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Original Contribution

TOWARD A CONCEPT OF LOGISTICS ERGONOMICS: HUMAN FACTORS IN INTELLIGENT WAREHOUSE SYSTEMS

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Abstract: *Digitalisation and automation have transformed warehouse operations, but they have not removed the human operator from the logistics system. Instead, warehouse work increasingly combines physical handling with digital instructions, time pressure, exception management and interaction with intelligent technologies. This conceptual paper develops logistics ergonomics as an engineering-logistics perspective that considers physical workload, cognitive workload, the technological environment, work organisation and logistics performance within a single analytical frame. The study synthesises established ergonomic methods and recent warehouse research and proposes a preliminary Logistics-Ergonomics Risk Indicator (LERI), implemented as a four-domain screening profile for identifying operations that warrant deeper ergonomic assessment. LERI is not presented as a validated risk scale and is not intended to replace RULA, REBA, NASA-TLX, the Revised NIOSH Lifting Equation or other specialised methods. The framework is intended to connect human-factor analysis with warehouse design and operational decision making and to provide a basis for subsequent expert validation and empirical testing.*

Key words: *Logistics ergonomics, Engineering logistics, Warehouse operations, Human factors, Cognitive workload, Physical workload, Smart warehouse, Ergonomic risk.*

1. Introduction

Warehouse systems are commonly evaluated through throughput, cost, order accuracy, space utilisation and cycle time. These measures are necessary, but they do not fully describe the quality of a system in which human operators repeatedly lift, walk, reach, interpret digital instructions, respond to exceptions and work under time pressure. Digitalization may reduce some forms of physical effort while simultaneously increasing information processing and attentional demands.

The International Ergonomics Association defines ergonomics/human factors as a discipline concerned with interactions between humans and other system elements and with optimising both human well-being and overall system performance [1]. This systems perspective is directly relevant to intralogistics. Recent warehouse research confirms that ergonomics is no longer a peripheral issue: a systematic review by Nasir, Venkitasubramony

and Jakhar identifies fatigue, safety, human factors and technological interventions as major themes in warehouse ergonomics research [2].

The aim of this paper is to conceptualize logistics ergonomics as an integrated engineering-logistics approach and to propose a preliminary framework for analyzing physical and cognitive workload in intelligent warehouse systems. The object of study is warehouse and intralogistics work systems; the subject is logistics-ergonomics risk arising from the interaction of workload, technology, work organisation and logistics performance. The proposed framework is conceptual and is intended for subsequent expert and empirical validation.

2. Related work

Physical ergonomics remains central to warehouse work because manual order picking, pallet handling, packing and replenishment involve lifting, carrying, pushing, pulling, reaching and repetitive motion. Loske et al. provide empirical evidence of musculoskeletal strain in retail intralogistics and connect ergonomic conditions with social sustainability [3]. Established observational methods offer different views of such exposure. RULA focuses on upper-limb, neck and trunk posture [4], REBA supports whole-body postural assessment in dynamic work [5], and the Revised NIOSH Lifting Equation provides a structured method for manual lifting evaluation [6].

Cognitive ergonomics has become more important as operators interact with WMS platforms, scanners, pick-by-light or pick-by-voice systems, mobile terminals and automated equipment. Kretschmer et al. discuss cognitive ergonomics in intralogistics in relation to human information processing and technology use [7]. Subjective workload can be assessed using NASA-TLX, which includes mental demand, physical demand, temporal demand, performance, effort and frustration [8].

Warehouse design research increasingly acknowledges the need to combine performance and ergonomics. Nasir et al. show that the literature includes technological interventions, assignment decisions, fatigue, learning and safety, but also identifies substantial opportunities for further integrated work [2]. ISO 6385 provides an additional systems-oriented reference by emphasizing the balanced design of human, technical and organisational components of work systems [9]. The present study builds on these foundations by translating them into a logistics-oriented conceptual structure.

3. Problem description and methodology

The conceptual problem is that ergonomic information is often generated separately from logistics performance information. A workstation may receive a posture score while the warehouse simultaneously reports picks per hour and order accuracy, yet these two views are not always considered within the same decision process. Logistics ergonomics is proposed here as an integrative engineering perspective, not as a new clinical or regulatory discipline.

Five components are used in the conceptual model: physical workload, cognitive workload, technological environment, organisational regime and logistics outcome. The components and their engineering-logistics relevance are summarised in Table 1.

