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Lean Ergonomics—are relevant synergies of digital human models and digital twins defining a new emerging subdiscipline?

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Abstract

Manufacturing companies are facing new kinds of challenges. High cost and time pressure as well as the variety of product variants have added to supply chain issues due to unvorseeable major political, societal or natural events. This requires more than ever load optimization for all agents of a socio-technical system, to enable them to operate competitively and sustainably. Digital tools offer the possibility to proactively plan and analyze diverse processes. Recent developments indicat that human-centric (DHM) and process-centric (DT) tools are diverging rather than converging. The objective of this position paper is to analyze whether the vacuum created by human-centric and process-centric tools can be filled by the new subdiscipline of Lean Ergonomics (LE). LE is defined by synergies of production ergonomics and production management.

Practical Relevance: By elaborating a methodological separation of Digital Twin (DT) and Digital Human Modeling (DHM), science and the economy shall be motivated to close the gap. Lean Ergonomics as an intersection of human-centered and system-centered engineering has the potential to incentivize companies to move towards sustainable ergonomics, as the company will directly benefit from this. Ergonomic methods and Key Performance Indicators (KPIs) at the micro level of the individual workstation enable the ergonomic and psychophysiological assessment of the human being in digital and analogue form. This is mirrored on production-organizational methods and KPIs and thereby tested for dependencies and interactions, which enable a holistic optimization of the socio-technical system.

Keywords Lean Ergonomics · Digital Twin · Digital Human Modeling · Theory of Science · Human-Centered Engineering

Lean Ergonomics – Definieren relevante Synergien aus digitalen Menschmodellen und digitalen Zwillingen eine neu entstehende Subdisziplin?

Zusammenfassung

Produzierende Unternehmen stehen vor neuartigen Herausforderungen. Hoher Kosten- und Zeitdruck sowie die Vielfalt der Produktvarianten führen zu Problemen in den Lieferketten. Dies wird intensiviert durch unvorhersehbare politische, gesellschaftliche oder natürliche Großereignisse. Eine Belastungsoptimierung für alle Akteure eines sozio-technischen Systems ist somit unabdingbar, um wettbewerbsfähig und nachhaltig agieren zu können. Digitale Tools bieten die Möglichkeit, diverse Prozesse proaktiv zu planen und zu analysieren. Aktuelle Entwicklungen zeigen jedoch, dass sich menschorientierte (DHM) und prozess- bzw. systemorientierte (DT) Methoden eher separieren statt verbinden. Das Ziel dieses Positionspapiers ist es, zu analysieren, ob das Vakuum, das durch menschzentrierte und prozesszentrierte Vorgehensweisen entstanden ist, durch die neue Subdisziplin „Lean Ergonomics" (LE) gefüllt werden kann. LE definiert sich durch Synergien von Produktionsergonomie und Produktionsmanagement.

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Praktische Relevanz: Durch die Ausarbeitung einer methodischen Trennung von Digital Twin (DT) und Digital Human Modeling (DHM) sollen Wissenschaft und Wirtschaft motiviert werden, die Lücke zu schließen. Lean Ergonomics als Schnittpunkt von menschzentrierten und systemzentrierten Engineering hat das Potenzial, Anreize für Unternehmen zu schaffen, sich in Richtung nachhaltiger Ergonomie zu bewegen, da Unternehmen direkt davon profitieren. Ergonomische Methoden und Kennzahlen (KPIs) auf der Mikroebene des Einzelarbeitsplatzes ermöglichen die ergonomische und psychophysiologische Beurteilung des Menschen in digitaler und analoger Form. Dies wird auf produktionsorganisatorische Methoden und KPIs gespiegelt und dabei auf Abhängigkeiten und Wechselwirkungen geprüft, die eine ganzheitliche Optimierung des sozio-technischen Systems ermöglichen.

Schlüsselwörter Lean Ergonomics · Digitaler Zwilling · Digitale Menschmodelle · Wissenschaftstheorie · Menschzentriertes Engineering

1 Introduction

Work in general and the manufacturing industry in particular are facing numerous challenges. The already longer existing high time and cost pressure is intensified by the increasing number of product variants and declining product life cycles (Prasch 2010; Schenk 2015). This problem is amplified by the demographic change and reduced performance and resilience of aging workforces, which in combination with the shortage of skilled workers is causing major problems for Germany as a production location (Baur 2013; Burstedde et al. 2021). Furthermore, new technologies are entering the factories and have to be implemented adequately to avoid undesired side effects (Sträter and Bengler 2019). The Covid pandemic revealed further limits to the production system, starting with massive disruptions to supply chains, extreme fluctuations in demand, and personnel-related production stoppages (Raehlmann 2020). These challenges are exacerbated by the war in Ukraine, which disturbs the structures of large value streams in the world, but especially Europe. In addition to the logistical problems, pre-assembly tasks must be brought geographically closer to the original equipment manufacturers (OEMs) in a flexible and agile manner in order to maintain the production system (Ozili 2022). Besides these volatile, uncertain, complex and ambiguous (VUCA) developments, unexpected business challenges occur and interact. The call for sustainability in factories is getting louder as energy prices have risen massively, particularly in Germany compared to other industrialized countries such as the US and Canada (Ari et al. 2022). For all these reasons, manufacturing companies need to re-evaluate efficiency in every area from these perspectives and therefore also consider creative and explorative approaches (Grömling 2022; Boston 2022; Celi et al. 2022). High and widely distributed dependencies within and between companies currently are leading to diverse problems that can largely be explained by globalization and intensified lean processes (Raehlmann 2020). It can be assumed that production companies will have to bundle more competence in-house again in order to be prepared for new VUCA developments (Mayer and Wilke 2022). This also means critically examining the production system, which in the 21st century will primarily be lean production (Janoski and Lepadatu 2021).

The diverse networking of systems fueled the individual VUCA hotspots resulting in large-scale and far-reaching problems, as was evident from the negative example of the Covid pandemic and the disruption of supply chains. In this context, however, the adequate networking of systems in analogue and digital can also be an opportunity for new synergies in the production environment.

The goal of combined “anthropo-centric” and “techno-centric” systems (Dworschak and Zaiser 2014) is systemic planning of detailed work situations and their lean embedding in higher-level operational contexts in which individual and contextual factors are taken into account in a digital model. This would optimize sustainability and efficiency in equal measure and make the factory system more resilient and agile (Papacharalampopoulos et al. 2021; Trauer et al. 2021).

