Conception and evaluation of an age-differentiated task analysis and screening method

M. Keil, B. Spanner-Ulmer

Chemnitz University of Technology, Professorship of Human Factors and Ergonomics
E-mail: mathias.keil@mb.tu-chemnitz.de, birgit.spanner-ulmer@mb.tu-chemnitz.de

Abstract

In the light of the proceeding demographic change in Europe, companies have to face the challenge to cope with the changes of the working environment with a continuously aging workforce. Hence, the design of age-based work systems and processes becomes an important factor of German companies. Having this in mind, a task analysis and screening procedure (ATS) was developed to consider age-related changes directly by planning and to avoid an overstraining in older people. With the conception and evaluation of ATS, a first basic approach could be generated to identify age-critical fields of activity in the product development and production process. Due to the comparison of work requirements and age-related abilities, it is possible to illustrate age-related spheres of activity and to infer design recommendations in order to design work systems in a corrective and conceptive way.

Keywords:

Chemnitz Age Database, Chemnitz Age Model, age effects, ATS

1 INTRODUCTION

The automobile industry is one of the biggest employers generating almost one quarter of the German industry´s total sales. Thus, it represents a model for recent and future developments within the working environment. Nevertheless, an increase in shorter product life cycles, in product variety as well as in aggregation of work contents and in productivity requirements, let the companies of the automobile industry see themselves compelled to continuously restructure their production processes in order to remain competitive [1]. This fact as well as the use of innovative manufacturing technology and the claim to control those technologies in a process-safely way, lead to new task and requirement situations for the human beings employed in the process. Therefore, it is essential to enhance the plant availability and therewith guarantee a trouble-free and uninterrupted production process [2]. The problem-solving ability and the design of complex action strategies heighten cognitive requirements. Monitoring the plants leads to elevated requirements for the sense organs and attentiveness. An increased perception of quality tasks substantially requires an extensive knowledge of quality criteria, finished products and production processes associated with a greater versatility of the employee [3].

Due to changes of the working environment along with the current demographic challenge in Europe, many companies face the problem of coping those changes with a continuously aging workforce. Despite these problems, future work and production processes have to be designed, specifically for the age-related changes of the performance conditions of the employees [3]. Not having developed sustainable concepts for the exposure to an aging workforce, companies risk losing their productivity and innovation [4].

2 STATE OF RESEARCH

The demand for research and a scientifically founded consultation for coping with the demographic change have strongly increased, especially in the past years. Both aspects become apparent with the numerous aided networks and research programs on the European and national level addressed to this subject [5]. Since the end of the ‘90s, results from different academic disciplines have been available demonstrating suggestions for the maintenance of the working ability, the health as well as the age-based human resource development, mostly in the form of applicable action guidelines [6] [7]. Besides the introduction of operational health management systems and the suggestion to analyze and to valuate workplaces, especially approaches of the work structure and organization are considered to be productive. The workplaces are analyzed concerning their health risks with the help of ergonomic methods, e. g. job rotation approaches or mixed-age teams [8]. In fact, younger and especially elderly employees benefit from a well designed ergonomic work place and operational health services. Anyhow, from the ergonomic view, it needs to be stated that tangible design suggestions for an age-based design of work-systems exist only rudimentarily.

The term “work-system” relates to a system that includes a work task, the in- and output, the human being as a worker, the operating or working material, the production process as well as the predominant environmental influence. Work-systems stand for the fulfillment of work tasks and consequently, refer to a workplace with its work-system elements in the direct field of the automobile production [9].

Still, objective instruments and methods presenting tangible design suggestions for a systematic age-differentiated work-system design are missing. It is striking in terms of anthropometric, movement, organizational, physiological and informational aspects, based on age-related performance changes [10].

The absence of a valid database regarding age-related performance changes is the cause. However, results on age-related changes are available in the form of scientific publications in different scientific disciplines, e. g. medicine, sports science, psychology or engineering science [11]. So far, the identification, evaluation, and editing of the publications have effected the applicability for the design of the age-differentiated work-systems and processes only sporadically. Nevertheless, the access to secured scientific knowledge on the extent of age-related performance changes is the necessary basis for planning and designing age-based work-systems. Primarily on the basis of the obtained data, and despite the change of the working environment, it will be possible to develop ergonomic instruments allowing the demonstration of design fields in the product development and manufacturing process that are age-relevant, preferably at an early stage. The earlier ergonomic instruments are developed in the planning process, the greater and the more cost-effective is the design margin to find effective solutions for the human being, the technology and the organization [3] [12].

