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Lean Ergonomics—an empirical combination of Management Science and Ergonomics

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Abstract

This paper presents Lean Ergonomics (LE) as an employee- and process-related method in a practice-oriented way. Stagnations in economic improvements of the processes, combined with known, high stresses of the basic workers on the shopfloor with ambiguous starting points of ergonomic measures hold broad analysis and optimization potential. This can be shown exploratively based on LE. 12 representative work processes at large reactors in the chemical industry form the study area. Each individual work process receives a Lean Ergonomics data set consisting of time data [standard deviation in min & %], objective ergonomics [EAWS] and subjective ergonomics [Borg, NASA-TLX; both pseudonymized]. Two process-identical production halls are provided, which is why KFzA (short questionnaire for work analysis) is also collected anonymously for additional general analysis of work system design. Consequently resulting in a diverse data structure of quantifiable person-related methods, objective, process-related loads and economically relevant, likewise process-related KPIs.

Keywords Lean Ergonomics · Lean Management · Human Factors Engineering · Operational Excellence

Lean Ergonomics – eine empirische Zusammenführung von Betriebswissenschaft und Ergonomie

Zusammenfassung

In diesem Artikel wird Lean Ergonomics (LE) als mitarbeiter- und prozessbezogene Methode in der Praxis vorgestellt. Stagnationen bei wirtschaftlichen Verbesserungen der Prozesse, verbunden mit bekannter, hoher Belastung der Basisarbeitenden am Shopfloor bei jedoch uneindeutigen Ansatzpunkten ergonomischer Maßnahmen bergen breites Analyse- und Optimierungspotential, das explorativ anhand LE aufgezeigt werden kann. 12 repräsentative Arbeitsprozesse an Großreaktoren bilden den Untersuchungsraum. Jeder einzelne Arbeitsprozess erhält ein Lean Ergonomics Daten Set, das sich aus Zeitdaten [Standardabweichung in min & %], objektiver Ergonomie [EAWS] und subjektiver Beanspruchung [Borg, NASA-TLX; beide pseudonymisiert] zusammensetzt. Es stehen 2 prozessual identische Produktionshallen zur Verfügung. Zur weiteren allgemeineren Analyse des Arbeitssystems wird der Kurzfragebogen zur Arbeitsanalyse (KFzA) pseudonymisiert erhoben. Folglich ergibt sich eine vielfältige Datenstruktur an quantifizierbaren personenbezogenen Methoden, objektiven, prozessbezogenen Belastungsfaktoren und wirtschaftlich relevanten, ebenso prozessbezogenen Key Performance Indicators (KPIs).

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Schlüsselwörter Lean Ergonomics · Lean Management · Ergonomie · Operational Excellence

1 Introduction

Lean management is considered the gold standard in industrial manufacturing (Womack 2007; Dombrowski 2015; Pereira et al. 2023); the original idea was a bottom-up process of introducing and applying Lean, but operational practice shows a lack of real employee involvement (Womack et al. 1990; Anderson-Connolly et al. 2002; dos Santos et al. 2015). Lean management is often applied to simple work, as this work has a high potential for optimization (Dombrowski 2015; Brawner et al. 2022).

Basic work is usually characterized by a high level of physical strain and/or psychomental monotony; specifically, due to the physical dimension, there is an increased risk of musculoskeletal overload over time in the context of demographic change, as workers continue to perform simple tasks into old age (Baur 2013). The burden is further exacerbated by night shifts and demanding work environments, which are the prevailing conditions of many basic workers (Vicente-Herrero et al. 2016) and the sample for this paper. As a result, many basic workers would directly benefit from explicit ergonomic interventions (Hall and Sevindik 2020). Business success is often expected to motivate investment in workplace ergonomics, but the success is sometimes difficult to recognize or only with a significant time lag. This time lag discourages many companies from explicitly pursuing production ergonomics scientifically and independently (Chintada and Umasankar 2022; Jiang and Duffy 2021). Furthermore, demographic change means that not only will age-related overload occur, but also that employees will leave the company prematurely due to physical overload and cannot be adequately replaced. For companies, this is clearly noticeable in the form of economic problems in production processes. In some cases, this leads to targeted investments in ergonomics (Jennex and Durcikova 2009).

According to Dul et al. (2012), ergonomics takes a systems approach at the micro, meso and macro levels. People, methods and processes, define the individual levels but there is a lack of an overarching view that can link several levels in a practical way (Brawner et al. 2022). Against this background, a more holistic approach was sought: In order to achieve a sustainable and targeted relief of the core workforce in the companies, it is assumed that the economic prospects for success motivate the companies to consider ergonomics on the one hand as a success factor in everyday operations and on the other hand as a strategically valuable factor in the form of operational excellence (Brunner et al. 2022). On this basis, this research illustrates how ergonomics can be demonstrated as a business success factor. Lean Ergonomics (LE) is used to implement this research approach.

2 Problem definition and motivation

According to Brunner et al. (2022), Lean Ergonomics LE is understood as the combined consideration and pursuit of economic and ergonomic synergies and goals for a holistic and sustainable increase in productivity while maintaining the health and performance of employees. Conceptually, LE was first defined in 2022 as a scientific sub-discipline that claims to capture synergies between production ergonomics and production management (Brunner et al. 2022). In its policy paper on the future of Ergonomics, the International Ergonomics Association (IEA) pointed out that Human Factors/Ergonomics (HFE) basically aims at two outcomes (Dul et al. 2012): "well-being" and "performance". According to the IEA, it is the latter value, or its perception, that should be elaborated in future research and communicated to stakeholders, particularly the stakeholder group consisting of system designers. Consequently, the present work examines whether LE can live up to this claim of the IEA, by identifying a coherent business and work science potential for improvement.

