Methods of Forecasting Environmental Stress and Strain on Working Humans in the Digital Factory

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Abstract. According to the stress-strain concept of ergonomics, a distinction must be made between the stress on the working human and the resulting individual strain. Furthermore, it must be taken into account whether several influences act simultaneously or one of them acts successively. Therefore, point in time-related and period-related influences are to be considered, whereby in the latter case a connection to discrete event-driven simulation is necessary. It has been known for many years that simulation methods can be used to analyze stress on the human caused by the work task itself, at least in macro-ergonomic terms with regard to time utilization. In addition, anthropometric and work-physiological aspects of the work task can be analyzed using digital human models. The evaluation and assessment of influences from the indoor working environment are more difficult. In this case, both micro- and macro-ergonomic analyzes can be performed. In the following, it is explained in more detail to what extent such forecasts can already be carried out in Digital Factory tools. The result shows that there are still a lot of research and development tasks to be solved before a comprehensive forecast of ergonomic influences can be carried out.

Keywords: Stress-Strain Concept, Indoor Work Area, Time-Related Analyzes, Evaluation, Assessment.

1 Problem statement and relation to associated guidelines

The computer-aided planning of production systems involving working humans takes place over several levels of detail. It ranges from the human supported material and information flow concepts to the planning of personnel deployment in a certain operational area to methods' design at individual workplaces. The last two levels of detail mentioned have been already reported at this conference: The personnel deployment planning is performed using event-driven simulation procedures that have also been considering service companies for some time [1]. The planning of work methods is already realized nowadays by Digital Factory tools, which not only include time management, but also enable ergonomic issues to some extent [2].

The associated software procedures have been the subject of several guidelines of the Association of German Engineers (VDI) for many years: In VDI Guideline 3633 Part 6 [3], the state of the art for ergonomic analyses of working humans in simulation procedures is regarded (see also [4]). For this purpose, it is shown how the temporal workload and other macro-ergonomic aspects can be dealt with in existing software-procedures. Furthermore, from a micro-ergonomic point of view, methods for anthropometric and work-physiological work design in Digital Factory tools are addressed. They are presented in VDI Guideline 4499 Part 4 ([5]; see also [6] for an overview).

Following the stress-strain concept according to Rohmert [7], the two VDI guideline parts mentioned only deal with one ergonomic aspect, namely the effects on the working human through the work task itself. So what is still missing is how stress from the work environment and the resulting strain on the individual human can be taken up in Digital Factory tools.

This question is investigated in this paper referring to the Guideline Project VDI 4499 Part 5 (see for this project [8]). Since this guideline part is currently in the final phase of its publication, only some methodological points can be discussed here. It is also shown which role the simulation plays in the prognosis of environmental influences in an indoor work area.

In the new guideline VDI 4499 Part 5, the environmental influences affecting humans working in an indoor work area are dealt with. According to the stress-strain concept, each of the treated influences is differentiated according to the effective stress and the resulting strain on the individual human. A further distinction is made according to their evaluation, i.e. the assignment of a numerical value, and the assessment using legally binding comparison values. Furthermore, a distinction can be made between person-related and location-related as well as between point in time-related and period-related forecasts in the Digital Factory.

2 State of the art of forecasting environmental influences

Thus, this guideline part supplements the previous ones, which deal with the inclusion of working humans in simulation procedures and Digital Factory tools. In addition, it can be stated that there is extensive knowledge about the effects of the work environment and about existing legal requirements. This comes in part from occupational health and safety regulations (see the required risk assessment in the German Act on the Implementation of Measures of Occupational Safety and Health [9], § 5 pp.).

In Germany, software procedures are also available for forecasting purposes, but apart from one exception detailed below, these are not included in the Digital Factory. The existing methods not only come from the ergonomic field, but also to a large extent from building physics and planning. In this respect, the prognosis of environmental influences on working humans represents a new field of the Digital Factory.

Almost no corresponding forecasting methods are known on the international level. In the International Ergonomics Association there is a Technical Committee "Digital Human Modeling and Simulation", but this specialists' group primarily deals with human modeling, primarily in an anthropometric and work-physiological sense (see e.g. [10]). Also in international ergonomics congresses (see e.g. [11]) and in more recent English-language publications (see e.g. [12]) there is hardly any reference to this. Also in the German-speaking countries there are only a few publications that indicate the importance of the prognosis of environmental influences (for one exception see [13]).