In planning and proactive ergonomics, it is necessary to be able to evaluate work situations and work systems coherently in order to increase speed and flexibility with higher prediction quality and enable consideration of increasing planning parameters and interactions as well as interferences between workstations and work processes. This paper will discuss how to explain the separation of macroscopic processes and analyses of production management and microscopic processes and analyses of workstation design and why the separation leads to multiple losses of potential. Furthermore, the vacuum between production management and production ergonomics is analyzed and closed in terms of scientific theory with the hypothesized proposal of a new subdiscipline. Here, the Digital Twin (DT) and Digital Human Modeling (DHM) serve as central approaches and practical application of the theoretical derivation.

2 The factory as a socio-technical system and its subdisciplines

2.1 Historical classification of Lean Ergonomics

The interface and the gap addressed in this article is between production ergonomics and the production system. For this derivation, lean production is assumed to be the fundamental production and management concept. In this paper, the term "Lean" is used for methods and KPIs of lean production, lean management and the philosophy of the Toyota Production System, as they are synonymous (Dombrowski and Mielke 2015).

This article is to understand as a position paper that introduces a new subdiscipline that is defined as follows: Lean Ergonomics (LE) is the unified consideration and pursuit of *ergonomic* and *managerial* synergies and goals to holistically and sustainably increase *productivity* while maintaining employee *health* and performance. The concept can be deliberately interpreted in two ways. On the one hand, as the actual core idea that the two systems "production" and "ergonomics" are still too separated and that, however, synergies can be expected from their merger. The separation is still reflected in science as well as company practice and organization, which is shown for the Digital Twin and Digital Human Modeling in this paper but exists equally in analogue and physical form at the factory floor. On the other hand, the interpretation in the form of lean integration of ergonomic projects into the present system is possible through LE. Lean Ergonomics is an attempt by the authors to open up a new subdiscipline that is explicitly located in between and analyzes potential dependencies of microscopic and macroscopic processes and KPIs. According to system theory, the emergence of both systems leads to more knowledge gain than mere addition (Ropohl 2009). It was searched for the term "Lean Ergonomics" without any restrictions of the publishing year in Google Scholar, Scopus and Web of Science to get an historical and semantic overview: The first verbal mention in scientific literature of the term *Lean Ergonomics* was by Love (1999) in an SAE Technical Paper on the fit between workplace and human. Than the next mention of LE dealt with the continuous improvement process in the context of ergonomics (Scheel and Zimmerman 2005). The closest connection in terms of content comes from Fröleke (2017), who assumes unknown but relevant interactions of lean and ergonomics in the overall system of production. A few more points of contact exist, but in unstructured contexts, without a definition and without the mention of the term "Lean Ergonomics" and without the synergistic effect of Lean and Ergonomics described here and the potential of a new (sub)discipline through emergence (Amin and Mahmood 2018; Naranjo and Ramírez-Cárdenas 2014; Nunes 2015; Brito et al. 2018a; Kester 2007). One reason for the frequent mention from the late 2000s onward is discussed below.

The standard literature on lean management by Womack et al. (1991), *The Machine That Changed the World* focuses on the inexplicable rise of Japanese enterprises due to a new type of production concept that requires few resources, is less wasteful but more productive and that is also much more flexible than the large, *fordistic* concepts in the Western automotive industry. Although the employee was given a great deal of attention as a quantitative adjusting screw, ergonomics was not mentioned as a success factor. Womack's et al. study was for a long time the basic source of information for further thoughts and publications on Lean. From this, it is evident that ergonomics was not given due consideration.

2.2 Necessity of ergonomics in lean management

With the introduction and the subsequent intensification of Lean concepts in the West and the accompanying problems of occupational physiology and ergonomics perspectives on Lean changed. The prevalence time of musculoskeletal disorders (MSDs) can amount to decades (Baur 2013). When it was decided to introduce an explicit Lean method based on the findings of Womack and colleagues in the early 1990s, the ergonomic impact was not relevant because it was not known. The predicted black figures first spoke for themselves. 20 years later, there were then strikingly high incidences of MSDs at workplaces that have all been optimized with Lean measures. Lean no longer shows itself to be an all-purpose weapon—not when used alone. This raises the question: "Is lean mean?" (Anderson-Connolly et al. 2016) To this day, it is discussed controversially and with a wide variety of results (Conti et al. 2006). This question alone does not allow a conclusion to be drawn about an ergonomic solution, but the existing disagreement shows that Lean has different unknown downsides.

More generally formulated and decoupled from a simple yes-or-no question, it can be stated based on literature and longitudinal studies that a focus on ergonomics was erroneously considered inferior to the Lean system due to a supposed lack of rationalization and quantitative recording (Westgaard and Winkel 2011). In connection with this Nunes (2015) showed that ergonomic interventions were only carried out after accidents, significant and unexplainable or frequent days of sick leave, and health complaints, as no reason was previously apparent from the perspective of top management. Measures of lean production mostly exclusively addressed an increase in productivity via process-related analyses and interventions, in which it was not the goal at all to include the employee as bio-psycho-social individual (Melton 2005). As a result of the evaluation of