It is assumed that Management Science and Ergonomics are synergistically related if this relationship can be statistically and causally derived in advance and is relevant to practice. For the company, this means an increase in profitability on two levels. On the one hand, operational successes can be expected if ergonomic investments are proven to be interdependent. On the other hand, ergonomic options can be selected according to economic efficiency without running the risk of making misguided investments in short-term problem areas that are of secondary importance in terms of the overall improvement potential.

For this paper, appropriate methods were analyzed and applied to convert subjective-qualitative "floor talk" and informal communication on the shop floor into quantifiable data. It is assumed that the overarching corporate culture and socio-psychological framework provide relevant insights for the holistic approach of LE. This approach requires frequent presence of LE experts on the shop floor and acceptance by the workforce. Womack et al. (1990) described a similar process for implementing "Lean", namely observing production processes on the shop floor and communicating with employees who are the actual process experts and are expected to contribute their knowledge to improvements.

This paper explores the research question of whether LE can identify relationships between process or productivity metrics and microergonomics (objective and physical or psychological) and link them to macroergonomic work system design with added scientific and practical value.

3 Method

In an LE research collaboration with an industrial partner in the chemical industry, the method framework according to Brunner et al. (2022) is to be implemented in practice. The industrial partner provides access to two production halls (A & B) and two internal LE project managers. In both halls, the same process is used to produce the same end product on large chemical reactors. Production takes place 24 h a day in early, late and night shifts of eight hours each in a five-shift system in combined site and workshop production. The work is basic and involves physical labor under increased environmental stress. Technical and organizational differences between the two halls will be taken into account only if they are relevant to the LE methodology.

The project team consists of stakeholders from occupational medicine, works council, production management, and plant management.

3.1 Quantification of general qualitative suspicions

During initial stages, open discussions in the project team and expert interviews led to the definition of the basic approach and the selection of methods. LE was therefore applied in halls A and B, but was also used to compare the two production halls. According to the assessment of company experts, a difference between the two halls is expected in the area of environmental stress and the socio-demographics of the two workforces, so it was decided to conduct an orienting, pseudonymized employee survey using the KFzA (short questionnaire for work analysis; Prümper et al. 1995). There are 112 employees in hall A and 45 in hall B. In hall A, 85 employees take part in the survey with the KFzA and in hall B 37. The KFzA was supplemented by an age survey of five-year intervals from 20 to 65 years and a self-assessment of health according to the Short Form 12 Health Questionnaire (SF-12) (Wirtz et al. 2018). From the latter, two questions were taken—health status in general and impairment in daily life and work due to pain within four weeks—each to be answered on a five-point scale from 1 (positive expression) to 5 (negative expression).

From circumstantial evidence and informal communication heard before and during the project and the research questions posed, hypotheses could be derived that will be tested using KFzA:

H1 Hall B is generally more dissatisfied.

H2 There are fewer work interruptions in hall A.

Table 1 12 Workprocesses
Tab. 1 12 Arbeitstätigkeiten

Task	Activity	Description
1	Large screw ring	Manual bolting of a large reactor (50–70 bolts of 1–2 kg each by e-screwdriver of 3–5 kg; depending on the installation space, partly manually with torque wrench)
2	Screwing fine threads	Manual screwing (fine motor, highly repetitive, shoulder level) with open-end wrench + sealing of smaller lines (joining and overhead work)
3	Erect safety scaffold	Movement + installation of a reactor enclosure for its clearance (roller bearing, approx. 400 kg, approx. 3 × 2 m)
4	System inputs + feedback	Non-physical task; operating a tablet and collecting and reporting process data (requires high concentration and appropriate software operation)
5	Control crane	Driving of the hall crane
6	Transport of the product	The material produced in the reactor is transported out of the hall by means of electric pallet truck for further processing
7	Removal of used operating fluids	Once the reactor hood is removed, consumables are removed from the bottom plate (extensive personal protective equipment required)
8	Cleaning	Cleaning of the reactor bottom plate
9	Operating industrial vacuum cleaner	
10	New equipment with consumables	The equipment removed in task 7 is cleaned and reattached to the base plate
11	Installation of further consumables	To prepare for production of the new batch of finished products, additional equipment is installed in the open reactor. This installation requires manual dexterity and visual laser-based verification of alignment
12	Insulation	

3.2 Process-related data

For the LE project, 12 representative work activities with experts and employees were selected. The number of $n=12$ was determined by a power analysis (Faul et al. 2007) for the intended statistical analysis using multiple linear regression. The 12 processes comprise a total duration of four to five hours, roughly representing a single shift, i.e. an eight-hour working day. On average, each worker completes the process twice per shift. They can be meaningfully separated from each other, which is necessary to collect process-related and employee-related data within the same section. The individual process durations range from five to 35 min. The 12 activities, broken down and illustrated in Table 1, are basic work and primarily physical in nature. More detailed technical and process information cannot be provided for reasons of confidentiality and is not required for LE here. The general sequence is consistent in its chronology and does not differ significantly from hall to hall.

