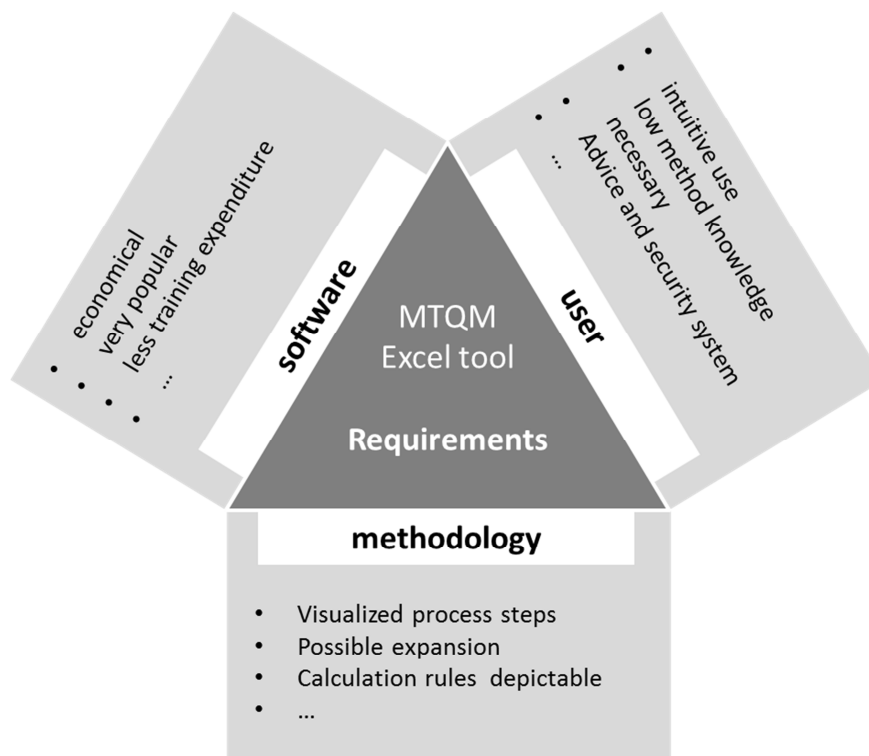

Fig. 3 - MTQM software tool - grouped requirements (extract)

The analysis tool is primarily designed for the assembly planning in small and medium sized enterprises (SME), which are frequently restricted in financial resources and method knowledge. To prospectively carry out risk analyses in SME it is necessary to choose an economical software basis to develop the analysis tool. The software basis should preferably be widespread regarding companies, so that expensive investments and laborious trainings can be prevented. Furthermore, this increases the necessary acceptance of testing the developed software tool in the industrial practice. As a result, the analysis tool should be based on the globally well-known software MS Excel in order to generate an economic analysis tool which can be used with low training expense. This inter alia offers the considerable advantage that simple arithmetic operations can directly be performed in Excel. In order to make the software tool useful for as many employees as possible and also for those having only little method knowledge in HRA methods, an intuitive and safe menu navigation along necessary process steps should be implemented. With it, the user should be gradually led through the analysis procedure and be directly pointed to the operating error in case of wrong or incorrect inputs. Hence, this inherent note and control system prevents the analysis from being useless.

The method for determining human error probabilities in manual assembly is steadily developed further and expanded, as well as improved by data from previous risk analyses.

Therefore, the developed analysis tool should not be designed as a closed system, but for expansions, e.g. modified computational regulations. Hence, the fields for later users and the fields for potential expansions by an administrator must be clearly separated and protected from unauthorized access.

In order to determine the influence of individual requirements on customers` satisfaction, it is useful to classify them by using the Kano model. Therefore, the main features of Kano´s model will be presented in the following section.