3 SCIENTIFIC APPROACH FOR GENERATING A VALID DATABASE OF AGE-RELATED PERFORMANCE CHANGES

3.1 The Chemnitz Age Model

Taking the obtained knowledge of different scientific disciplines into account, a variety of theories and age-specific approaches can be identified [13]. The predominant paradigm of ergonomics is the ergonomic compensation model [14] assuming that the deficits accompanied with the aging process could mostly be compensated by a human work design and lifestyle [15]. Furthermore, aging has to be seen as a dynamic, differentiated process experiencing a decrease in functions, whilst other abilities develop positively during the course of life. In contrast to studies that are empirically comprehensive, ergonomic approaches always focus on special parts of the work-system, e.g. age-differentiated adaption of human-computer-interaction. This has to be seen in contrast to age-related researches of psychology and sociology longitudinal studies, as the Seattle Longitudinal Study (SLS) [16] being in progress since 1956. A longitudinal study is a correlational research study that involves repeated observations of the same variables over long periods of time, often many decades.

However, a generally accepted, ergonomic age model has to consider all the relevant health-supporting and age-based work design components of a work-system. Thus, it includes the working person (human being), the operating and working materials (machine) as well as the age-relevant physical, mental and social influences of the working environment with its interdependencies.

According to the stress-strain-concept [17], work tasks causing age-related decreasing performance factors can lead to a higher strain of the elderly worker under the same stress level and the same stress duration [18]. The effect of negative work-system influences on age-related changing human abilities needs to be pointed out when we refer to an age-differentiated design of work-systems. Additionally, the effect has to be evaluated and formatively corrected in case of an overstraining in elderly workers. Unless this happens, increased strains in the course of life can lead, besides a decrease of the performance and the physical well-being [19], to a higher fatigue of the elderly employee. Furthermore, it can provoke signs of wear and damages manifesting in the form of inactive periods caused by illness or even lead to health impairments [14].

An ergonomic approach that considers influences of the age-related performance changes, and relates them with the strain and stress, has not been found, yet. In order to demonstrate the correlation of the requirement limits, looking at quantitatively measurable stress limits and the age-related abilities, an independent approach, the "Chemnitz Age Model" (figure 1), was initiated.

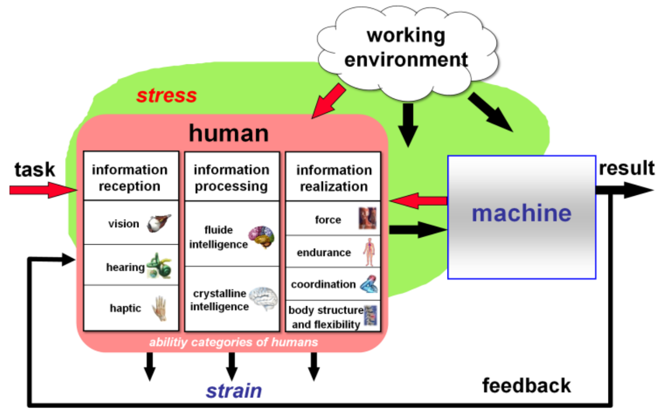

Figure 1: "Chemnitz Age Model" based on the structure scheme of human work [19] with categories of human abilities

For the first time, all age-relevant influences of the work-system can be described in the "Chemnitz Age Model". Age-relevant stress influences on the human (red arrows) occur due to different system elements. The work task describes the action of the human being in the work-system, the human-machine-interaction as well as the physical and social influences of the working environment. The stress factors affect the human being employed in the work-system by reacting to the abilities and capabilities with a subjective strain.

Within the design of age-differentiated work-systems, the human being with its age-related abilities marks the central unit. Thus, the same task requirements (objective stress values) can lead, on the basis of age-related ability changes, to the fact that a younger employee clearly exceeds the given work requirements regarding its age-related abilities and experiences, to a "normal" strain. However, age-related abilities that change in a negative way, using the same work requirements, can lead to an excess of its predominant abilities in the elderly employee. According to the model, the elderly person exceeds its individual ability limits [14] leading to a higher strain of the elderly in comparison to the younger employee. Fatigue, signs of wear up to the point of health impairments in the long run can be caused.