The basic idea of LE is to generate new knowledge from existing data through meaningful connections. Time data, for example, proved to be useful and meaningful because it is automatically generated for almost every single work process. A time study was conducted for the work processes, for which no times were automatically generated in the system. Other possible KPIs, such as yield, productivity, or work errors are not available in a suitable granularity and cannot be calculated in a scientifically tenable way on the LE samples of the work processes. Specifically, the standard deviation of execution time was calculated for each of the 12 work processes and used as an economic KPI. The standard deviations were calculated based on 20–30 individual execution times.

The standard deviation in minutes per work process and the percentage standard deviation from the specified time thus function as the necessary managerial variables in the method. They also indicate potential for improvement, since high standard deviations can be associated with uncertainties in the overall process that may be conspicuous from an operational, ergonomic, and technical point of view and therefore initially represent neutral potential for improvement without further analysis. Neutral improvement potential is understood here as the lack of information or knowledge about the reasons for a conspicuous or unexpectedly high standard deviation. This can be of an operational nature, such as blocked paths that need to be cleared to allow material flow, or it can be related to resources that have not been cleared according to the 5S system. For example, a conspicuously high standard deviation due to ergonomic reasons could be understood as reduced lighting that has to be supplemented by additional mobile lighting for non-routine activities, i.e. standard deviations that are conspicuously increased mainly due to purely ergonomic influences. The same applies to technical influences, such as a material defect in tools or products.

The processes with the highest standard deviation in terms of average execution time should be prioritized for analysis and improvement and serve as the point of attack with the greatest leverage (Mapes et al. 2000; Karsh et al. 2006; Dul and Neumann 2005). Since longer activities may justify higher absolute standard deviations, the standard deviation was normalized to the average processing time. Consequently, there is an absolute [min] and a normalized [%] standard deviation per activity. Another reason for choosing the standard deviation is that it counteracts the time-dependency of the EAWS (Ergonomic Assessment Worksheet) and thus allows a more objective and valid correlation to be calculated. It can be assumed that the EAWS value would also increase as the mean values of the execution times increase, which would only lead to a spurious correlation. If only the mean values of the execution times were included, the LE team would expect dependencies between the EAWS and the execution times that could be verified with the literature and would be consistent with the logic of the EAWS (Chander and Cavatorta 2017; Schaub et al. 2013).

The complementary ergonomic, process-related variable is therefore EAWS (Schaub et al. 2013). In the same way as the standard deviation of the processing time is available for each individual work process, the ergonomics is evaluated on the basis of EAWS for each individual work step. The evaluation is supported by a walk-through with the expert team and the TiCon software (MTM). This results in 12 standard deviations (absolute and normalized) of the work process times and 12 EAWS ratings per hall.

3.3 Employee-related data

Regarding the activity of the employees in LE, the stress-strain concept (Rohmert 1984) is of great importance. Stress is measured for each part of the activity in relation to the employee (pseudonymized) using the Borg scale (Borg 1985) and the NASA-TLX (N-TLX) (Hart and Staveland 1988; NASA Task Load Index). A prior weighting of the dimensions of the N-TLX was omitted for economic reasons. Due to the number of processes ($n=12$), the two halls (A & B) and a number of employees of $AB_{total}=157$, a limitation of the employee-based Borg and N-TLX surveys was made, because the basic feasibility and cost-effectiveness of the LE method is necessary to enable subsequent application.

A five-shift system is used per hall for which an even distribution of Borg and N-TLX surveys across all shifts was considered the only prerequisite. After literature reviews and expert discussions, a range of 20–30 Borg and N-TLX surveys per work process was targeted (Saha et al.

2017; Dadashi et al. 2022) and achieved. For hall A, 29 employees (six in each of four shifts and five in each of one shift) were interviewed about stress using Borg and N-TLX immediately after the completion of each work process, and for hall B, 22 employees (five in each of two shifts and four in each of three shifts) were interviewed. Informed consent was obtained before the interview and a pseudonym code for anonymity was written on the paper. Thus, the code allows the employee- and process-related linkage of Borg, N-TLX, and the non-activity, but employee-related KFzA with age class in five-year segments and two SF-12 questions, as well as the place of employment (A or B).

3.4 Methodological consolidation

The clear definition of 12 work processes and the division of the LE data sample into employee-related and process-related data made it possible to present the process in a transparent way to the employees and the interdisciplinary project team. The term "Lean Ergonomics Data Sample" became familiar, and its naming and use meant that the entire content of methods and KPIs per work process did not have to be named.

The KFzA does not allow a process reference, but provides an overall picture through its subdivision into factors, which on the one hand serves the hall comparison and on the other hand allows a connection to the Borg and N-TLX values via the pseudonymization code. The KFzA factors can therefore be used to derive basic requirements which, when correlated, show an effect on the physical and/or psycho-mental stress perception of the employee during the performance of one of the 12 activities.

The process- and employee-related Borg and N-TLX values represent stress by employee and by work process.

The EAWS and time data are exclusively related to the work process.

A wide range of results with different statistical methods emerged as a result of this explorative research collaboration. New insights into the application of LE emerged during the project, which were generated by the choice of methods and an agile, inclusive project management on the part of the company and the university. At the time of writing, detailed and methodologically more sophisticated extracts are still being evaluated, so this paper will focus on the more universal and macroscopic elaboration.

Based on paragraphs 3.2, 3.3, and the research question, hypothesis H3 is stated:

H3 Standard deviations (absolute or relative) are positively correlated with EAWS and Borg or NASA-TLX values.

