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How to improve worker's well-being and company performance: a method to identify effective corrective actions

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Abstract

In manufacturing context, social dimension is often neglected. With Industry 4.0, companies focus more on technologies and data. However, human continues to play a key role in cyber-physical systems and company growth. This work proposes a method to help the company to evaluate workers' experience and identify the optimal solution to improve workers' well-being and company performance. It starts from personalized social analysis within a production plant to identify ergonomics problems and intelligently suggest effective corrective actions. The latter are selected achieving the best trade-off between social, economic and productive aspects. Three case studies are proposed to validate the method.

Keywords: social sustainability; manufacturing systems; human factors; Industry 4.0

1. Introduction

Social sustainability has been often neglected in recent years. In literature there are no methodologies and tools to objectively evaluate processes' impacts on human. Similarly, there are not objective correlations between the well-being of the operator and company performance. These evaluations become indispensable if we become aware that human continues to play a key role for company growth [1]. In addition, industries are now going through a technology transition toward the Industry 4.0. New technologies, on one hand, offer new opportunities for ergonomic evaluation of operator and environment, but, on the other hand, they can cause new stressors deriving from human-machine interaction (HMI). In this context, a human-centered design approach is needed. Designer should integrate ergonomic evaluations during the design phase [2]. Ergonomics is the multidisciplinary science that concerns the understanding of the interactions between the following three elements that characterize a work system: man, machine and environment [3]. Domains of specialization within the discipline of ergonomics are broadly the following: physical, cognitive, environmental and organizational [4]. Physical ergonomics deals with human-machine-environment interactions from a mechanical and physical point of view. In the specific context, relevant topics include working postures, materials handling, repetitive movements, work related musculoskeletal disorders, workplace layout, safety and health [5]. The literature proposes many methods/tools for the assessment of related risks (e.g. RULA [6], OCRA [7], Revised NIOSH Lifting Equation [8],). However, most of them requires a manual data acquisition, which is based on direct observation of the operator during the execution of a specific task. In this regard, the diffusion of IoT technologies could be exploited to automate this phase with considerable benefits in terms of time, costs and accuracy of results. Cognitive ergonomics focuses on the analysis of cognitive process and is used to support humans in their interaction with a system, according to their skills and

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limitations [9]. Relevant topics include attention, perception errors, strategies, workloads, information visualization, decision support, HMI, situation awareness and training [10]. The interest of this aspect of ergonomics is growing due to a wide variety of information systems that can increase operator's mental workload. Current studies mainly focus on self-assessment tools (e.g. NASA-TLX [11]) or are limited to specific sectors (e.g. aerospace, medicine). Environmental ergonomics analyzes the main physical factors that determine microclimate (temperature, relative humidity, radiant temperature and air speed), noise, lighting level and air quality in the workplace [12]. This domain has been extensively treated due to the strong regulatory pressure. As a result, most of the analysis focus on verifying compliance with regulatory requirements, rather than the operator well-being. Few studies directly involved workers in order to assess the perceived well-being in terms of comfort, satisfaction and health [13]. Finally, organizational ergonomics concerns the optimization of sociotechnical systems, including their organizational structures, policies and processes [14]. Topics such as resource management, work planning and work time planning are covered. In particular, the planning and organization of production is mainly based on the knowledge, ability, physical and psychological well-being of workers in order to reduce stress, improve motivation and employee satisfaction [15]. To complete the analysis of the well-being of the operator in the factory environment it is necessary to consider also human-robot/machine interaction [16]. With the fourth industrial revolution, the figure of the Operator 4.0 inside an intelligent factory is born [17]. In this context, it is essential to start giving measures to social concerns. So, it is necessary to quantify these ergonomic aspects through Key Performance Indicators (KPIs). In the literature there are several KPIs to analyze ergonomic or company performance aspects. However, there is no a complete KPIs classification to evaluate all four ergonomics domains, nor do they include aspects of productivity. The challenge of this paper is being able to achieve the right trade-off between company performance and physical-cognitive needs of individuals operating in the production context. It starts from personalized social analysis within a production plant to identify the main risk factors, suggest effective corrective actions and evaluate the related benefits. Currently, there are no complete and detailed classification of all ergonomic risks in the manufacturing context and a classification of corrective actions to be applied in case of a risk detection. This paper aims to fill this gap by proposing a method that supports companies to carry out a social sustainability analysis and identify the most suitable corrective actions for specific risks.