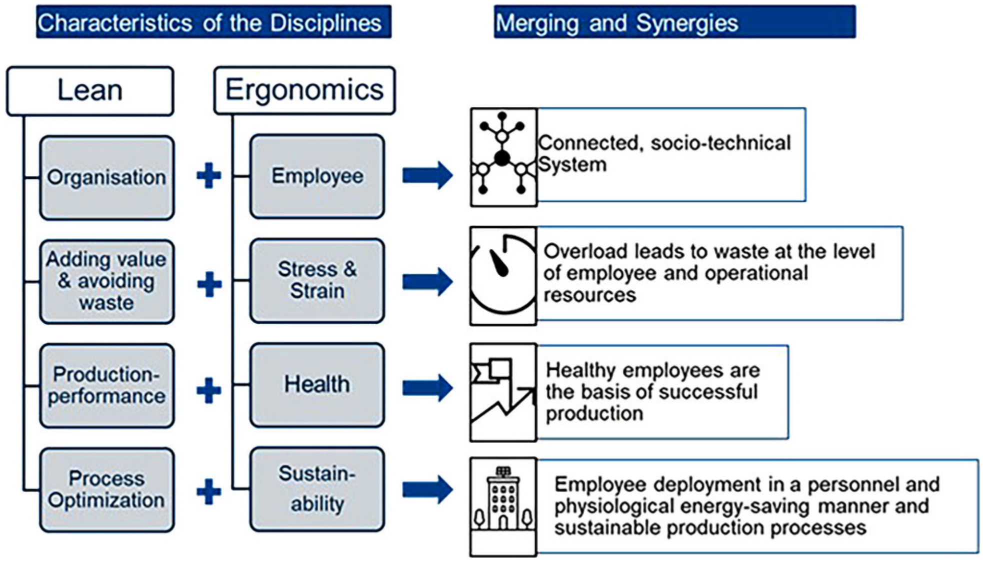

Fig. 1 Synergies in Lean Ergonomics
Abb. 1 Synergien in Lean Ergonomics

such projects, ergonomics, or the not included employee, mistakenly appeared as a limiting bottleneck because, according to dos Santos et al. (2015), it stood out negatively precisely for the reason of not being addressed thus shaping the awareness of a dichotomy between the two systems. As called for above, this dichotomy needs to be resolved in a scientific and practical way. In practice, various known challenges show the need for exactly this thematized interface. In Fig. 1, the characteristics and the relevant theories of the disciplines Lean and Ergonomics are matched. On the Lean side, the fundamental focus is on the organization as a whole. The performance of the overall system is more important than individual, ergonomic subtleties at the single workstation. Ergonomics primarily centers on individuals, not the overall system. However, the connection between the two is already a manifested concept, at least linguistically, namely the *socio-technical system*. This is interconnected in many ways and shows various dependencies and interactions as the historical introduction of lean showed above.

The motivation of Lean is the avoidance of waste and the limitation to processes and activities that lead to an increase in value from the customer's point of view. The counterpart in ergonomics is the stress-strain model, which analyzes work-related external effects on employees and the internal impact of these effects on an internal physical and psychological level. A combination of the two leads to the conclusion that inappropriate utilization of analogue, digital and biological systems lead to wear and tear and inefficiency. This is reflected on the Lean side in production through poorer performance of specific KPIs and on the employee side through deterioration in health. Via the LE concept, the core message of the investigations and case studies of Onan Demirel et al. (2021) is supported, which is that employee health and corporate sustainability are not separable. The last dominant pair is process optimization and sustainability. Even if mechanistic or digital systems allow a balanced process optimization, this cannot be transferred to humans without further ado. Process optimization must be combined with sustainable human resource planning in order to enable both humans and machines. This can be further explained via the lean concept 3M, in which differentiation is made according to types of waste. *M*ura as uneven production, *M*uri as overload and *M*uda as waste also exist in relation to the biological counterpart, the employee. The employee, like production, experiences health and performance impacting limitations in the event of unevenness, overload, and mental or physical waste (Pienkowski 2014; Saptari et al. 2015; Brito et al. 2018b). With this new understanding, KPIs and methods of factory planning and ergonomics should be exploratively analyzed and correlated to improve economy of the plant and working conditions of the employees. The fundamental dependence of economic success and workplace ergonomics has already been examined several times (Zare et al. 2016; Barthelmes et al. 2019). Furthermore, Lean Ergonomics works as a theoretic framework to set up and streamline processes and decisions in an interacting socio-technical system.

2.3 Digital human models and digital twins as practical application of the Lean Ergonomics framework

As a concrete and current use case in Lean Ergonomics, the digital twin and digital human models are considered below and discussed within the framework Lean Ergonomics. Digital Twins and digital human models are seen as relevant trends and enablers for overcoming the problems described at the beginning (Lim et al. 2020; Ibrahim et al. 2022). Subsequently, a scientific-theoretical consideration

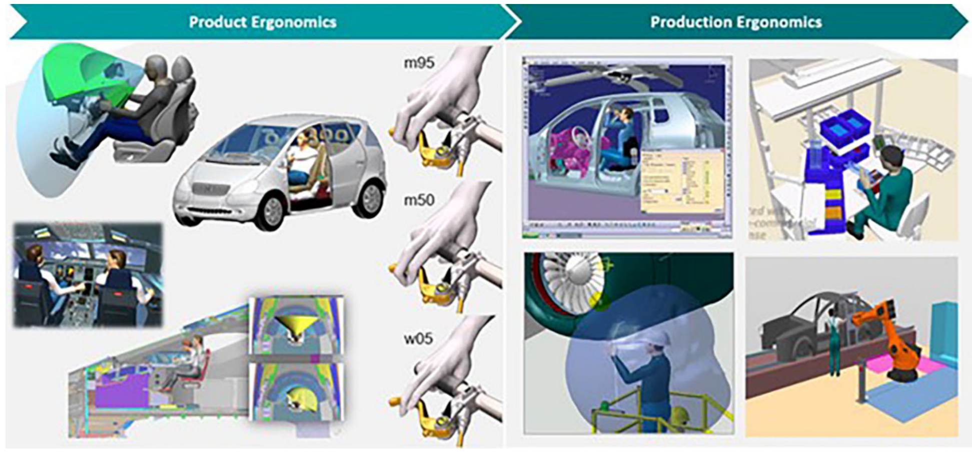

Fig. 2 Use of digital human models in Product and Production Ergonomics (Spitzhirn et al. 2022b)
Abb. 2 Verwendung digitaler Menschmodelle in Produkt- und Produktionsergonomie

is used to derive how the gap can be closed by LE and why LE is a relevant subdiscipline in which DT, representing Lean, and DHM, representing Ergonomics, must complement each other.

According to Bullinger-Hoffmann and Mühlstedt (2016), digital human models are virtual images of humans that simulate work-scientific processes. According to the German Federal Institute for Occupational Safety and Health (BAuA 2022) and Bullinger-Hofmann and Mühlstedt (2016), the terms *digital ergonomics* or *virtual ergonomics* can be understood as computer-based methods or even (software) tools that are used in the product development and product manufacturing process for the ergonomic design of products, processes, and work systems. An essential component of virtual ergonomics are the digital human models as part of CAx systems, which can be characterized via different anthropometric variables (e.g., gender, percentile, age, proportions) and model geometric properties of humans (Mühlstedt 2016).