3 Simulation application for period-related forecasts and its validity

3.1 The EPRI method

For the period-related prognosis of environmental influences, a connection with a discrete event-driven simulation procedure is necessary, but as far as the author is aware, only actually implemented in one specific example: Figure 1 shows the coupling of such a simulation procedure with the prognosis of a temporally constant gamma radiation in a work area [14]. In order to limit the radiation exposure of the maintenance staff, two workers are deployed and their exposures are monitored by virtual dosimeters. The attached Gantt chart shows when it will be necessary to replace the active by the stand-by worker.

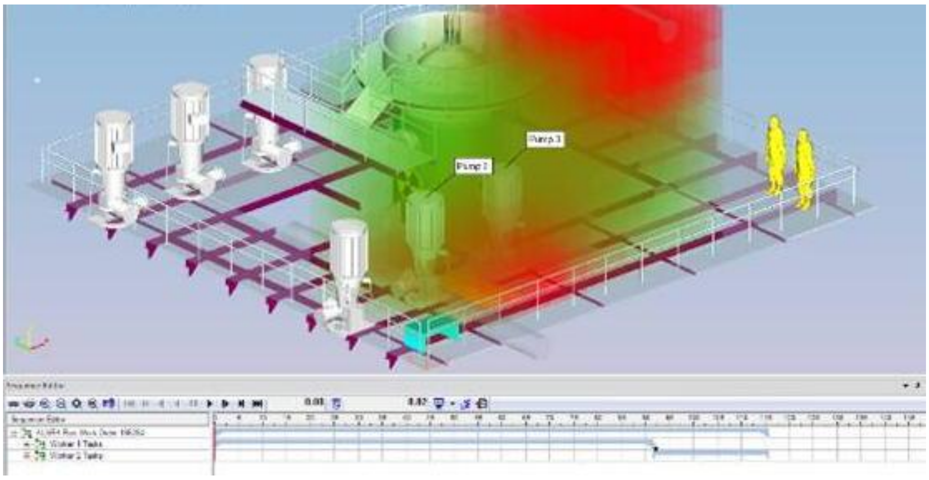

Fig. 1. Work area with calculated radioactive load and two workers deployed (Source: [15])

In this example there is no shield between the radiation source and the maintenance worker active in the area. The calculation method used by the American Electric Power Research Institute (EPRI; [16]) also provides for such shielding: In addition to the radiation strength of the source and the absorption value of the shielding material, at least one real measured value at a point in the work area must be known (Fig. 2). On this basis, the method then calculates the radiation loads at other calculation points therein.

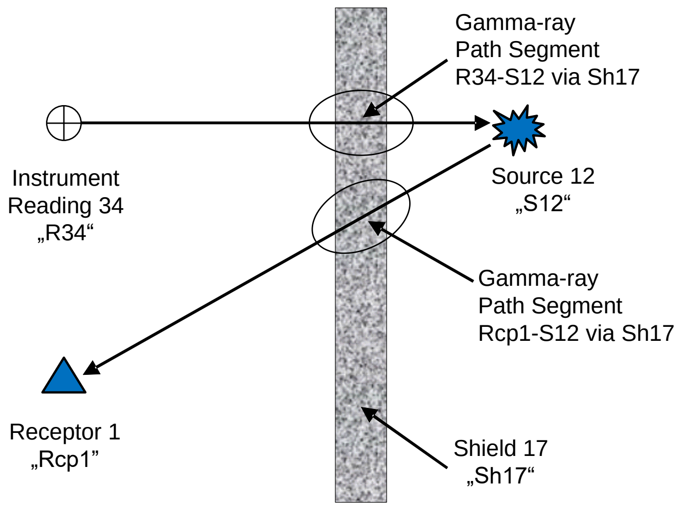

Fig. 2. Scheme of the forecast calculation using the EPRI method with shielded radiation (Source: [16], p. 2-2)

3.2 Validation studies

The algorithm developed was validated in several studies by the EPRI, initially under ideal conditions in a laboratory test ([16], pp. 2-6). Two directly shielded radiation sources and two measuring points were used for this purpose. The real exposure rates were measured on these positions and compared with the calculated algorithmic values. The validation exhibits deviations of 2% and -15%, respectively.