Therefore, it is essential to determine, if and to what extent ability limits are exceeded by the given work requirements. Thus, the nine human age-related ability categories of the "Chemnitz Age Model" have to be further differentiated. An ability category consists of many age-related performance factors. Each of this performance factors is able to rise or lower the performance ability of the respective ability depending on the age. The term "performance ability" comprises all those criteria that determine the performance structure of a worker on a physiological and psychological basis. The physiological aspect stands for the performance capacity of the organs respectively of the apparatus, and the latter comprises the performance potential of mental functions and informational-mental components [14]. Correspondingly, the ability categories break the human performance ability down into the function of several organs and apparatus as well as into mental functions. With the help of several performance factors, physical and mental functions can be further specified [18]. The ability category "vision", for example, refers to the eye as an organ of vision. The performance factor, specifying this ability category, comprises the visual acuity, accommodation ability and adaptability, glare sensitivity, color and contrast vision, depth perception as well as the field of vision. By breaking down the ability categories into the level of age-related performance factors, precise correlations of work requirements, in terms of performance requirements, and performance qualifications can be demonstrated and compared. Finally, in order to compensate the age effects, the elements of the work-system have to be designed as such that occurring deficits of the human performance ability can be compensated [3].

3.2 The Chemnitz Age Database

At first, a solid database has to be created to generate valid information about the evaluation of existing work requirements. On the basis of a comprehensive literature research resulting from various studies of different scientific disciplines, results of the age-related change of the performance factors were collected. Reasons to be considered are the variety of the existing work influences in the field of human abilities, the human-machine-interaction as well as the physical and social working environment influences. The comprehensive interdisciplinary literature research was expedited with the help of the "Chemnitz Age Database", a SQL database, controlled by a web-interface [11].

By evaluating and editing the scientific publications, the aim of the Chemnitz Age Database is to identify those physical and mental changes occurring in terms of a typical development process of normal aging, healthy male and female human beings aged 20 to 70 years. "Aging in a normal way" refers to typical and mental development processes in terms of changes that are located in a normal range including all individuals. Thus, it is linked to an expected value of mean or typical development processes within the respective age group of all survivors. It is useful to concentrate on normal age changes when determining reliable reference data. The reason for that is the difficulty to predict the probability of disease appearances in relation to the period of life („pathological aging"). In addition, the degree of severity and the interactions are different between several individuals to the age-dependent performance factors. Therefore, it is important to pay attention to studies that only consider participants without diseases and pathological influences on the examined performance factor.

Next to the typical development process of people aging in a "normal way", work design possibilities that influence and compensate the performance are measured for every age-related performance factor within every single ability category [10].

Likewise, publications are included that present information on existing dependencies and interdependencies of single performance factors in relation to other performance factors and design conditions of the working environment. This is of utmost importance as meaningful conclusions for the design of work-system elements can only be derived by visualizing the interrelations.

The changes of the performance factors over the course of life can be pictured with performance charts. By including statistical indicators, e. g. dispersion and standard deviation, a statement could be derived on the spreading width of the age-related performance course. By integrating a search function, it is possible to realize a directed research on performance changes of certain age-related abilities as well as the research on publications of certain authors or the limitation on evaluation periods. Furthermore, the understandable handling of scientific technical terms is guaranteed by an "encyclopedia". The automatic linking of words and phrases help the user to gain a clearly understandable access to definitions and explanations of the technical terms in use. Thus, the linking enables every user to obtain results of the age-related changes without any specific previous knowledge.

More than 1.000 scientifically founded studies on different human age-differentiating performance factors have already been compiled in the "Chemnitz Age Database". Therewith, a data pool of scientifically founded information on age-related changes was generated. It can be considered as a novelty because there is no existing comparison. To ensure the quality of the database, scientific publications are evaluated regarding a defined catalogue, e. g. criteria of the test design, criteria of the test procedure as well as criteria of the test evaluation and the interpretation of the results. By comparing different studies of an age-related performance factor and by controlling the research results with the help of the defined quality criteria, a selection of high-class research results on age-related performance changes can be guaranteed. They are separately registered in terms of age-related reference values and provide the basis for the development of ergonomic evaluation instruments to identify age influences.