DHM contains anthropometry, loads, and physiological capabilities (ibid.). Starting in the 1960s, dozens of different human models were developed. The original idea was to digitally verify costly real-world procedures in advance. Increasing computing power and the desire for standardization and modularization reduced the scope and brought together isolated solutions (Bullinger-Hoffmann and Mühlstedt 2016). The aim of the systems is to visualize various scenarios and conduct analysis for ergonomic aspects as part of an early analysis and to generate results on accessibility and visibility. Further analysis functions such as investigations into discomfort, load handling, posture, or fatigue offer additional possibilities for ergonomic design and evaluation. *RAMSIS* (Human Solutions GmbH n.d.), *Jack and Jill* (Siemens PLM), *Human Builder* (Dassault Systemes 2022a) and *ema Work Designer* (emaWD) (imk Industrial Intelligence GmbH n.d., Leidholdt et al. 2016) are one of the most used digital human models. In addition to these models, other models exist with a focus on specific functions that can be applied for biomechanical issues such as *AnyBody* (AnyBody Technology 2022) or visualization aspects such as Poser or Make Human (Bullinger-Hoffmann and Mühlstedt 2016; Gunter 2021). Fig. 2 shows some examples of the usage of digital human models in Product and Production Ergonomics.

Using simulation already enable to create, to compare and to discuss different alternative scenarios of current as well as to be planted process. In this way, different product and workplace configurations can be examined for different populations (small woman to large man) and design measures derived in advance. A 3D visualization of the created product or work process in addition to the evaluation methods such as vision and reachability analysis, biomechanical analysis (e.g. EAWS) can be used for the identification of possible hazards as well as for optimization. However, a simulation generates model-based movement data that can show deviations from the real execution depending on the simulation approach and conditions. To avoid this obstacle users and researcher in the DHM field can use motion capture systems to add dynamics to the manikin (Hanson et al. 2022). This leads to accurate and individual results on the micro level. Therefore, the definition of a standard movement for the evaluation of the motion capturing recordings is required. Planning systems such as ema Work Designer or Process Simulate offer options for integrating and analyzing movement data to add value of both approaches (Siemens 2022; Spitzhirn et al. 2022c).

For the evaluation of the product and process different methods such as visibility, accessibility, posture, load, or time analyzes can be used. Standardized methods for ergonomic analysis such as EAWS (Ergonomic Assessment Worksheet), RULA (Rapid Upper Limb Assessment), and duration times for specific activities (e.g. MTM-UAS) can be used (Bullinger-Hoffmann and Mühlstedt 2016). In addition, special analyses such joint forces or muscle activity can be used in certain DHM (e.g. AnyBody) for special investitgations (e.g. exoskeletons), but they are difficult to standardize and do not allow for quick comparisons (Hanson et al. 2022; Fritzsche et al. 2021).

For interaction and visualization users also combine DHM with virtual reality (VR) and augmented reality (AR), but mostly within a microergonomic framework (Hanson et al. 2022). Systems such as ema Software Suite (Uhlig 2022) or Process Simulate (Damm and Ragavan 2020) can be used directly in VR and offer the possibility to change layouts, generate simulation and evaluate this processes and production lines related to ergonomic and economic aspects directly. In addition, such systems offer interfaces to other VR systems too which could help to bring together systems from different areas. The use of VR helps to enter the environment directly and could be used in interactive workshops regardless of location. VR and AR could also be seen as mediator between DHM and Digital Twin, but the current trend seems to go to DHM use cases for VR and AR without links to higher-level production planning processes.

The concept of DHM is contrasted by the digital twin (DT). The history of the latter is considerably younger. The technology was first mentioned in 1991 in the publication *Mirrow Worlds* (Gelernter 1991). However, the term did not appear with specific reference to the production environment until 2002 (Grieves and Vickers 2017). The Fraunhofer-Institut defines the digital twin as "a concept with which products, as well as machines and their components can be modeled using digital tools [...]" (Fraunhofer-Institut 2022). This definition is expanded to include digital images of intangible goods, such as data, processes, and services (Stark et al. 2019; Eigner 2020). The DT then enables presentation of real time states and changes, the representation and linkage of process or resource states and a comparison of the target state in digital (Stark and Damerau 2016).

Gartner (2022) selected DT technology and associated potential as one of the top 10 strategic technologies three years in a row from 2017 to 2019. The original and still current main focus of DT is to map the complete product or process life cycle (Hartmann and van der Auweraer 2021). The projected market in 2026 is $48bn (Research and Markets 2022). Current efforts are related to the development of executable DT, this is a DT that is directly co-produced with its physical machine and can be commissioned with the physical counterpart upon delivery to the customer without major effort (Hartmann and van der Auweraer 2021). Ergonomics is only involved to the extent that the software for operating and implementing the DT must satisfy usability requirements, which is a part of product but not production ergonomics. At the same time, efforts are being made to map and equip increasingly complex products and processes with a DT and to enrich them with a wide range of information that is available along the entire supply chain, from assembly to distribution (Yi et al. 2021). Recent reviews on DT also show no human-centered engineering aspect toward ergonomics (Liu et al. 2021; Semeraro et al. 2021). Interconnected systems and DT tend to focus on improving human capabilities on the factory floor rather than on micro-level fit-based load allocation, which for example Ariansyaha et al. (2020) analyzed with electromyographic (EMG) measurements. The team used AI to analyze the EMG data and feed it back to the physical and virtual production and assembly area. Here, the first promising results of integrating DHM into DT were explored, although they raised unresolved questions of data protection and ethics.

Human-robot collaboration is still being studied in depth in the context of DT, as well as general human-machine interaction and employee envelopes, but otherwise no movements on microergonomics are apparent (Lo et al. 2021).

3 Problem and research needs

The definitions show that DHM and DT are two fundamentally separate disciplines. The historical classification provides plausible reasons for this. DHM does not look into superordinate structures of management science and acts microergonomically. DT, which is understood as human-inclusive from outside its discipline, does not have the human being—or only quantitatively—intuited, as it was by Womack et al. (1991) in his investigation. Thus, there are always new, more powerful discipline-internal derivatives, but no interdisciplinary overall conceptualization of man and production as a functional, digital image. The developmental and traditional separation in science and practice is still present. The operationally completed horizontal and vertical networking in companies is not reflected in the methods of production and microergonomics, so isolated analyses, methods, and key performance indicators must face the diversification into the interdisciplinary. VUCA developments described at the beginning of the paper endanger the sustainability and efficiency of entrepreneurial processes. A prior mapping of volatile and uncertain processes in the digital medium can test reality for upcoming fluctuations and make it more adaptable. It is assumed that titling the gap and attributing a claim to a new subdiscipline within it will direct research interest to it.