4 Results

4.1 Quantification of general suspicions

According to Haiden et al. (2002), the polarity of the KFzA was rectified for all factors, which facilitates interpretation. This applies to the factors qualitative workload, quantitative workload, interruption of work and environmental load. Thus, the rating of an item does not imply an expression of the corresponding misload "but illustrates, in the case of a high expression, the non-existence of the corresponding stress factor" (Haiden et al. 2002).

The thresholds to the positive and negative are 3.5 and 2.5, respectively, and are marked in Fig. 1 (Prümper and Richenhagen 2011). As marked in the figure (*p-value < 0.05; **< 0.01; ***< 0.001; applies to entire paper), the two halls differ significantly in the factors *versatility, quantitative and qualitative workload, environmental load, social backing, cooperation, information and participation,* and *operational benefits*.

Of the 112 employees in hall A, we received 83 completed KFzA questionnaires and of the 45 employees in hall B, we received 35 completed questionnaires. Four questionnaires were excluded in their entirety, which were consistently rated only maximally positive, or maximally negative, or incomplete.

Averaging 48 years of age, participants from hall B were four years older than hall A participants, which is consistent with the demographics of the halls, including non-participants.

Hall A reports health score at 2.44 and hall B at 3.10. Age correlates significantly ($p < 0.05$) with health in both halls (A: $r = 0.4$; B: $r = 0.5$). Older employees consistently rate themselves as less healthy.

Using structural equation modeling (SEM), health and age are analyzed. Instead of two individual regressions (Health_1 & Health_2), the SEM calculates a common latent factor from the two individual health values. Table 2 shows the result of a structural equation modeling to show the effect of the collected variable *age* on the latent factor *health*, which is formed within the measurement model (under "Latent variables" in Table 2) by the two variables *Health_1* and *Health_2* collected in the health questionnaire. The structural model ("Regression" in Table 2) shows the significant linear correlation of the variable age on the factor health with a positive coefficient (0.052). A higher value represents "worse" health as evaluated by the question (5-point Likert scale).

No age dependence was found in the KFzA. However, in a correlation analysis averaged over both halls, health positively correlates moderately to highly with the KFzA factors versatility, holism, social backing, information & participation, and operational benefits. Hence, we conclude that health positively influences the factors or existing factors positively influence health.

For further evaluation and similar studies, SEM is recommended in order to be able to consider special features in companies or levels of given factors or items separately.

4.2 Process and employee reference

Multiple linear regression (MLR) is used to assess the degree of expression of the criterion standard deviation of process time [min and %] on the basis of the predictors EAWS, Borg and N-TLX. The N-TLX is included as the mean of its six dimensions per employee and per activity. The Borg score stands alone and is included as a mean per activity. Thus, 12 EAWS values, 12 N-TLX means, and 12 Borg means enter the MLR per hall as predictors that predict the dependent variable standard deviation (SD). Separate MLRs are performed for predicting absolute SD in minutes and for predicting normalized SD as relative from the standard time in percent. Each of these models are evaluated separately for hall A and hall B, resulting in four MLRs in total. The prerequisites of the MLRs are defined according to Casson and Farmer (2014). Our review found no significant violations of assumptions of MLRs that would restrain the model interpretation. The significance level was chosen at 0.05.

The model MLR A1 for hall A includes the predictors N-TLX, Borg and EAWS and the dependent variable absolute SD (abs. SD). MLR A1 is significant with $R^2=0.692$ (F-value = 5.997 and p-value = 0.019). The coefficients and their p-values are presented in Table 3.

The MLR A2 model includes the predictors N-TLX, Borg, and EAWS and the criterion variable percent standard deviation (% SD). MLR A2 is not significant with $R^2=0.305$ (F-value = 1.168 and p-value = 0.380). The coefficients and their p-values are shown in Table 4.

The MLR B1 model includes the predictors N-TLX, Borg and EAWS and the criterion variable absolute standard deviation. MLR B1 is not significant with $R^2=0.518$ (F-value = 2.870 and p-value = 0.104). The coefficients and their p-values are shown in Table 5.

The MLR B2 model includes the predictors N-TLX, Borg, and EAWS and the criterion variable percent standard deviation (% SD). MLR B2 is significant with $R^2=0.921$ (F-value = 31.282 and p-value = 0.001). The coefficients and their p-values are shown in Table 6.