4 FUNCTIONALITY AND EVALUATION OF THE AGE-DIFFERENTIATED TASK ANALYSIS AND SCREENING METHOD (ATS)

4.1 Structure and Functionality of the ATS

The evaluation instrument for identifying age influences, developed at the Professorship of Human Factors and Ergonomics of the Chemnitz University of Technology, is part of the group of the situation-related analytical methods [20]. Subject of the evaluation instrument is the worker-independent analysis of technical, organizational and social working conditions within the given work-system unit aiming at the determination of work and workmanship conditions of the work task. The method raises the claim of an ergonomic screening-method adverting to the demonstration of action fields for an age-differentiated optimization of the work task and the design of the work-system. This newly developed evaluation instrument is going to be labeled "age-differentiated task analysis and screening method (ATS)". The schematic structure of the ATS is depicted in figure 2. An overview is described below.

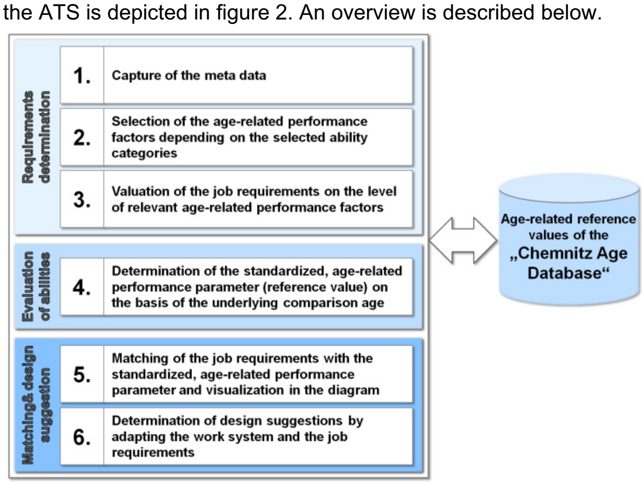

Figure 2: Schematic structure of the "age-differentiated task analysis and screening method" (ATS)

In **step one**, in the context of the determination of requirements, the metadata is captured. At first, the rough description of the work tasks is analyzed that constitute the subject, e. g. with the help of workplace instructions and task descriptions. By means of the "Chemnitz Age Model", the relevant elements and ability categories, undergone by work evaluations, are chosen for comprehensive observations of all age-relevant work-system parameters.

In **step two**, the user is asked to specify the relevant work requirements with the help of the chosen work-system elements and ability categories of the "Chemnitz Age Model". For that, the user chooses by means of questions if the relevant age-related performance factors apply to the work task to be analyzed. In order to understand the process in an appropriate way, the performance factors are specified and defined, the occurring age-related changes are explained, existing work influences are shown by giving reference examples, and possible age-critical work tasks are pointed out.

In **step three**, the evaluation of the work requirements is initiated on the level of relevant age-related performance factors. Thus, depending on the respective performance factor, the objectively measurable work-system parameters, necessary for the evaluation, have to be typed in. For instance, the parameter can be taken from the specification sheet or by capturing the necessary data on site, at the workplace. Furthermore, there is the possibility to evaluate the work task or the relevant strained part of the task by measuring the time. According to the strain level and strain duration, a ranking of all age-relevant performance factors can effect the execution of the method, at the end. Once, age influences occur, i. e. the performance requirement exceeds the predominant age-related performance ability of the given person, especially for longer strain periods, work design measures must be used in order to countervail an overstraining. An automatic matching of the work requirements with the age-related performance course (representative reference values depending on the age) of the relevant performance factor allows an immediate statement, whether there are any age influences (i. e. no expected increase in strain), or up to what point in time an increase in strain can be expected. The relevant performance factors are obtained from the data pool of the “Chemnitz Age Database”.

In **step four**, the age of the worker employed in the work-system is recorded in combination with an evaluation of the abilities. It is possible by determining the comparative age that symbolizes the planning premise. According to this age specification, the standardized age-related performance parameter is measured (ability evaluation) based on the age-related reference value of the respective performance factor.