KANO´S THEORY OF CUSTOMER SATISFACTION

According to the Kano-Theory customers evaluate the quality of a product using several factors and dimensions which lead to different shapes of customer satisfaction (Lofgren, 2008). Explaining the relationship between customer satisfaction and product attributes Kano developed a famous two-dimensional model (Kano, 1984).
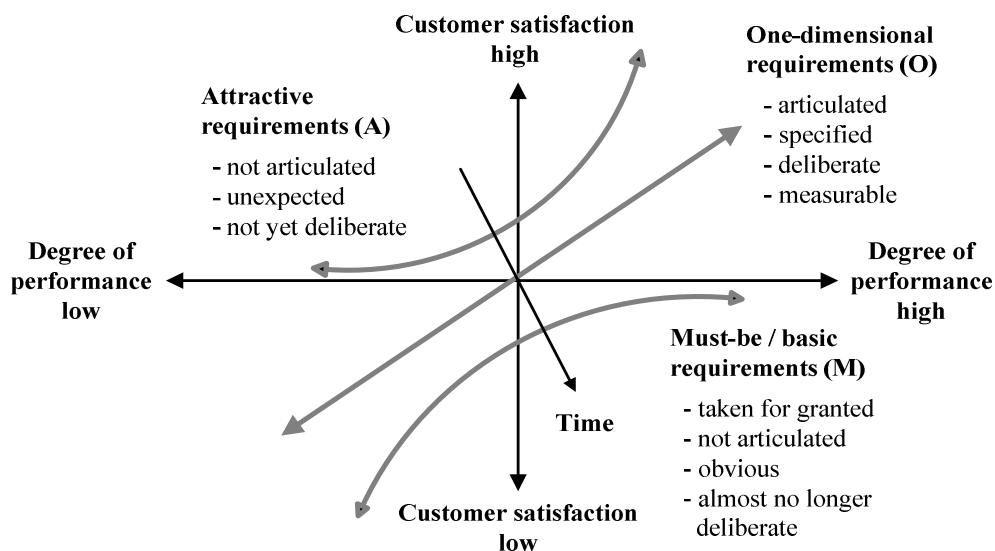

Fig. 4 - Kano model for classifying product attributes

By using Kano`s model of customer satisfaction it is possible to structure customer requirements based on groupings in various requirement categories (Lee, 1997). As shown in Figure 4 the main Kano requirement categories are (Chen, 2008):

- Must-be / Basic requirements (M): If product features classified as basic requirements are not available or the performance is low customers become dissatisfied. With regard to high performance of basic requirements customer satisfaction does not rise above a neutral level.

- One-dimensional / Performance requirements (O): In this case customer satisfaction is linear to the performance of the corresponding product feature. Low attribute performance leads to low customer satisfaction and vice versa.

- Attractive / Delight and surprise requirements (A): Attractive requirements are neither explicitly expressed nor expected by the customer. Therefore, fulfilling these requirements leads to disproportionate satisfaction. Even if attractive requirements are not fulfilled by the manufacturer there is no feeling of dissatisfaction.

- Indifferent requirements (I): Customer satisfaction is not affected by the performance of product features corresponding to indifferent requirements. In Figure 4 this requirement category correlates to the x-axis.

Depending on the allocation of potential customer expectations to an addressed requirement category, the model allows to make statements about the influence of individual product attributes on customer's satisfaction with the product (Hölzing, 2008). In addition, the identification of indifferent product requirements can disclose possible saving potential. As a result, the deployment of the Kano method allows companies of industry and services sector to improve their products in terms of consistent customer orientation (Shabin, 2017).

In order to be able to allocate product attributes to individual Kano requirement categories and thereby to derive a basis for optimizing the product quality under the aspect of consistent customer orientation, several customer interviews must be carried out and assessed within a Kano project and the help of a special designed Kano questionnaire.