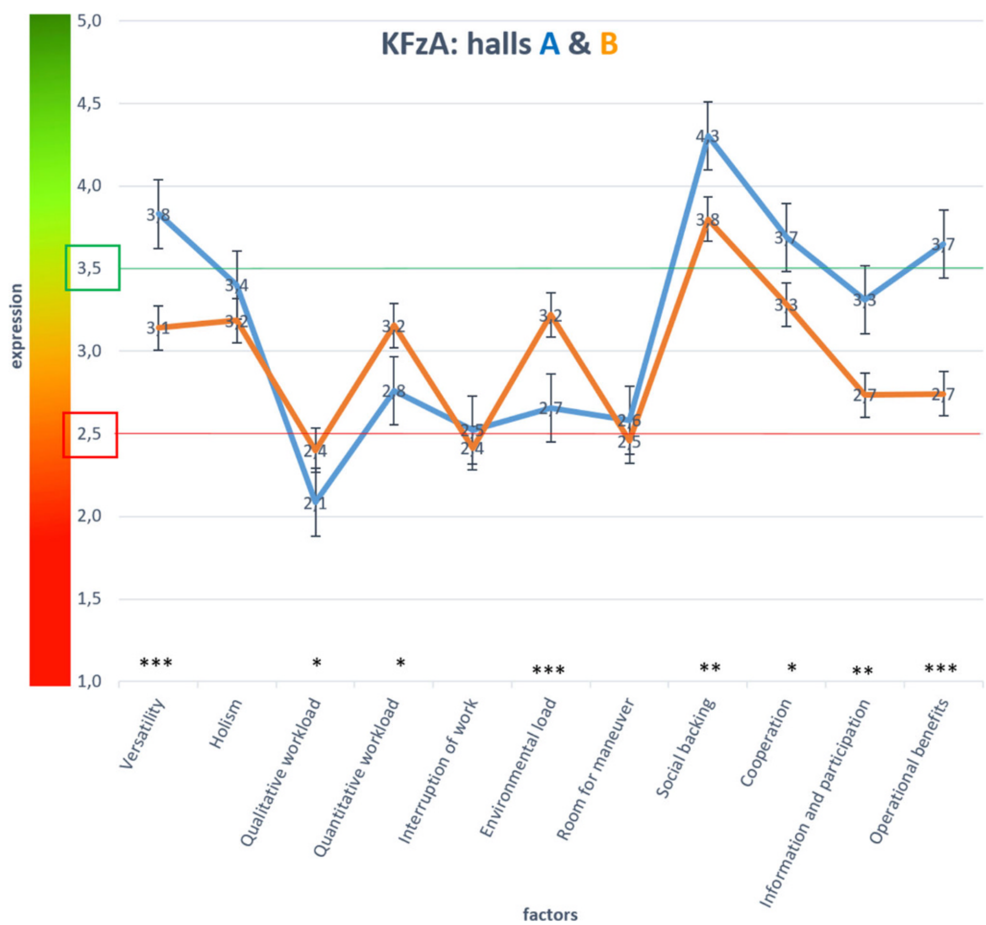

Fig. 1 KFzA differentiated by hall
Abb. 1 KFzA nach Halle

4.3 Exploratory investigation of the stress profile

The results of the N-TLX is evaluated by dimension and shown in Fig. 2 on a process-by-process basis for both halls.

The stress profile does not differ significantly between the halls. Task 12 is conspicuous in that it differs between the halls, particularly in the "frustration" item, which was clarified in the follow-up analysis on the basis of technical differences in the installation of the insulation cassettes. The stress profile is generally considered to be reasonable and ergonomic, since "mental demands" and "physical demands" in particular are in an antagonistic relationship. Increased values occur especially when "mental demand" and "physical demand" collide (task 11). In order to maintain this balance, it is recommended that the chronological order of the sequence be maintained or systematically rotated based on this analysis. It can be concluded from Fig. 2 that systematic job rotation can be expected to produce a diverse stress profile.

5 Discussion

5.1 General work system design

The KFzA enabled satisfactory and informative results for university and company. The comparison of two production halls over the factors was found to be well understood and reasonable. The hypotheses set up at the beginning can be worked on as follows.

H1 is assumed on the basis of the KFzA factors. Hall B differs significantly from hall A in the factors *versatility, information and participation,* and *operational benefits*. The last two factors are unexpected, since both halls are under the same management and explicit care is taken to provide identical information and communication. *Operational benefits* also does not differ in real terms, as this is determined by the group. This assessment is seen as an indicator of increased dissatisfaction, since hall B reports lower *quantitative workload* and *environmental stress* than hall A, but hall A nevertheless reports significantly higher *versatility, information and participation*, and *operational benefits,* although objectively the same conditions apply. The team of authors suspects that this discrepancy and conflict situation is an expression of a general dissatisfaction in hall B, which cannot be elaborated here, but would confirm suspicions of the managers.

H2 is rejected. Item *interruption of work* for hall A with 2.5 and for hall B with 2.4 does not differ in favor of hall A to the extent that assumptions from the expert panel suggested. In hall A, lean production is applied and trained more intensively due to the larger structural dimensions, for example to keep material flows running; however, the *work interruption* factor does not differ significantly between the halls.

The factors *qualitative workload, interruption of work* and *room for maneuver* lie in the critical range and are identified as potential for improvement. The critical range was defined as less than or equal to 2.5 per item of the KfZA (see above; Haiden et al. 2002; cf. Prümper and Richenhagen 2011).

The factor *room for maneuver* of the KFzA does not differ significantly between the halls, but is on the threshold of negative in both, which means that this factor is critical or not pronounced enough in the work. The factor correlates with the dimensions of *time pressure* and *frustration* of the N-TLX in the evaluation of the individual process. Employees who rate *room for maneuver* in the KFzA as low also report significantly lower *temporal demand* and *frustration* scores on the N-TLX in the 12 specific work activities. A positively pronounced and thus more than satisfactorily existing *room for maneuver* in the overall work system evaluation based on KFzA thus leads to more tolerance at the individual activity level in the factors *frustration* and *time demand* (both N-TLX). A kind of buffer effect occurs, which should be monitored operationally and investigated further scientifically.

The lack of age dependency of the KFzA can be seen as positive, since age dependency would be a fact that cannot be changed in the short or medium term. Also, from a demographic point of view, a long-term change would probably require technical or organizational support. The design of the work system seems to be age- and ageing appropriate.