Supplementary field studies were carried out in a nuclear power plant with the participation of software developers, in whose software procedures the spatial geometry, the radiation sources and the measured exposure rates were entered ([16], pp. 2-8; see also [17]). In one case, a room with three high-pressure charging pumps and the associated radioactive pipelines as well as 19 real measuring points was chosen. For the maintenance staff, a total of 24 calculation points were assumed, for which the values were determined using the algorithm. The validation showed deviations in the range of approximately ± 55%.

Compared to maintenance work actually carried out and monitored by dosimeters, this result was nevertheless described as relatively good ([16], pp. 4-11). The deviations were attributed to differences in the work durations and locations of the real maintenance activities. In particular, approximately the same values resulted between the forecasts of the algorithm and manually calculated estimates.

For further validation studies in this field of investigation, reference must be made to the publication mentioned. Overall, it can be seen that validation studies for forecasting methods can only very rarely be found in the literature. Another validation study of environmental prognoses for lighting and noise in a workshop for tool production has been reported elsewhere ([18], pp. 156) with promising results.

4 Challenges for Data Modeling

In the following, two essential challenges to the information technology modeling of environmental influences and their evaluation and assessment in tools of the Digital Factory will be discussed. This involves, on the one hand, avoiding redundant entries in corresponding data models, and on the other hand, the issue of providing comparison values so that assessments can also be derived from legally binding information. Both topics are not only important for the modeling of environmental influences, they also concern the modeling of ergonomically relevant data in general.

4.1 Object-oriented data modeling

Keller ([18], pp. 83) has already pointed out that it makes sense to use an object-oriented approach for data modeling of environmental influences in an indoor work area (see also [19]). For this he used the notation of the Unified Modeling Language (UML; [20]). Figure 3 shows the object-oriented model of the stress situation at a work place. The basic elements for modeling all objects in the work area are 3D objects, which in turn consist of polygons.

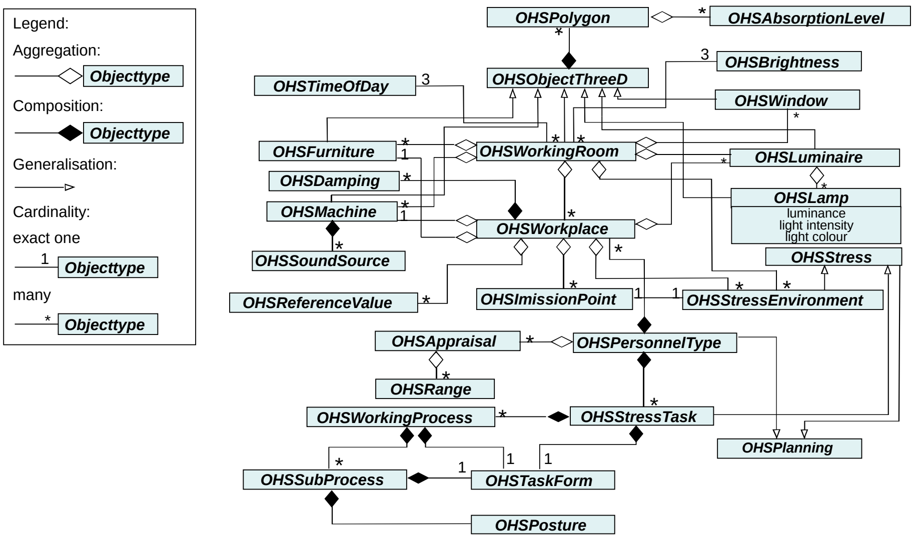

Fig. 3. Object model for calculating the stress situation at a workplace (according to [18], p.140)

The use of this object-oriented approach offers considerable advantages when modeling occupational health and safety (OHS) data as it occurs when there are environmental influences. It gives a logical structure to the complex relationships and avoids redundancy of data entries. With the principles of inheritance and composition, hierarchically structured data models and complex functionalities can be implemented. In addition, methods for calculating stress situations can be integrated into this data model.

Each object class is described by attributes and applicable methods as well as the relationships between object classes by associations. The "workplace" object class can, for example, contain several elements of the "lighting" object class. The data relevant to occupational health and safety are integrated into the data model as attributes of the related objects. The "lamp" object contains, for example, the attributes "lamp type", "luminance", "light intensity" and "light color". The methods for calculating environmental stress are specializations of the object class "environmental stress" and are linked to all object data required for their calculation. This then ensures that a change in the property data leads to an update of the calculated stress situation.