KANO PROJECT ON REQUIREMENTS OF THE MTQM SOFTWARE TOOL

For reasons of the comprehensibility and clarity of the questionnaire and due to the fact that a lengthy questionnaire scares off the interviewee, it was essential to limit the object of the survey. After defining several selection criteria (e.g. recognizable interface to the customer, relevant for the purchase decision, traceable by the programmer) the scope of services and the usability of the software tool were chosen to be the objects of the Kano project survey. Afterwards, 22 testable customer requirements regarding the quality of an Excel-based software tool were gathered (e.g. visualized process steps, less training expenditure, intuitive use, advice and security system available, cf. Figure 3) via research in pertinent literature and the internet, via own considerations of the authors and via brief explorative interviews with participants from the end-customer field.

Fig. 5 - Example of the typical questioning technique in a Kano questionnaire

In the next step, in conformity with the Kano philosophy (cf. Kano, 1984), two questions were formulated for each product requirement - one positively formulated functional question

to illustrate the level of customer satisfaction to clarify if the queried product attribute is met by the producer and one negatively formulated dysfunctional question to capture the reaction of the interviewee when the product requirement is not fulfilled. Subsequently, all functional and dysfunctional questions were completed by the same five Kano-typical options for response (cf. (Kano, 2001)). The following diagram illustrates the structure of the developed Kano questionnaire.

After formulating the Kano questions, they were grouped according to attributes. For this purpose, all questions were divided into the following five questionnaire sections:

- Questions concerning the navigation through the software tool (4 questions)
- Questions concerning the handling when creating an assembly profile (4 questions)
- Questions regarding the components of the risk analysis (6 questions)
- Questions concerning the depiction of the risk forecast (3 questions)
- Questions regarding the summary of the analysis results (5 questions)

The questionnaire was programmed in Unipark, a computer software used to carry out internet-based customer interviews and online market research surveys. On completion of the programming and formulation of the questionnaire, all questions, introductory texts and explanatory texts were checked in a final step for ambiguous formulations and unsuitable formatting. After the questionnaire was completely finished and any programming errors were remedied the questionnaire was subjected to a two-week test run in order to confirm the principal suitability of the Kano method as an instrument to categorize and evaluate customer requirements on an Excel-based software tool for predicting human error probabilities in manual assembly. During the pre-test ten industrial partners of the research department of the authors took part in the Kano survey.

The first phase of evaluating the questionnaire represented an evaluation according to absolute frequencies. Using a Kano assessment table (cf. (Kano, 1984), (Hölzing, 2008)) it was possible for each combination of responses that were given to the functional and the dysfunctional question on a certain product attribute by the interviewees to determine if the corresponding product requirement represented a basic requirement, a one-dimensional requirement, an attractive requirement or an indifferent requirement. Figure 6 and Table 1 demonstrate the evaluation system and illustrate in which Kano category the queried customer requirements were allocated by the majority of the survey's participants.

In order to deduce recommendations of action and measures for a customer-oriented product development after categorizing all of the queried product requirements, the next step of the Kano project deals with the interpretation of the analysis results.

A relatively simple but very effective analysis method is the use of the M > O > A > I- rule which makes up an easy applying implement for measurement prioritization. The evaluation rule firstly recommends taking those product requirements into consideration that are allocated to the requirement category M (basic requirements), because disregarding of such elementary basic elements creates dissatisfaction (Hölzing, 2008). According to M > O > A > I -rule, product properties illustrating performance and attractive requirements from the customers' point of view are only optimized or rather new integrated to the product when fulfillment of all basic requirements is already assured. Indifferent product requirements exhibit the least acuteness because they only have a minor influence on customers' satisfaction or rather dissatisfaction with the product.