On this basis, now, work requirements and abilities can be compared on the level of the relevant age-related performance factors and thus statements on a likely resulting strain of the worker employed in the work-system can be generated (**step five**). The results of the comparison are illustrated in the form of an evaluation diagram. If the performance requirements exceed the performance parameter of the comparison age and the tolerance range, there will be a high overstraining risk and work design measures will be imperative. The tolerance range is a statistical dispersion of the mean performance factor (a simple standard deviation). The excess of the tolerance range is visually highlighted by a red coloring. Not taking on any work design related measure risks, depending on the strain duration, an indisposition, fatigue, loss of power and productivity up to health impairments will occur. If the performance requirement and the performance parameter are close and within the tolerance range, there will be a medium risk. Furthermore, if work influences are excluded, measures for designing a workplace will be introduced. If the performance parameter exceeds the performance requirements and the tolerance range, there will be no risk. Consequently, no work design measures are necessary. It is visually highlighted by a green coloring.

Besides the evaluation diagram, the user gets a detailed impression of how the performance ability, depending on the age, changes (intra-individual variability of the age). It is illustrated in the performance progression diagram (figure 4). Explicitly, a decrease in performance can be observed during the planning of work and production process due to the specific temporary performance development during the course of life.

Furthermore, the ATS offers the possibility to target control levers for the design of work-systems and the work task (**step six**). Thus, single influencing factors can be adapted via formula-related, mathematic correlations. Additionally, the representative limit value selected for the comparison age can be evaluated. The very first time, quantifiable statements can be generated to prospectively eliminate age-related work-system influences.

4.2 Evaluation of ATS in a manufactory line of an automobile company

Validity, objectivity, reliability, applicability and expenditure for the analysis and the evaluation as well as the acceptance of the results of the ATS could already be proven by means of the evaluation of different workplaces alongside of one assembly line of an automobile company. In the following, the potential of the ATS is demonstrated by stating an example.

Subject of the analysis is an automotive manufacturer whose workplace is in the field of the assembly. Here, the steering wheel and the airbag are assembled into a vehicle. According to the head of the production section and the group leader, the employees consider the requirements for the vision during the alignment of the steering wheel to be very inconvenient and straining.

During the workplace inspection, the worker is monitored via multiple working cycles. After reading the construction contract, the employee picks the steering wheel and the airbag, prepares the two vehicle components for the assembly (oiling the steering wheel, documentation of the airbag-component number) and leans into the vehicle interior for the assembly. After pressing the ignition for the correct alignment of the steering column, the steering wheel will be attached. Now, the age-critical and intensive work task in terms of the visual requirements commences. The steering wheel has to be aligned with the help of two centering pins. The geometric dimensions of the centering pins have been determined by means of a vernier caliper. This involves two notches sized 0.5 mm in the metal that are hardly silhouetted against the metallic surface. The eye distance of the centering pins to the worker was evaluated with the help of a laser rangefinder and amounts to 350 mm. The employee knowingly downsized the viewing distance to better perceive the centering pins. The measurement of the light density at the steering wheel in the vehicle interior by means of a lightning diameter led to a light density value of 3 cd/m². For the light density at the production line outside of the vehicle, a mean light density value of 55 cd/m² was determined. An interview with a worker employed at the assembly (age 37 years) verified, despite a two-hour job rotation, that the alignment of the steering wheel, via the centering pins, is a straining and fatiguing task. Moreover, he underlined the fact that elderly as well as younger workers feel inconvenient to work in the field of an assembly.

Based on the workplace inspection, the process plan of the workplace was analyzed and relevant parts of the work task were identified for the evaluation with regard to the content and time. There are work requirements at the workplace to be analyzed that

- necessitate a detailed perception of objects,
- require the focusing of objects in the immediate vicinity, and
- necessitate the perception of objects in different illumination conditions (from dark to bright and from bright to dark illumination).

The age-related performance factors vision, accommodation ability, adaptability and glare sensitivity were chosen using the ATS for the verification of existing age effects. By means of the present objective workplace data, a workplace can now be examined regarding existing age influences. In the following, the results of the evaluation of relevant work task parts of the performance factor vision are presented and interpreted (figure 3).