4 Lean Ergonomics as a subdiscipline: a theoretical derivation

According to Niiniluoto (2018), a new scientific discipline can arise for any one of six reasons: by separation from philosophy (1), by branching off or migration from another discipline or many disciplines (2), by emergence of a new topic in the scientific community (3), by connecting and bringing together linked disciplines (4), by theoretically integrating originally separated disciplines (5), and lastly by scientification of art and technology (6). For LE, the reasons 1, 5, and 6 are excluded.

Splitting off from philosophy (1) is excluded because neither production ergonomics nor production management originate from the fields of philosophy. Theoretical integration of originally separated disciplines (5) is excluded because of its practical relevance to planners and employees. LE is not a theoretical construct and has been researched in the past; it was not just defined and not seen as a new (sub)discipline with relevant benefits and synergies (cf. Brito et al. 2018a; Kester 2007; Nunes 2015). Similarly, there is no scientification of art or technology (6), since LE is neither art nor technology. Ropohl defines technology as the science of technics and of the general functional and structural principles of technical factual systems and their creation and use (2009). This definition cannot be applied to LE. Consequently, options 2, 3, and 4 remain relevant and possible according to Niiniluoto (2018). In this article, the scientific-theoretical emergence will not be addressed in detail, but it will be evident that LE can be assigned reasons for claiming to be a new subdiscipline. The direct connection of production management (*Lean*) and production ergonomics (*Ergonomics*) can be directly linked to the fourth reason according to Niiniluoto (2018). Similarly, according to reason 2, this process can be seen as downward migration from production management and upward migration from workplace ergonomics.

Modern science needs and lives through emergence of new disciplines, as it happens in the case of LE by combining two disciplines to solve dependent problems (Darden 1978; Haaparanta 2003). The legitimacy of Lean Ergonomics as a new field of science can be derived through interfield theories. These come about to link two fields of science into a potentially novel one. The theory of an interdisciplinary field emerging can be adopted when two fields share an epistemological interest of a phenomenon with different perspectives and the two disciplines provide and create relevant background knowledge for it (Darden and Maull 1977). This is the case for the educts production management and production ergonomics. The common epistemological interest is minimization of waste and holistic implementation of sustainable processes in the sociotechnical system. Sufficient own background knowledge of each discipline is available due to sufficiently long existence and exercise of knowledge in science, teaching and economy. A limitation of interdisciplinary theory is that it must be applied to fields or disciplines rather than theories. This can be readily taken as a given for LE. Neither lean management nor ergonomics are mere theories. Both are disciplines with a manifested practical core in science, teaching and business.

As derived above, LE can be attributed the science-theoretical potential to close the described method gap of DT and DHM. This prevents the loss of potential with regard to the profitability of the company and the health of the employees and thus indirectly reduces the separation of DT and DHM into two disciplines through direct, methodological involvement of the counterpart.

5 The gap between DHM and DT in practice

5.1 Current development trends of DHM and DT

As a case study in the context of workplace ergonomics, Caputo et al. (2019) provide an approach that maps the assembly line as a DT and can output physical and operational ergonomically relevant parameters and allow derivations in EAWS and MTM (Methods Time Measurement). Such research aims at the described gap and needs to be intensified and enriched with DHM. This is because Caputo et al. (2019) also only use macroscopic processes and data to make initial statements about ergonomics. These statements are only derived from geometric dimensions and physical process data of technical-mechanical systems and have no psychophysiological component. However, they are contrasted with the human being in form. When used and interpreted in isolation, this data runs the risk of being considered sufficiently ergonomic and employee-centered. However, literature reviews must be used as more holistic and representative trend barometers, and in these, the human-centered orientation is not evident, or is evident to a very small extent. This was shown by Lim et al. (2020) in a state-of-the-art review on DT. Here, the terms "digital twin", "virtual twin", and "cyber twin" were searched for in online portals of scientific literature. Of 256 articles, 123 were included and evaluated. One article of the 123 described DT as a moderator of human-wellbeing but did not examine it as a core motivator (Elhabashy et al. 2019), another was the study by Caputo et al. (2019) and yet another study addressed optimization of workplace lighting conditions with DT (Dupláková et al. 2019). This is of clear benefit but does not fit into the Lean Ergonomics gap. All the others had nothing to do with ergonomics and DHM and involved humans as a relevant actuator if at all based on human-robot collaboration (Petković et al. 2019; Bilberg and Malik 2019). This shows that there is no sufficient integration of DT and DHM at all and currently no relevant trend of exploring possible merging concepts is present.

Table 1 Essential and optional parameters for DHM Case Study "Screwing Process"
Tab. 1 Essentielle und optionale Parameter für die DHM Fallstudie

Essential	Optional
CAD Product data of the car especially body shape or surface as CAD file	Recording of In-vivo forces (e.g. force measurements at shopfloor) and entry in simulation
Worker manikin 50th percentile male + working task	CAD-Details of specific model
Angle screwdriver	Detailed Environment (assembly line)
Plug points interior	
Spatio-temporal sequences (cycle- to-single activity)	
Phantom cable (for placement process)	

5.2 Case study of lean implementation of DHM

Research by the Chair of Ergonomics in an explorative DHM study showed at least indirectly that a planning system with DHM provides useful results with regard to workplace design, but that the integration of macroscopic data and processes and their digital mapping can be challenging. The project took place at a manual automotive assembly line and involved a cycle that was dominated by screwing tasks. The primary goal was to test how much it takes to properly implement and use a DHM in manual assembly, what data are needed and which output can be generated under aspects of efficiency and adaptability of the DHM.

This pilot project with an industry partner aimed to test the exemplary implementation of the DHM software ema Work Designer (emaWD) from the company imk Industrial Intelligence GmbH.

The *ema WD* is part of the ema Software Suite and can be used independently or in combination with the ema Plant Designer. emaWD enables a parameterized motion and process simulation for planning, designing, and optimizing of work processes and human robot interactions (Fritzsche et al. 2019; Spitzhirn et al. 2022a, b, c). The software includes a library of predefined "tasks" that are used to create a job description by specifying the parameters pertaining to the job to be executed and the work environment (objects to be handled, target positions etc.). This job description is evaluated geometrically by a simulation module for plausibility and collision detection and avoidance for human/object as well as human/human. In addition, motion capturing data can be imported and combined with simulation data. The generated simulation can be evaluated using ergonomic (e.g. vision analysis, reach space analysis, EAWS, NIOSH, job profiles), standard time (e.g. MTM-UAS) and safety criteria.