Requirement		Dysfunctional question				
....		I would like that	I take it for granted that it is	It does not matter to me	I could probably accept that	That would bother me
Functional question	I would like that	Q	A	A	A	O
	I take it for granted that it is	R	I	I	I	M
	It does not matter to me	R	I	I	I	M
	I could probably accept that	R	I	I	I	M
	That would bother me	R	R	R	R	Q
M = basic requirement				I = indifferent requirement		
O = performance requirement				R = reverse requirement		
A = attractive requirement				Q = questionable answer		

Fig. 6 - Kano evaluation table

Table 1 - Evaluation results according to absolute frequencies

Product requirements / product attributes	Requirement category	Product requirements / product attributes	Requirement category
Navigation from module to module	Attractive	Insertion of stress values via sliders	Attractive
Navigation via a central menu	Reverse	Color marking of already entered values	Indifferent
Navigation via additional pop-ups	Indifferent	Reset of the stress vector via touching a button	Indifferent
User forms for profile creation	Indifferent	Automatically updating calculations	Basic
Information fields for doubtful definitions	Performance	Presentation of analysis results via pop-up menus	Attractive
Subsequent removal of individual elements	Indifferent	Simple HEP value comparison	Performance
Subsequent addition of forgotten components	Basic	Marking the HEP value in a reliability graph	Attractive
Insertion of additional assembly steps at any position	Performance	availability of a difficulty display of task items	Indifferent
Illustration of the stress vector in a compact form	Attractive	Color-highlighting of the most error-prone motion sequences	Basic
Own scaling aid for each component of the stress vector	Attractive	Color-highlighting of the achieved reliability class	Attractive
Insertion of stress values via user form objects	Basic	Highlighting of the achieved reliability class via flashing	Indifferent

Therefore, a detailed analysis of indifferent product requirements only makes sense when all basic, performance and enthusiasm product requirements have already been taken into consideration.

If not possible to meet all the performance features and attractive features ranked by the interviewees due to personnel, time or technological reasons, Category Strength (CAT) is a suitable aid to determine where to set priorities within a requirements' category (Sauerwein, 2000). The Category Strength index (CAT) which can be calculated by using the formula (CAT = most frequently-given nomination in per cent minus second most frequently nomination in per cent) allows to determine the strength of an allocation of a product attribute to a Kano requirement category (Lee, 1997). The higher the Category Strength value, the clearer the observed product requirement was allocated by the survey participants in this requirement category and the higher is the satisfaction potential of the queried product attribute in case of realization. Based on the results of an absolute frequency evaluation the following table illustrates the values for the Category Strength calculation for the Kano requirement category `Attractive`.

Table 2 - Evaluation results according to absolute frequencies

Product requirements / product attributes	CAT (A) = nomination Attractive (%) - second most frequently nominated (%)	Ranking
Navigation from module to module	66,67 (A) - 16,67 (I) = 50,00	2
Illustration of the stress vector in a compact form	33,33 (A) - 33,33 (I) = 0	5
Own scaling aid for each component of the stress vector	75,00 (A) - 15,00 (I) = 60,00	1
Insertion of stress values via sliders	66,67 (A) - 16,67 (M) = 50,00	2
Presentation of analysis results via pop-up menus	50,00 (A) - 33,33 (I) = 16,67	4
Marking the HEP value in a reliability graph	50,00 (A) - 16,67 (I) = 33,33	3
Color-highlighting of the achieved reliability class	66,67 (A) - 16,67 (I) = 50,00	2

The above-mentioned enthusiasm requirements (A) stand out due to the fact that the second most frequent nomination with one exception can be found in the Kano requirement category `Indifferent requirements` (I). Only the requirement `Insertion of stress values via sliders` displays a tendency to the requirements category `Must-be/basic requirements` (M) (cf. table 2, line 4). For reason of the comparatively high potential of Must-be/ basic requirements which may give cause to customer dissatisfaction, it is advisable to consider these separately when determining priorities and to depart from the ranking listed in Table 2 to the effect that the product attribute `Insertion of stress values via sliders` is afforded the highest priority within the requirements category "Attractive". Then the following priority assignment should occur with the help of the order of rank given in Table 2.