Table 2 Structural equation model to survey the relationship between health and employee age
Tab. 2 Strukturgleichungsmodell zur Bestimmung des Zusammenhangs zwischen Gesundheit und Alter der Beschäftigten

Latent variables			
–	**Estimate**	**z-value**	***p***
Health_1	1.000	–	–
Health_2	1.237	8.128	< 0.0001
Regression			
Health ~ Age	0.052	6.466	< 0.0001

Table 3 MLR A1
Tab. 3 MLR A1

Coefficients	Unstandardized	t	*p*
N-TLX	–0.090	–0.202	0.845
Borg	–2.127	–3.287	0.011
EAWS	0.355	4.214	0.003

Table 4 MLR A2
Tab. 4 MLR A2

Coefficients	Unstandardized	t	*p*
N-TLX	–0.080	–0.023	0.982
Borg	–8.742	–1.698	0.128
EAWS	1.235	1.843	0.103

Table 5 MLR B1
Tab. 5 MLR B1

Coefficients	Unstandardized	t	*p*
N-TLX	0.054	0.072	0.945
Borg	0.136	0.164	0.874
EAWS	0.211	1.493	0.174

5.2 MLR models

To be able to generate quick and comprehensible models or statements, MLR was used as the preferred method. The four models form the largest possible macroscopic framework of the Lean Ergonomics project and derive indications for connections between business science and ergonomics in a practice-oriented manner.

MLR A1 shows high elucidation of the absolute standard deviation via fitted predictors. The unstandardized coefficients cannot be fully explained empirically. In particular, Borg becomes conspicuous with –2.127, as with an increase of the Borg rating, i.e. an increased physical demand, the absolute standard deviation of the execution times would be reduced by 2.127 min. One explanation may be that with higher physical demands, a "faster processing" of current and upcoming tasks is sought (Bosch et al. 2011; Straker and Mathiassen 2009). A one-point increase in EAWS score leads to 0.355 min longer standard deviation of execution time. A dependency of EAWS and absolute standard deviation was already suspected in advance if the assumption holds that longer work activities also tend to cause higher values of the standard deviation, which is why it was decided to consider the percentage standard deviation at the target time of the work activity in an additional model.

Since longer execution times of the activities can also be accompanied by longer standard deviation, a model of percentage standard deviation from the execution time was generated for both halls. For hall A, there was no significance for model A2.

Table 6 MLR B2
Tab. 6 MLR B2

Coefficients	Unstandardized	t	*p*
N-TLX	6.460	0.218	0.085
Borg	4.362	0.229	0.261
EAWS	2.720	0.788	0.002

Model B1 would provide good clarification with $R^2 = 0.518$, but is not adopted due to a lack of statistical significance. This means that the present absolute standard deviations have no relationship to physical and psycho-mental stress and the objective workplace ergonomics.

Model B2 is significant at high reconnaissance ($R^2 = 0.921$). The percentage standard deviation is closely related to objective ergonomics via EAWS, physical stress via Borg and psycho-mental stress via N-TLX. Further investigation of the collected data must be evaluated at the individual process level, as it can be assumed that the stress network is heterogeneous. This would correspond to a microscopic LE approach. The unstandardized coefficients are in line with observations from empirical studies and with the assessment of company experts. N-TLX is not significant at $p = 0.085$, but practical relevance is assumed. Under this assumption, increased psycho-mental stresses during work activities lead to higher percent standard deviation, which is analogous to a whole work shift (Macdonald and Bendak 2000). At the time of publication, we cannot provide a data-based explanation of why the correlations in the A-model series are not apparent. One approach could be a mediating effect of the dissatisfaction described above for hall B, which is evident here in the N-TLX. A one-point increase in the N-TLX rating results in a 6.46 percentage point increase in the standard deviation. EAWS behaves analogously with an increase of 2.72 percentage points. This suggests that the physical stress based on Borg, is already covered by EAWS and N-TLX, since Borg did not become significant. The physical dimension is already included in N-TLX, which means that Borg does not bring any new clarification to the model (Chatterjee et al. 2022). This is also confirmed by the high correlation ($r = 0.764$) between the variables "Borg" and "N-TLX-physical" (see Table 7). A mere assessment using EAWS, without collecting N-TLX, could not have provided this finding. Future experimental design will be planned without Borg.

The non-significant N-TLX coefficients in all four models can be explained by the fact that the models were calculated over all processes. As can be seen in Table 1 and Fig. 2, some of the processes serve extremely different psycho-mental as well as work-physiological requirements, competencies, and performance prerequisites. For example, while processes 4 and 5 suggest a lower physical demand based on the description, steps 1 and 12 are particularly physical in nature. The influence of the individual items of the N-TLX is likely to vary in these aforementioned processes. Future evaluations should take this into account and split the N-TLX into its items and aggregate processes according to their profiles. The correlation matrix in Table 7 suggests that N-TLX items could be aggregated as well. Furthermore, based on the high correlation of *Borg* and *N-TLX-physical* and for economic reasons, it is recom-