The rest of the paper is organized as follows. Section 2 introduces and describes the method proposed. Section 3 illustrates the application of the proposed method through three case studies. Finally, conclusions close the last part, Section 4.

2. Method

The method, shown in Fig.1, contains guidelines to support companies for carrying out social sustainability assessments. The first steps have already been presented by authors [18]. This paper focuses on an updated version of the last three steps, formalizing risks, corrective actions and KPIs and investigating their correlation. It may be self-consistent or preceded by the configuration of an IoT framework, supporting both risks identification and KPIs assessment.

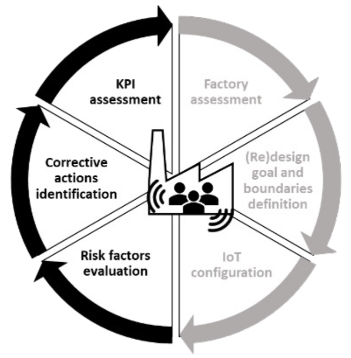

Fig. 1. Design method for social sustainability assessment.

The methods presented in Table 1 have been followed for the identification of risk factors, corrective actions and KPIs.

Table 1. Method of data research.

	Literature review	Workplace Health & Safety national DB	Commercial solutions
Risk factors	√	√	
Corrective actions	√	√	√
KPI	√		

For their classification the following inclusion criteria have been considered: manufacturing context, in particular, the production area, at least one of the four ergonomic domains and human-related performance. The resulting classification is presented in Table A1 and described in more detail below.

2.1. Risk factors evaluation

Based on literature review and workplace health & safety national database consultation, six macro-categories of risk factors were identified [19, 20, 21, 22, 23]:

- *Awkward posture*, where all the risks that can cause damage to physical parts of the body have been included;
- *Workspace* considers risks deriving from an inadequate workstation, which do not allow workers operate within the recommended zones;
- *Work activity* examines risks deriving from manual handling and movements required to perform the task;
- *Work organization* analyses risks related to organizational choices, impacting on the overall workers experience;
- W*ork environment*, where are considered all environmental factors that indirectly affect the operator's activity;
- *Tools and devices*, which includes aspects related to HMI that mainly affect the cognitive domain.

2.2. Corrective actions identification

Subjected to literature review, workplace health & safety national database consultation and commercial solutions, corrective actions categories were summarized [24, 25, 26]:

- *Equipment* considers all physical solutions designed to support workers during the task execution;
- *Design* analyzes solutions related to (re)design of the workstation, layout, and all the relative accessories aimed at preventing wrong postures or unnecessary efforts;
- *Workplace* includes solutions to improve operators environmental comfort. They are not necessarily related to a specific task, but consider the overall work environment;
- *Management* considers organizational solutions. All these solutions aim to make the work environment more stimulating. The main goal is to reduce the mental workload and avoid that stress-related diseases emerge;
- *Training* classifies solutions that aim to improve the risks awareness and skills of workers', reducing the cognitive effort during the task execution.

2.3. KPI assessment

Following literature analysis, KPIs were identified and grouped into five categories [27, 28]:

- *Factory performance* contains the most common objective indicators that help companies to evaluate productive benefits and resources management;
- *Perceived workload* considers indicators related to the worker's perception of work. In particular, the first six indicators are part of NASA-TLX assessment tool;
- *Work-related diseases* monitor acute, recurring or chronic health problems caused by work context. Usually, these indicators give long-term findings as some diseases have long latency periods, making difficult to identify the impact of each work-related risk factor;
- *Knowledge* analyses workers' awareness and skills about health and safety risks, operations, and technologies;
- *Workplace* includes indicators concerning all workplace' ergonomics aspects and the collaboration between humans and human-automation.