Object-oriented three-dimensional building models are increasingly being used in building planning. Building Information Modeling (BIM; [21]) is used for data storage and, in particular, for data exchange between manufacturers. The so-called Industry Foundation Classes (IFC), which are standardized in ISO 16739-1:2018 [22], are used as an open data standard. This data modeling was originally developed for building construction, later also for civil engineering. It is to be expected that this approach will also be used in the future for modeling objects in work areas.

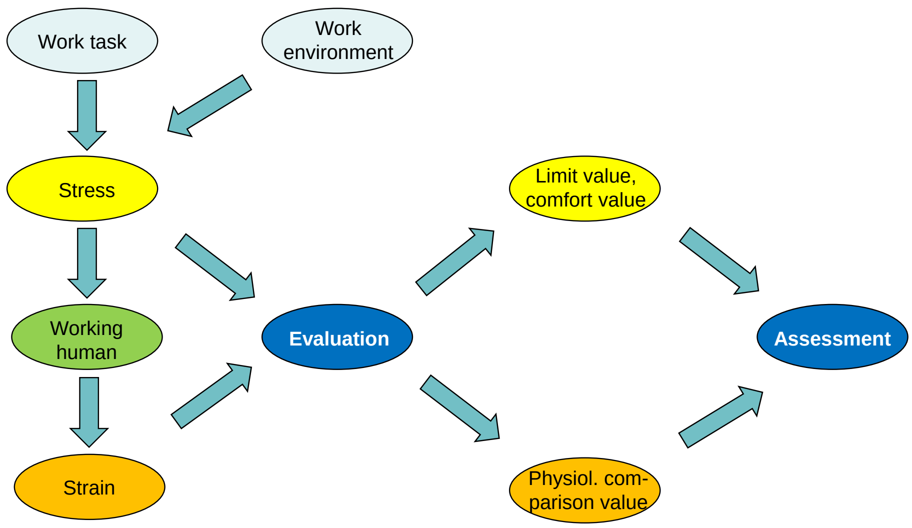

Fig. 4. Ergonomic evaluation and assessment

4.2 IT provision of comparison values for assessment purposes

A special problem is the assessment of a determined stress or strain value (Fig. 4). For this purpose, a comparison value is necessary, which may be available in the form of a limit and occasionally a comfort value. Such values may be found in an ordinance, standard or as a recommendation with regard to a certain type of exposure (see e.g.

comfort values at [23]). For types of strain, physiological comparison values are required in an analogous manner. However, such information is only available in text form, if at all.

In the case of a point in time-related prognosis in the Digital Factory, first the stress value (more rarely a strain value) is usually determined first at a calculation point. A corresponding comparison value is then manually taken from a regulation or another source, which is often achieved today through research on the Internet. An assessment of the determined value is then carried out, taking into account the task at hand. Ultimately, this requires a process performed by personnel.

Accordingly, there is no automized IT provision of the comparison values together with the associated context data. In order to achieve this, existing sources would first have to be processed into a structured knowledge base using IT (Fig. 5). This can be done through text and data mining.