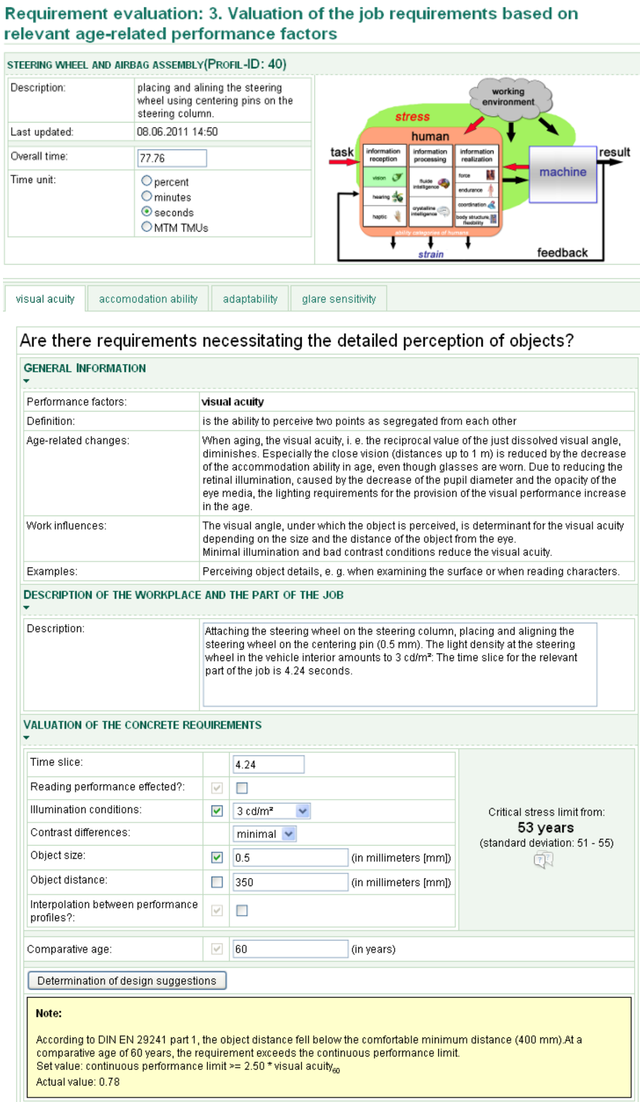

Figure 3: Evaluation of a steering wheel and airbag assembly with the ATS, performance factor visual acuity

After describing the metadata (step one) and determining the ability category "vision" to be the relevant influencing value in the "Chemnitz Age Model", the age-critical performance factors are possible to be chosen (step two). Now, the work requirements on the level of the relevant age-related performance factors have to be evaluated (step three). For the performance factor of the visual acuity, the relevant part of the work task has to be described first. The work task consists of attaching the steering wheel on the steering column and placing it by aligning the centering pins (object size 0.5 mm) within an object distance of 350 mm. This is carried out within illumination conditions inside the vehicle interior of 3 cd/m². The given time for this part of work amounts 4.24 seconds.

The input of workplace requirements leads to a critical stress limit starting from the age of 53 years (standard deviation 51 to 55 years). Thus, in the statistical average, an approximately 53-year-old person could just cope with its age-related performance ability. In order to be able to let elderly team members carry out this task in the future, a comparative age of 60 years was defined as a planning premise (step four). Furthermore, this method gives information about an underbidding of the given standards of the EN 29241-3 [21] for the comfortable viewing distance of 400 mm. Beside that, it states that an employee aged 60 does not reach the continuous performance limit (set value: 2.5; actual value: 0.78). Based on this fact, the evaluation diagram depicts (figure 4) a delta between the existing performance requirement (X^A) and the performance parameter (ability) on the basis of the planning (X^F) (step five). The vertical arrows in the evaluation diagram indicate that the illumination and contrast conditions affect the requirements in a negative way. Besides the high visual acuity requirements, the reason can be located in the minimal object size of the centering pins and the object distance.

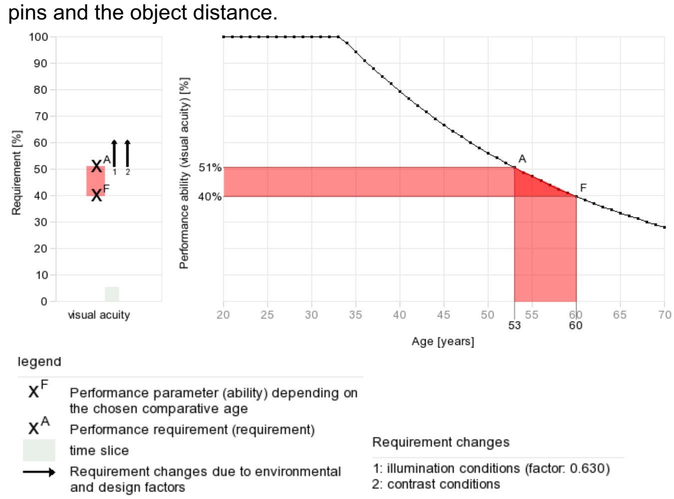

Figure 4: Evaluation diagram of the steering wheel and airbag assembly with ATS, performance factor visual acuity