CONCLUSION AND OUTLOOK

Based on the presentation of the assembly planning method MTQM (Methods Time and Quality Measurement), this paper clarifies how the MTQM method including the necessary method knowledge can be transferred into a computer-aided methodology which enables an automatically conducting and evaluating of time and risk analyses for manual assembly tasks. To initiate a high user-friendliness, a high acceptance and a high level of dissemination of the developed software tool this contribution subsequently deals with a Kano survey concerning customer requirements on the addressed software tool. The executed Kano project confirms the suitability of the Kano method as an instrument to categorize and evaluate customer requirements on an Excel-based software tool for predicting human error probabilities in manual assembly. When evaluating the Kano questionnaire an allocation of the queried requirements in the Kano requirement categories was done via frequency evaluation and concretized by an evaluation according to the Category Strength rule. Due to the fact that valuable indications for future product improvements have already been revealed within the preliminary study presented within this contribution it is currently planned to extend the survey to a larger clientele in order to verify the analysis results with a larger database.

Nevertheless, the authors of this contribution are convinced that Kano`s model must be modified in order to take the subjective weighting of individual requirements by the customer, as well as the weighted degree of customer satisfaction into account. As shown by the presentation of the original Kano model of customer satisfaction and according to Kano`s theory, requirements can be classified into attractive requirements, one-dimensional requirements and must-be-requirements. It is assumed that the correlation between fulfilling requirements and satisfaction is not necessarily linear (cf. (Hölzing, 2008), (Sauerwein, 2000), (Xu, 2009), (Kuo, 2012)). For this reason, the current research of the authors of this article deals with quantifying the Kano requirement curves by integrating a case and product specific weighting-factor (cf. (Refflinghaus, 2017)). Depending on customer specific weightings the graphs may have a flatter or a steeper progress. As a result, the weightings given by the customer will cause a weaker or a more intense impact of the meeting of requirements on customer satisfaction (cf. Figure 7).
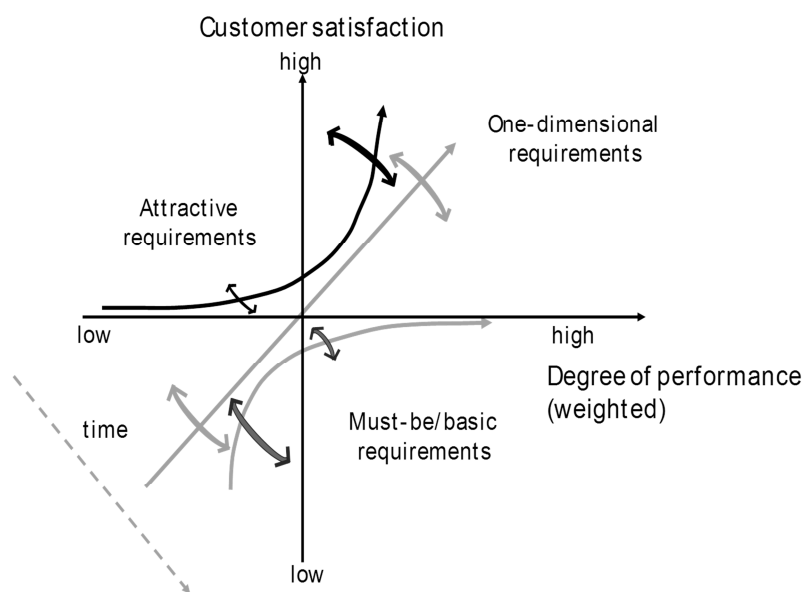

Fig. 7 - Effects of weighting factors on the Kano requirement curves

Considering all Kano-categories during the weighting process it is imaginable that the fulfilment of a one-dimensional requirement might produce a greater contribution to the customer satisfaction than the fulfillment of an attractive requirement. Following this approach during the evaluation process of large-scale Kano-projects it is possible to draw a separate Kano-curve for each of the queried requirements. As a result, when quantifying the Kano curves by adequate formulas the impact of each individual requirement to the satisfaction of the customers with the product can be disclosed. This is analyzed in current research.

ACKNOWLEDGMENTS

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