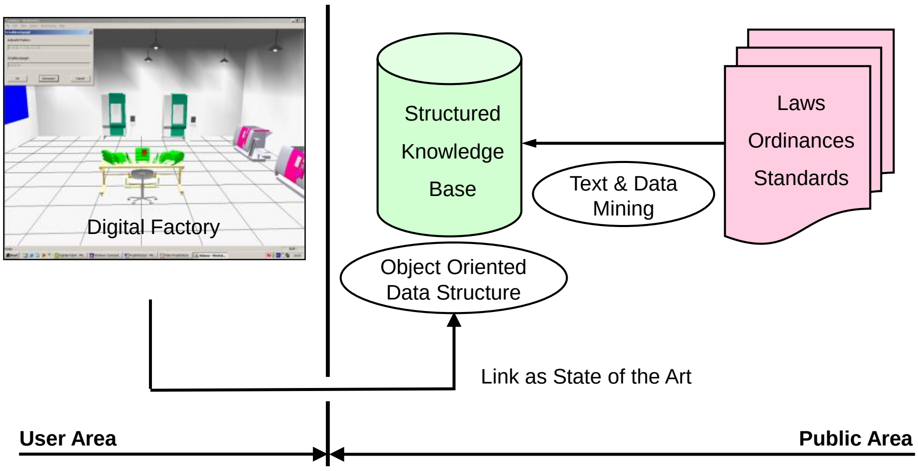

Fig. 5. Development of an occupational health and safety knowledge base

The problem with such a publicly available data is that many sources (e.g. guidelines and standards) are not provided free of charge. If possible at all, the user could take the evaluation data from the Digital Factory to access the public knowledge base in a structured manner and finally derive the assessment algorithmically from it. Such a concept would certainly simplify and improve the use of occupational health and safety regulations considerably. As far as the author is aware, this approach has not yet been pursued through research funding.

5 Further development of environmental forecasts in the Digital Factory

A major number of calculation methods are already available for the prognosis of environmental influences. However, these mainly relate to a certain type of stress; the associated software procedures are (with a few exceptions) not integrated into the Digital Factory. With regard to the resulting strain on the working human, first methods and software procedures are available.

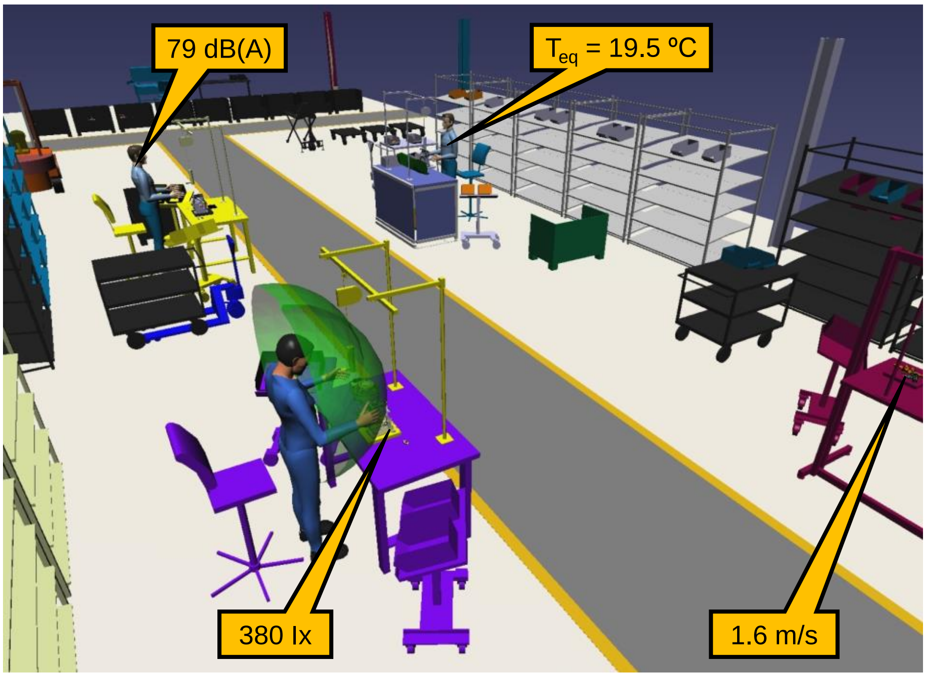

Fig. 6. Vision of forecasting environmental stress in the Digital Factory (Layout Graphics: [27])

In addition, the existing methods usually concern time-related evaluations, and they are often no suitable methods for period-related influences. Only a few examples of successive exposure to a single environmental influence are available. In this regard, reference can be made to the calculation method for evaluating a fluctuating sound pressure level (person-related daily noise exposure level according to the German Noise and Vibrations Occupational Safety and Health Ordinance ([24], § 2 (2)).

Even more there is a lack of evaluation methods and procedures for simultaneously acting environmental influences, and this also for combinations of different types of stress caused by the work task and the work environment. A counterexample is the evaluation of energetic heat work (see e.g. [25], pp. 14). In this respect a lack of integrating methods can be stated. The lexicographical approach developed for this purpose for simultaneously acting influences ([26], p. 42) can only represent a workaround.

All of this shows that there are an important number of open questions about the prognosis of environmental influences in the Digital Factory. Thus, multiple research efforts are required before a comprehensive prognosis can be made (Fig.6).

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