Table 1. Conceptual model of logistics ergonomics

Component	Typical content	Logistics relevance
Physical workload	lifting, carrying, pushing, pulling, reaching, repetition, posture	fatigue, musculoskeletal exposure, work capacity
Cognitive workload	attention, memory, instructions, decisions, exception handling	accuracy, error probability, response quality
Technological environment	WMS, scanners, terminals, picking aids, robots	may reduce or redistribute workload
Organisational regime	pace, shifts, breaks, rotation, staffing	recovery, fatigue accumulation, work sustainability
Logistics outcome	throughput, errors, safety, quality, cycle time	system-level performance and trade-offs

The methodology is based on conceptual synthesis. Established ergonomic methods are not combined mathematically because they address different constructs and employ different scales. Instead, they are retained as specialised follow-up tools. The proposed Logistics-Ergonomics Risk Indicator (LERI) is consequently formulated as a screening profile for identifying operations that warrant more detailed assessment.

4. Conceptual results and discussion

The first conceptual result is a working definition: logistics ergonomics is an interdisciplinary engineering-logistics approach concerned with adapting logistics processes, workplaces, technologies, information systems and organisational regimes to human physical and cognitive capabilities while maintaining safe, reliable and efficient material-flow performance.

The second result is the LERI screening framework. Rather than adding heterogeneous ratings into an apparently precise universal score, the framework groups observations into four diagnostic domains and retains the resulting domain profile. This avoids the misleading implication that a high physical-demand rating could be numerically 'cancelled' by a low cognitive-demand rating.

Table 2. Preliminary LERI screening domains

Domain	Indicative observations	Suggested screening scale
Physical demand	force, load handling, repetition, posture, reach, walking distance	1 low – 5 high
Cognitive demand	instruction density, memory, attention switching, error consequence, time pressure	1 low – 5 high
Technology and interface	clarity of WMS/terminal information, device interaction, automation exceptions	1 supportive – 5 demanding
Organisation and recovery	pace, breaks, rotation, staffing, variability of workload	1 favorable – 5 unfavorable

Logistics outcome is deliberately not scored as a risk domain in LERI. It is treated as a paired outcome dimension, because throughput, error rate, quality and cycle time describe system performance rather than ergonomic exposure itself. Keeping exposure domains and performance outcomes analytically separate makes it possible to examine trade-offs without conflating cause and consequence.

A screening result should be interpreted as a profile rather than as a validated exposure limit. An operation receiving high ratings in any domain should be examined with an

appropriate specialised method. For example, lifting tasks may require the Revised NIOSH Lifting Equation [6], postural concerns may warrant RULA or REBA [4, 5], and subjective workload can be explored using NASA-TLX [8]. The LERI profile is therefore a triage mechanism for engineering-logistics analysis, not a substitute for established ergonomic assessment.

A single additive score is deliberately not used at this stage. Without empirical validation and justified weighting, such a score would create a degree of numerical precision that the present evidence cannot support. Retaining separate domain ratings preserves diagnostically useful information and provides a clearer basis for validation. A subsequent empirical study could examine inter-rater agreement, content validity and associations between domain ratings, error frequency, cycle time, discomfort and fatigue before any composite index is considered.

The logistics value of the framework lies in the possibility of using ergonomics at the same decision point as layout, slotting, picking technology and staffing. For example, a proposed increase in picking rate should be assessed together with reach frequency, walking distance, information density and recovery opportunities. Similarly, automation should be evaluated according to whether it reduces total human burden or merely converts physical demands into cognitive or organisational demands.

The study has three main limitations. First, the proposed definition and LERI domains are conceptual and have not yet been validated empirically. Second, the framework does not establish exposure limits or support clinical conclusions. Third, warehouse technologies and work organisation vary considerably, so local adaptation is necessary. Future work should include expert assessment of content validity followed by pilot observations in real warehouse processes.

5. Conclusion

Logistics ergonomics provides a way to bring the human operator into the same engineering analysis as material flow, technology and performance. In intelligent warehouses, this is increasingly important because automation changes the distribution of physical, cognitive and organisational workload rather than simply removing human work.

The proposed five-component conceptual model links physical and cognitive workload with technology, work organisation and logistics outcomes. The LERI framework is intentionally conservative: it is a preliminary screening profile, not a validated universal risk index. Its practical value should be tested through expert review and empirical observation before thresholds or composite scores are introduced. This methodological caution provides a more defensible basis for subsequent research and for applied engineering-logistics assessment.

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