With the function „determination of design suggestions" (step six) appropriate control levers for an age-based workplace design can, now, be identified and quantified by varying the illumination conditions, object size and object distance. As the standard of the DIN EN 29241-3 [21] amounting to 400 mm is undercut with an object distance of 350 mm, first of all, a viewing distance of 400 mm should be kept during the assembly to ensure a prevention of fatigue due to high accommodation requirements. Accordingly, the object distance has to be adjusted to 400 mm and maintained alike. The level of the viewing requirement can only be adjusted by the illumination condition and size of the centering pins (figure 5).

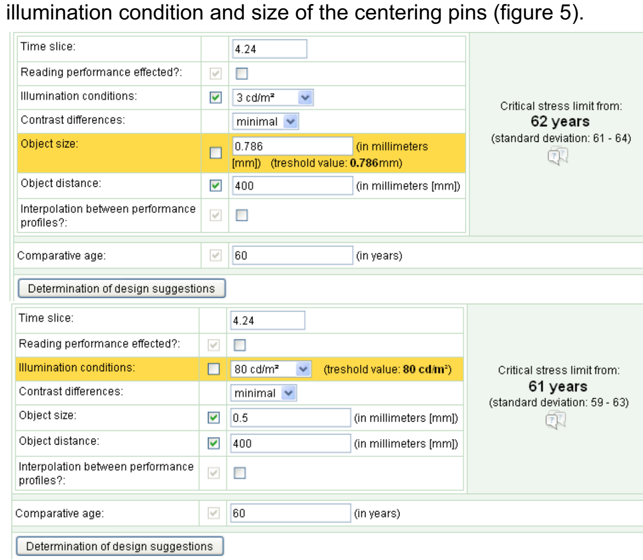

Figure 5: Evaluation of a steering wheel and airbag assembly with ATS, performance factor visual acuity

The verification via the adjustment of the illumination conditions points out that the illumination conditions should be raised to 80 cd/m² in order to avoid age effects. However, it is doubted that a sole compensation of the age effects by increasing the illumination, in fact, leads to the proposed result. By adjusting the size of the centering pins, existing age effects can be compensated as well. ATS sets the limit value that is based on the comparative age and the predominant illumination conditions of 3 cd/m², at 0.79 mm. This adjustment would lead to the situation that a 60-year-old worker who is ophthalmologically healthy is able to perform the task, regarding its performance values of the visual acuity.

5 SUMMARY AND FUTURE PROSPECTS

Despite the changing working environment, the demographic change and the consequent aging of the workforce in Germany and Europe challenge the automobile industry in an enormous way. The ability-matched employment of staff and the age-differentiated design of the work-system have become an advantage for companies to stay strategically competitive. Only those companies that consider the needs for an aging staff very early, concerning the product development and manufacturing process, will be efficient and innovative in the future. Therefore, the companies have to coordinate the potentials of human beings, the technology and the organization very precisely.

Although, there are many scientific research results dealing with the demographic change, it is difficult to give tangible suggestions for an age-differentiated work-system design. Hence, a basis for a valid database identifying and analyzing age-related changes was provided by creating the “Chemnitz Age Model“ as well as the “Chemnitz Age Database“. Based on the data research from the “Chemnitz Age Model”, an “age-differentiated task analysis and screening method (ATS)” has been developed and evaluated in an assembly line of an automobile company. With the help of the ATS-method, task demands and normal age effects of human abilities can be compared, and operation fields for the development and design of work processes are possible to be presented on the basis of age-dependent performance factors in a transparent way. For the first time, ATS quantifiable statements can be generated to eliminate age influences by evaluating design suggestions. Additionally, the systematic use of ATS within the product development and manufacturing process offers a potential to adjust work-systems to determine requirements and needs of elderly employees as well as to compensate imminent economic consequences of the demographic change.

6 REFERENCES

[1] Kinkel, S., Friedewald, M., Hüsing, B., Lay, G., Lindner, R. (2008): Arbeiten in der Zukunft. Strukturen und Trends der Industriearbeit (Work in the future. Structures and trends in the working industry), Berlin.