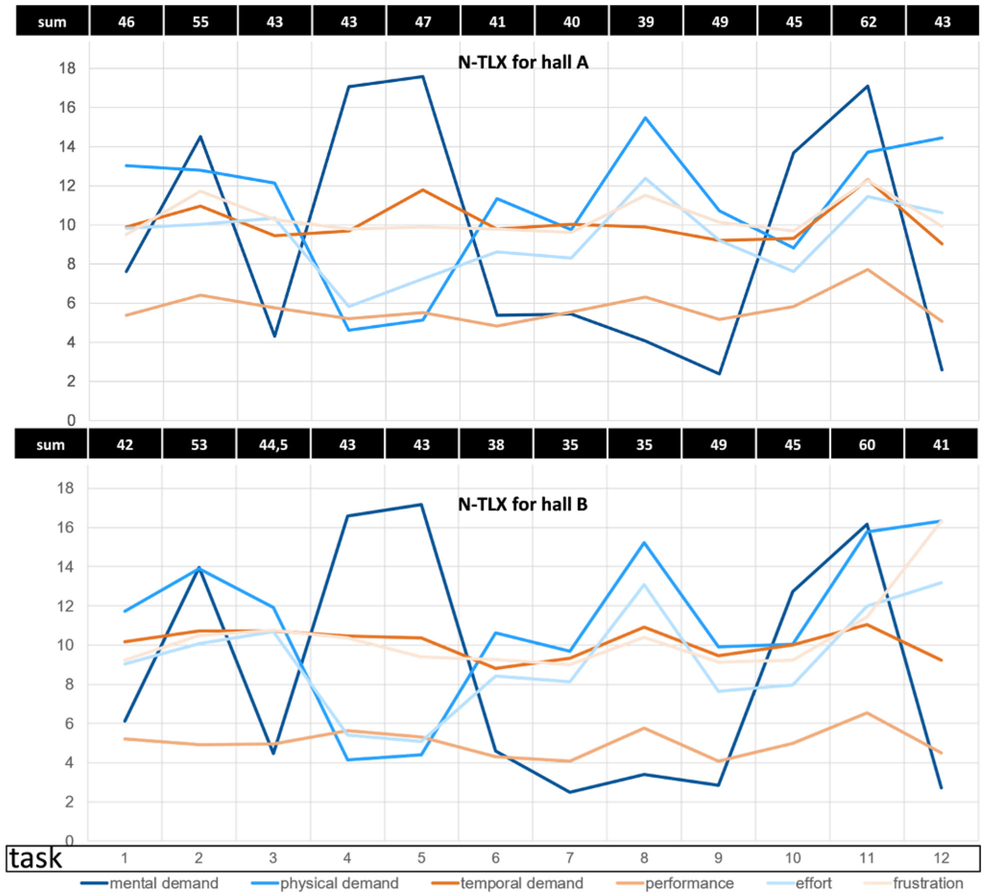

Fig. 2 N-TLX differentiated by hall

Abb. 2 N-TLX aufgeschlüsselt nach Halle

mended to abandon Borg for similar studies as there is no clear added value.

Hypothesis H3 (stated in Sect. 3.4) that higher standard deviations (absolute or relative) are associated with higher EAWS and Borg or NASA TLX values is rejected for MLR A2 and MLR B1 and accepted for MLR A1 and MLR B2.

Overall, the relationship between ergonomic and business KPIs becomes apparent and the method proves to be useful for identifying common potential.

5.3 Methodological consolidation

The approach of enriching process-related ergonomics with process-related economic KPIs and general personal information on demographics and health and evaluating it in an explorative manner proved to be of value to the research. Indications for dependencies of objective ergonomics, standard deviations of execution times and subjective stresses could be shown. The research question of whether LE can be used to identify correlations between process and productivity indicators and (physical) ergonomics can be answered in the affirmative. Based on the combination of "performance" and "well-being" demanded by the IEA, LE offers a practicable methodology that is comprehensible and can be applied flexibly.

In a matrix structure, the diverse variables can be presented to different participants and interested parties in a respectable manner and accordingly used for dedicated analyses. For example, it was found that well-developed *room for maneuver* (KFzA) acts as a kind of buffer for *frustration* and *time demand* (both N-TLX) at the activity level.

The derivation of a stress profile via N-TLX shows how closely Ergonomics and Operations Management/Management Science are linked. The stress profile can enable structured personnel planning, targeted training (task force) and a basis for future planning. From a purely managerial perspective, job rotation is nothing new; however, using the LE approach, this can be backed up with employee stress profiles, which strengthens employee health and corporate success in equal measure. The company did not actively plan the fundamentally different stress profile. The favorable sequence of stresses occurred by chance, which could not have been expected. This means that for similar investigations and new planning, a survey of the stress profile is relevant, since a more ergonomic and sustainable production pallet is possible based on it. In the present case, this also means that the ergonomic stress

Table 7 Spearman correlation of the variables Borg and the factors of the NASA-TLX
Tab. 7 Spearman Korrelation von Borg und NASA-TLX Faktoren

	Borg	N-TLX-physical	N-TLX-temporal	N-TLX-performance	N-TLX-mental	N-TLX-effort	N-TLX-frustration
Borg	1	0.764***	0.027	0.061	0.428***	0.568***	0.144***
N-TLX-physical	0.764***	1	0.003	0.076	0.339***	0.576***	0.078
N-TLX-temporal	0.027	0.003	1	0.041	0.247***	–0.074	0.530***
N-TLX-performance	0.061	0.076	0.041	1	0.168***	0.217***	0.009
N-TLX-mental	0.428***	–0.339***	0.247***	0.168***	1	0.243***	0.064
N-TLX-effort	0.568***	0.576***	–0.074	0.217***	0.243***	1	–0.018
N-TLX-frustration	0.144***	0.078	0.530***	0.009	0.064	–0.018	1

sequence is only given if the chronological sequence is followed. If employees are working on tasks with similar stress profiles before and after the break, it can be assumed that the increased stress will accumulate and possibly "carry over" during the shift. In the future, cluster analysis could be used to determine whether activities can be grouped according to their profile, which would allow for more targeted production and employee scheduling from a management perspective. Based on the same hypothesis, it is possible that the operational variable could also be transferred. This would imply that upstream ergonomics have an unwanted influence on downstream work. Both possibilities should be investigated further.