In the beginning, the cycle to be investigated was defined and a task and activity analysis oriented to the MTM basic movements was performed. It makes sense to orient the activity analysis to MTM basic movements, since emaWD runs these in the background as the basis of the movements and the software is oriented to the wording of MTM at the front end. This is advantageous because it enables standardized application and training and homogenizes process understanding. In this step, it became noticeable that during on-site observations in the factory, the employees showed large differences in terms of work technique. These showed up in particular due to the work experience and individual anthropometry. In emaWD this can be considered by adapt the parameter of simulation and by using individual anthropometric human models as well as percentile human models from small women (F05) to large men (M95) with different abilities (age-dependent flexibility, forces). In addition, motion capturing data can be integrated and combined with the simulation (Spitzhirn et al. 2022c). Because of the main goal of the project—an efficient implementation of a DHM-Tool—no motion data but different male human models with age group 40 and percentiles (P5, P50, P95) were used. A major challenge was then to determine the level of detail of the simulation and imported resources among all stakeholder from science and industry and which data was considered essential and which optional. Depending on organizational affiliation, different emphases emerged from macroscopic and microscopic analyses. The classification shown in Table 1 was agreed upon.

The main parts of the simulation are the human manikin and the product data of the car. Data for the surface of the body are sufficient, consequently a CAD file is suitable, also to safe computing power. For an initial analysis it was decided to use the 50th percentile male. The only used tool in this cycle is the angle screwdriver that could be customized exactly. Further the working task defined plug points in the interior which were set manually in the CAD file. The manikin can perform on basis of this information but for more realistic movements spatio-temporal circumstances were measured in real and imported and checked in the simulation. An optimization of the movements and speed is possible in emaWD by defining trajectories. As a last step, a phantom cable was built to enable realistic grabbing for the manikin because of the limp characteristics of the cable that have to be attached to the cable lug.

Presented data were collected and implemented in emaWD. It became apparent that there is a gap between the macroscopic processes of production planning and the

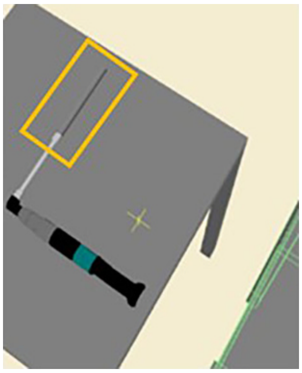

Fig. 3 Extended angle screwdriver

Abb. 3 Erweiterter Winkelschraubendreher

micro-ergonomic subtleties when it came to collecting different information and data and defining focus areas.

Thus, for science and industry, data acquisition is the first challenge for which it is necessary to design standardized processes for the large-scale introduction of a DHM. The attempt to implement a 3D scan of the assembly line (8 GB) failed because the existing file was too large for processing in emaWD. There is potential compression software and corresponding importers in ema that can be used with an additional license. Since the focus in the case study was on the efficient introduction of the emaWD at the industrial partner, no other program was used. Existing data was then incorporated and the manikin completed the work process in the software. In emaWD there is a library of various operating tools. Its tools can also be extended with geometric primitives, for example as in Fig. 3; the length of an angle screwdriver can be variably adjusted to the special use case which allows better fitting simulation (see orange marking). For reasons of confidentiality of the industry partner, no further illustrations of the worker's task at the body can be shown here.

Internal resources can be exported from different kinds of CAD programs (e.g. Catia, Dassault Systemes 2022b) and then imported in emaWD using scaling techniques too. After correct scaling the dimensions are matched; some objects have to be oriented correctly (Fig. 4). There were three different scaling factors for this project, depending on the software and CAD files used. For a lean implementation of emaWD a standardized factor would be preferable. Also, the scaling factors calculated with were computed just for second decimal place which is sufficient for this explorative pilot project but should be specified for day-to-day business.

The scenario then is specified via reference objects and markers for the detailing of specific movements and then evaluated via standard execution time (MTM-UAS6) and ergonomics parameters using EAWS (Schaub et al. 2012). There is the possibility in emaWD to simulate work processes with various human models with different characteristics (e.g. anthropometry, age, flexibility, nationality) in the same scenario and compare them whilst changing the setup (Table 2). Here, the same scenario was used for three manikins (M50, M05, M95 for age group 40). The EAWS-Score is lowest for the 50th percentile due to different adopted postures according to same working height for all three manikins. Finger Forces and weights were not relevant for the ergonomic evaluation due to limits of EAWS (force less than 30 N, weight less than 3 kg). It also was tested for weight changes of the screwdriver and for changes in length of the screwdriver extension. A weight addition from 2 to 2.5 kg made no difference in terms of the EAWS-Score as loads according to EAWS are only rated starting with 3 kg. The specific extension of the industry partner's screwdriver was beneficial because without it the EAWS-Score for the 50th percentile increased from 31.5 to 39.5. This demonstrates a simple way to test tools in emaWD as well.

emaWD proved to be a suitable analysis tool for simulation of work processes with sufficient lead time for data procurement and pleased usability. The visualization of the results and different KPI such as time and ergonomics helps interdisciplinary professional teams such as expertise from biomechanics, occupational physiology, industrial engineering, and system ergonomics to have a common presentation and basis for discussion. The development of the

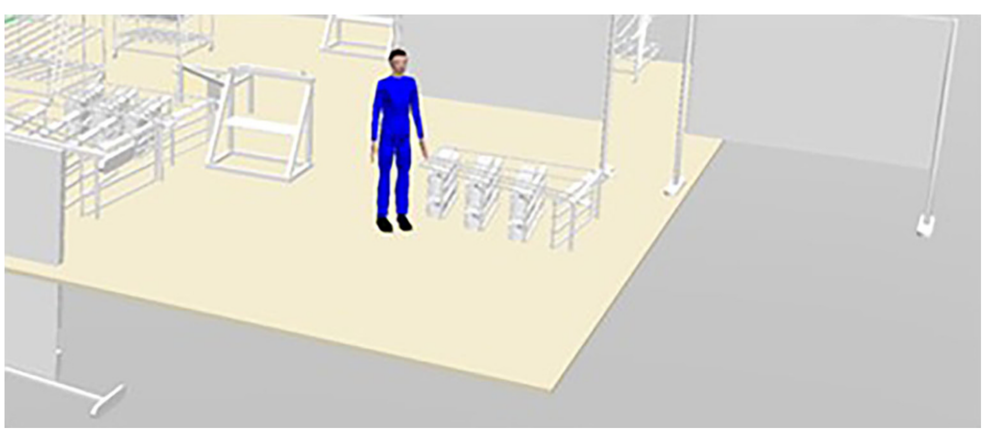

Fig. 4 Final dimensions of resources

Abb. 4 Finale Dimensionierung der Betriebsmittel

Table 2 EAWS Scores for different percentiles (*italic*)
Tab. 2 EAWS Wert für unterschiedliche Perzentile (*kursiv*)

	M50Age40	M95Age40	M05Age40
Information	50th percentile, male, age group: 40, performance factor: 1	95th percentile, male, age group: 40, performance factor: 1	5th percentile, male, age group: 40, performance factor: 1
Entire body [points]	*31.5*	*36*	*37*
Body position [points]	16.2	20.7	29
Torso rotation [points]	15	15	8
Pose [points]	31.5	36	37

design solutions should be done by interdisciplinary teams the integration of experience from various disciplines.