[2] Löschmann, F. (2008): Trends im Karosseriebau (Trends in car body manufacturing) in: R. Neugebauer, Karosserie-fertigung im Spannungsfeld von Globalisierung, Kosten-effizienz und Emissionsschutz (car body manufacturing in the area of tension between globalization, cost efficiency and emission control), pp. 55-65.

[3] Spanner-Ulmer, B., Keil, M. (2009): Konsequenzen des demographischen Wandels für zukünftige Produktions- und Technologieabläufe am Beispiel der Automobilindustrie (Consequences of demographic change for future production and technological processes on the example of the automotive industry), Zeitschrift Industrie Management, 2/2009, pp. 17-20.

[4] Brandenburg, U., Domschke, J. P. (2007): Die Zukunft sieht alt aus, Herausforderungen des demografischen Wandels für das Personalmanagement (The future looks old, challenges of demographic change for human resources management). Wiesbaden.

[5] Bundesministerium für Bildung und Forschung (2007): Das 7. EU-Forschungsrahmenprogramm (7th EU Research Framework Programme), Berlin.

[6] Boukal, C., Meggeneder, O. (2005): Healthy work in an Ageing Europe, A European collection of measures for promoting the health of ageing employees at the workplace.

[7] Bullinger, H. J. (2002): Zukunft der Arbeit in einer alternden Gesellschaft (Future of work in an aging society), Stuttgart.

[8] Spanner-Ulmer, B., Frieling, E., Landau, K., Bruder, R. (2009): Produktivität und Alter (Productivity and age), in: K. Landau, Produktivität im Betrieb (productivity in enterprices), GfA Herbstkonferenz, 23.-25.09.2009, pp. 81-117, Millstatt.

[9] REFA, Verband für Arbeitsstudien und Betriebsorganisation e.V. (1993): Methodenlehre der Betriebsorganisation (Methodology of business organization), 2. Aufl., München.

[10] Keil, M., Spanner-Ulmer, B. (2010): Conception of a task analysis- and screening-method for identifying age-critical fields of activity on the basis of the Chemnitz Age Model, in: K. Karwowski, G. Salvendy, Advances in Human Factors, Ergonomics and Safety in Manufacturing and Service Industries, 3rd international Conference on Applied Human Factors and Ergonomics, pp. 393-400, Boca Raton, USA.

[11] Keil, M., Spanner-Ulmer, B. (2009): Chemnitz Age Model – an interdisciplinary research basic approach to characterize age critical performance factors, in: 17th World Congress on Ergonomics – IEA 2009, 9th-14th of August, Beijing, China.

[12] Schaub, K., Landau, K. (2004): Ergonomie und Prävention in der betrieblichen Praxis (Ergonomics and Prevention in practice), angewandte Arbeitswissenschaft, Vol. 180, 52–70.

[13] Bengtson, V. L., Silverstein, M., Putney, N. M., Gans, D. (2009): Handbook of Theories of Aging, New York.

[14] Schlick, C., Bruder, R., Luczak, H. (2010): Arbeitswissen-schaft (Human Factors and Ergonomics), 3. Aufl., Heidelberg.

[15] Initiative Neue Qualität der Arbeit (INQA) (2006): Demographie: Initiativkreis 30, 40, 50plus – Älterwerden in Beschäftigung (Demographics: Initiative Group 30, 40, 50plus Ageing in employment), Dortmund.

[16] Schaie, K. W. (1996): Intellectual development in adulthood: The Seattle Longitudinal Study, New York.

[17] Rohmert, W. (1984): Belastungs-Beanspruchungs-Konzept (stress-strain concept), Zeitschrift für Arbeitswissenschaft, 4/1984, pp. 193-200.

[18] Keil, M., Hensel, R., Spanner-Ulmer, B. (2010): Process model elements adjusted to abilities for the generation of age-differentiated strain profiles, Zeitschrift für Arbeitswissen-schaft, 3/2010, pp. 205-215.

[19] Schmidtke, H. (1993): Teil 3. Belastung und Beanspruchung. (stress and strain) in: H. Schmidtke, Ergonomie (Ergonomics), 3. Aufl., pp. 110-116, München.

[20] Nerdinger, F. W., Blickle, G., Schaper, N. (2008): Arbeits- und Organisationspsychologie (Industrial and Organizational Psychology), Heidelberg.

[21] EN 29241-3 (1993): Ergonomic requirements for office work with visual display terminals. Visual display requirements.