The microscopic LE sample is composed of a work activity for which an EAWS assessment is available, the subjective values of Borg and N-TLX, and the standard deviation. The latter can be understood as a KPI of the system or technique and can be optionally replaced or supplemented by alternatives. The result is a practical and flexible methodology that combines anthropocentric and technocentric engineering, as recommended by Dworschak and Zaiser (2014). According to the preliminary study by Tropschuh et al. (2022) and the theoretical derivation by Brunner et al. (2022), anthropocentric and technocentric engineering are brought closer together. The method remains at the foremen level in the company. The goal is to enrich Operations Management and Ergonomics synergistically, which in turn leads to economic efficiency and makes the method even more attractive in industry.

5.4 Limitations

The 12 included tasks vary in length and it is not clear how the loads are represented as a function of the length of the work processes found. Due to the production principle, a temporal standardization (cycles of the same length) was not possible and would not make sense, as this would distort the real conditions in the shop floor. The addition of another business KPI to the standard deviation was considered but could not be realized due to the data situation, which is seen as potential and learning on the part of the industrial partner. Due to the combined construction site and workshop production, the activities differ not only in their duration, but also in their physical and psycho-mental stress requirements, so it was decided not to change the known and process-related sequence. In addition, the strict physical-chemical restrictions such as installation spaces, supply and discharge lines, dimensioning, and changing personal protective equipment lead to increased complexity compared to cycle-based assembly, which allows clear LE patterns (Tropschuh et al. 2022). Due to predefined process sequences, there are activities in the experiment, such as crane operation, for which no operational KPI apart from time data could be tailored or collected. Quantities such as output per shift or similar are available but can only be reliably calculated for a few activities.

The industrial partner was advised to explore the possibility of equipment-based data collection (Bae et al. 2019; Fischer et al. 2021). This would not run the risk of collecting performance-related data, but could still enrich the data landscape in a targeted way, which would also support the successful transition to Industry 4.0.

EAWS was carried out by the expert team and additionally elaborated with TiCon (MTM software house). The 12 activities only fill about 80–90% of an average working day. In order to obtain valid results for the EAWS, further proportions of realistic and comparable activities were defined, and a working day was constructed which company and university representatives judged as realistic.

Randomly selected employees can deliberately falsify surveys using Borg and N-TLX. The project managers were aware of this risk and all data was considered credible and realistic. In the KFzA, four questionnaires were excluded in their entirety because they were consistently rated only maximally positive, maximally negative, or incomplete.

5.5 Experience from practical application

Limitations in the project also meant that clear recommendations for action could be given to the industry partner on this basis. For example, the data collection and data situation proved to be too wide-grained, which must be addressed as quickly as possible during the desired transition to Industry 4.0. One approach is the introduction of equipment-based data collection. This allows for finer granularity of measurement and thus process improvements, and has the potential to shift control and confirmation activities away from the worker to the equipment, thus optimizing psycho-mental stress. It is conceivable that this could lead to an expansion of the scope of action, which was conspicuous in the N-TLX in connection with the factors of frustration and time requirements. This finding fits seamlessly with the classic Lean measures of job enrichment, job rotation, and job enlargement, and illustrates the compatibility of Ergonomics and Operations Management at this level.

Working with representatives from different levels and departments automatically resulted in a continuous evaluation of LE and interdisciplinary communication about Ergonomics. This corresponds to one of the strategies of the excellence plan formulated by Dul et al. (2012), which HFE (Human Factors/Ergonomics) will pursue in the future in the form of the IEA. Overall, a high level of interest was noted, even in departments far removed from Ergonomics, which can be an advantage of LE. On the shop floor there was also resistance and critical questions, but the method must be able to deal with such concerns. This was often achieved by clarifying the employee's focus by observing and questioning them in their activities.

The universality of the method and its integral requirement to accompany processes and employees opens up new perspectives that generate clear added value in the context of Industry 4.0 and Operational Excellence. The input of automatically generated scientific and technical data, complemented by, for example, daily stress feedback from employees on smartwatches or tablets, could transform LE into software. Such an enriched data set also makes LE relevant to Operations Management, enabling the preparation and support of strategic decisions. The original description of LE (Brunner et al. 2022) is aimed at production work, where basic tasks have a high priority. A further development for administrative LE to show waste and its relationship to load and stress in indirect production areas is a reasonable consideration.

From the results presented above, some differences could not be explained, suggesting that other influencing factors remain undiscovered. One important factor, which is particularly relevant in the context of (Lean) Management and could not be investigated in this study, is leadership. Above a certain level, of course, both halls are under the same leadership and management, but this level automatically goes hand in hand with a certain distance from the employees in terms of content and organization. The last hall specific level is that of the foreman, which means that LE should be located there.

6 Conclusions

In this paper on the practical application of LE, the basic methodological structure of LE from Brunner et al. (2022) was applied in practice and illustrated with concrete results. Overall, the four models of LE show evidence that ergonomics contributes to the stability and duration of work processes. In addition to this process reference, a holistic impression of the work system design by means of KFzA in the work system is produced by a pseudonymization code applied to N-TLX and Borg at the process level, which complements the quantitative approach in LE. Considering the limitations, it is recommended to keep the experimental design for work activities of the same or similar length. In addition to the necessary further elaboration of the content of LE, a system-theoretical and management-oriented view is necessary to clarify questions of operational responsibilities and embedding in a possible structural and process organization.

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