For an application in the company, as with other systems or methods such as MTM, user guides for the standardized procedure (e.g. structuring of the CAD environment, human models used) should be introduced. For an efficient application of digital work planning, it is necessary that people are adequately trained in the use of the software. In addition, it is necessary to prove the possibility of the integration of the software into the present IT landscape (CAD data, work process information, etc.) to ensure continuous flow of data within the company. For that purpose, emaWD offers various intersections for CAD data, process information, layout or motion data.

Currently, the time and ergonomics data are created manually in the company and then transferred to a separate tool. If the EAWS and MTM data should come from the digital planning tool emaWD, the data must be reconciled in detail with the in-house data before a replacement of analogue assessments with digital ones can be completed, which is a major challenge. Due to the different resolution of analog and digitally generated assessments (EAWS, MTM) there may be differences due to different assumptions (e.g. walking distances, distance ranges) and subjective bias. Digitizing the ergonomics assessment can increase objectification and the efficiency of the assessment creation (Wagner et al. 2013).

Thus, the recommendation for companies is to commission consistent and equally trained teams to use DHM in order to obtain reliable data. In combination with agile ways of scanning the shop floor and implementing more psychophysiological data emaWD can be the base of a promising further development of socio-technical systems in a digital medium. For a more holistic digital derivation of a production scenario emaWD can be combined with the ema Plant Designer (emaPD) (Spitzhirn et al. 2022a). Because of limiting factors this was not done in this case study but could be added afterwards for presented tasks, because the emaPD and emaWD can be used independently or together in one interface.

In terms of Lean Ergonomics the emaPD describes the lean part (e.g. using space requirements, costs, utilization of machines, Overall Equipment Effectiveness) at the macro level of production and assembly planning and the the emaWD the ergonomics and microeconomic part in more detail (EAWS, standard time using MTM). The interface between the emaPD and emaWD allows to transfer data form microscopic analyses to macroscopic and vice versa (Spitzhirn et al. 2022a). The emaPD allows quantifying of material flows and processing time but is not to understand as Digital Twin.

In this time and financially limited pilot project, one can speak of a legitimate introduction of emaWD, since some ergonomic and business KPIs can be displayed and tracked with little effort.

6 Possibilities to close the gap

In the from science and industry desirable but current hypothetical project to digitally map a whole supply chain of employees, machines, and processes, it is hypothesized, analogous to the bullwhip effect, that the hurdles mentioned multiply the further one moves away from the OEM. This poses the risk of the classic managerial bull-whip effect, supplemented by an ergonomic one. The effect describes the phenomenon of different demand patterns within a supply chain. A small change in demand on the customer side leads to intensifying demands of upstream units and finally arrives on the production and assembly level as a strong fluctuation (Lee et al. 1997). The employee experiences this as physical and psychological overload (Pienkowski 2014). Fluctuations in production management can be detected and buffered in time if digital ergonomics is working adequately, but the fewer resources that are used for this purpose, the greater the risk of ergonomic overload. DHM and DT, that are not coordinated with each other and not adapted to the use case, harbor the problem of a certain degree of risk of human overload because they are suggesting ergonomics and occupational safety just due to their

Table 3 Ergonomic-oriented KPIs for DHM
Tab. 3 Ergonomie-orientierte KPIs für DHM

Category	Example
Measurement Methods	Motion Capture, psychophysiological measurement methods (Heart Rate, ECG, EMG, lactate value, spiroergometry, near-infrared spectroscopy)
Expert Methods	EAWS, NIOSH, OCRA, RULA, REBA, MTM-HWD
Simulation Tools	AnyBody, emaWD, RAMSIS and more
Short Screening Methods	Borg, KFZA, KPB, LMM, NASA-TLX, WAI, COPSOQ[a]
Retrospectives	Statistics and registers
KPIs	Days of incapacity to work, demographics, chronic MSE, occupational accidents, current registers

[a]*LMM* Leitmerkmalmethode, *KFZA* Kurzfragebogen zur Arbeitsanalyse, *KPB* Kompaktverfahren psychische Belastung, *WAI* Workability Index, *NASA-TLX* NASA Task Load Index, *COPSOQ* Copenhagen psychosocial Questionnaire

Table 4 Business science-oriented KPIs for DT
Tab. 4 Betriebswissenschaftlich-orientierte KPIs für DT

Category	Example
Employee related	Processing times (MTM), waiting times, utilization and work errors (human), rework time, size/weight of work pieces, suggestions for improvement per time, turnover, qualification, personnel costs, etc.
Production related	Inventories, waiting times and utilization (machine), material defect, cycle change, value stream mapping, number of units, production costs, setup times, value added share, etc.
Customer related	Demand (fluctuations), returns, delivery reliability, customer cycle time, etc.

sheer existence. This must be critically taken into account if long and interplant material and value streams are to be digitally mapped. Otherwise, one is faced again with problems that become prevalent with a high time lag, as with the introduction of *Lean* at that time and their effect on the psychophysiology of the employee.

The question to be answered is how to close the gap between macroscopic and microscopic considerations and how to motivate science and industry to generate tools and methods and consequently link the disciplines. It can be assumed that this is relevant in the digital, but also in the analogue and in the operative daily business on the shop floor. From this it can be concluded that a combinatorial meso level is needed that links the holistic production system analyses with individual workplace analyses. Lean Ergonomics is suitable for this, as it acts as a new subsidiary discipline of production ergonomics and business management.

For the digital approach, basic software arrangements such as compatibility of file formats and sufficiently fast processing have to be in place and companies must be able to feed in relevant data and process these data in an understandable way to all stakeholders. To specify the gap and subsequently close it with diverse and creative research, it is proposed to collect key performance indicators, methods and tools of lean production and ergonomics systems and to examine them for statistical and application-relevant correlations and the possibility of combined further development to new KPIs and interventions. For example, an exploratory Lean Ergonomics analysis in the manual assembly of truck transmissions showed high correlations of ergonomic and business management KPIs (Tropschuh et al. 2022). In this study, NASA-TLX (NASA Task Load Index), EAWS and the Borg scale were used to investigate the number of work errors in manual assembly. Transferred to digital, DT and Enterprise Resource Planning System (ERP) systems could thus be used to track work errors per workstation and extend and combine these with ergonomics parameters collected via DHM. With sufficient data, the concept can be enriched with machine learning and thus simulated in agile ways. It would then offer the possibility of preventing business waste in the form of work errors and their rework and overload at the employee level.

The KPIs for DHM in Table 3 are suggested for expanding the input and collection parameters of the DHM (adapted from Kugler et al. 2010; Schmauder and Spanner-Ulmer 2014).

On the DT side, Table 4 shows data that can facilitate the entry into a meso level (adapted from Alves et al. 2019; Bertagnolli 2018). The three proposed categories are set up to involve all relevant business processes in a firm but also show the focus of a potential analysis easily and quickly. Whereas the variables of the category "Employee related" are very close to ergonomics, the "Customer related" variables seek to identify unexpected correlations, but therefore enable and motivate to widen the research activities in supposedly less considered departments.

Generally, the tables show that KPIs that are required for production planning processes are also collected in an employee-centric manner and that a combination of DT and DHM makes sense when it comes to holistic mapping and analysis. The synergetic effects made possible by the Lean

Ergonomics approach then become apparent in correlations and connections of the subject-specific KPIs and methods. From the perspective of the production planner, the question arises as to what requires an interdisciplinary analysis from the micro level, and from the perspective of the ergonomist, it must be analyzed what influences the employee from higher-level processes in a relevant manner. There is the possibility to simulate many suggested KPIs in emaPD (Lean aspect) and emaWD (Ergonomics aspect), which is beneficial because of a fast and compatible data transfer. For correlation calculations, additional statistic software has to be used.

Thus, two scenarios are considered for DT and DHM. These borrow from the "techno-centric" perspective and the "anthropo-centric" perspective of Dworschak & Zaiser (2014), whose scenarios emerged in the context of cyber-physical-production systems. For the consideration of DT and DHM in the context of the subdiscipline LE, comparable division into system-oriented and employee-oriented can be seen.

In the first case, a gap remains. This concerns specialist departments within the company that work too isolated, research projects within the classic disciplines of ergonomics and production that remain exclusively within their traditional boundaries, and methods, KPIs and unknown data that are not considered or processed as interdisciplinary. Here, planning efforts remain high due to shorter product life cycles, distributed locations, assessment requirements (e.g., Supply Chain Act), and supply chain variability. The resources used in science and practice fall short of their potential.

Therefore, in a second, preferred case, ways must be sought to return to workability with reasonable effort through end-to-end vertical and horizontal networking and digitization in planning and assessment, and not lose sight of the overall benefit from too many isolated analyses. This represents the ideal case, which has to be set up on the basis of the subsidiary discipline Lean Ergonomics introduced in this paper, in order to advance holism and sustainability in the super system factory. Via explorative analyses and initial statistical evaluations, new correlations of the two disciplines are to be recognized. In the context of Industry 4.0, it is expected that in the medium term, sufficient data will be generated to enrich Lean Ergonomics with machine learning and artificial intelligence. This would in turn enable the recognition of larger unknown correlations and consolidate the discipline.

7 Discussion and limitations of the position paper

Until publication date no own, quantifiable study in terms of the here suggested new sub-discipline *Lean Ergonomics* could be carried out and consequently underline this theoretical position paper. An initial explorative approach from the first-author can be read in Tropschuh et al. (2022). As this is not a systematic literature review for DT & DHM, but introduces LE as a subdiscipline to promote their integration, the literature taken into account is not all encompassing. However, to control for this effect existing current and high-quality literature reviews were taken into account. With the concept of theory of science, LE showed to develop in a stringent and logical way. Research objectives of ergonomics and holistic business science in a production company that tend to each other can be settled in LE and thus name its purpose in science and business more accurate. A clear business case and scientific entitlement of LE could be derived. Firstly because of a lot of already existing literature that is dealing in the context of LE but was not named after it and understood like. Secondly, a Case study could be carried out that demonstrated that departments are too separated to benefit from synergies and correlations LE allows. And as a third aspect, LE is deducible in terms of theory of science. The framework of LE, is able to unite current trends (e.g. DHM, DT) in ergonomics and industrial engineering. Next steps have to focus on multiple linear regression models that are using the variables as supposed in Tables 2 and 3 and apply LE to more methods and trends than DHM and DT.

8 Conclusion

Germany as a location for production of complex products faces various challenges, some of them unexpected. Increased and intensified aggravation in the near future cannot be ruled out and the manufacturing industry has to find innovative, systemic but also creative means for economic efficiency, sustainability, and keeping employees healthy. This can be realized by defining and entering new disciplines of research. Relevant disciplines for this are the management and planning system of production and production ergonomics, which are divided into system-oriented and human-oriented approaches.

The historical separation of production management and ergonomics is still evident in the most current procedures and methods such as DT and DHM. Both continue to develop internally in an innovative way, but thus steadily deepen the separation of the disciplines. Current challenges, however, are decidedly opposed to isolated developments and analyses. Increasing vertical and horizontal networking of companies must also be reflected in applied science. Over-complex and hyper-isolated analyses provide scientific added value, but they are too far removed from the major challenges of practice. Lean Ergonomics, besides describing and titling a new discipline, is an attempt to name and methodically address the gap between the employee microsystem and the factory macrosystem. From a scientific-theoretical point of view, LE could be derived via several mechanisms and basic assumptions and prerequisites of the emergence of a new field can be confirmed. The individual components of production management and workplace ergonomics hold the potential to provide new insights. A first step towards this is the systematic combination of the intradisciplinary KPIs, processes, and data. A potential interleaving automatically takes place in LE. An interdisciplinary combination of DT and DHM in LE is currently not yet evident to a sufficient degree. Scientific institutions, application-oriented researchers, and companies should follow this call and bring detailed, workplace-related processes and large, company-organizational and production-planning processes closer together in science and practice.

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