Each KPI could be evaluated by the set of specific indicators, belonging to the abovementioned categories, with which the company is more familiar. For example, for I1.2 they could be scraps, defects, First Pass Yield, human error incidence, etc.; for I5.1 there are OCRA Index, RULA score, percentage of activities within golden zone, etc.

2.4. Correlation

Once all risks, corrective actions and KPIs have been classified, it was necessary to identify the correlations between them, by answering to the following questions: Which corrective actions can be used to manage any individual risk? Which KPIs are affected (directly or inversely proportional) by the implementation of any corrective action?

For this aim, the methodology represented in Fig. 2 has been followed. Firstly, a knowledge base has been created by considering the evident logical correlations that exist "a priori" (e.g. R3.7/A1.1) and the hypotheses of correlations, then less obvious, coming from the literature analysis (e.g. A4.4/I3.6) or authors experience.

At this point, a multidisciplinary team (2 management engineers, 2 biomedical engineers, 1 design engineer, 1 mechanical engineer, 1 electronic engineer, 1 project manager, 1 psychologist and 2 doctors in work's safety) was involved to confirm the a-priori correlations, identify other ones and favor the discussion to analyze different points of view. Brainstorming consisted of two sessions, during which the correlations between risks-corrective actions and corrective actions-KPIs were analyzed respectively. If unanimity was reached before or after discussion strong and weak correlations were defined respectively. In case of controversial opinions, uncertain correlations were preliminary established based on the majority. However, correlations need to be empirically validated.

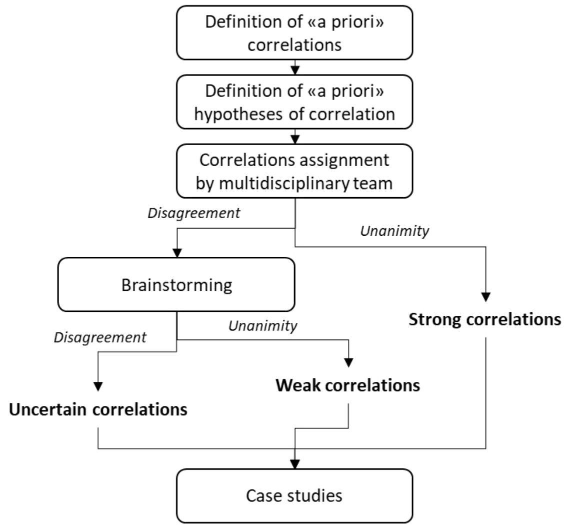

Fig. 2. Methodology for the validation of correlations.

Most of the members agreed from the beginning on which actions were most appropriate to manage a risk. No uncertain correlations resulted from the first brainstorming session. In general, stronger correlations involved R1, R2, R5, R6, A1, A2 and A3 and weaker correlations referred to organizational domain. In particular, it emerged:

- All risks related to awkward posture (R1) are mitigated by ergonomic equipment (A1), task design (A2), task allocation strategies (A4) and training (A5);
- Workspace risks (R2) are totally covered by equipment (A1) and workstation design (A2);
- Work activity risks (R3), especially manual handling, are mitigated by all action categories;
- Work organization risks (R4) are mainly faced by management (A4) and training (A5) actions;
- Work environment risks (R5) are directly covered by workplace actions (A3);
- Risks related to tools and devices (R6) are mainly tackled by training activities (A5).

The second session, instead, has been much more onerous and has led to numerous moments of discussion. The correlation between corrective actions and KPIs has not always been so foregone. The following considerations emerged:

- Knowledge (I4) and workplace (I5) have almost exclusively generated strong correlations;
- Work-related diseases (I3) mainly generated weak correlations due to the poorest knowledge of the domain by experts with engineering background compared to the medical one;
- Uncertain correlations mainly refer to perceived workload (I2), especially frustration (I2.6) and job satisfaction (I2.7), because of its subjective nature. In general, it emerged that they are mainly influenced by management actions (A4), apart from physical demand (I2.2) and effort (I2.5) that are also positively influenced by A1 and A2;
- Correlations involving factory performance (I1) are more articulated: stronger with A1 and A5, indeed, almost all corrective actions have a positive impact on productivity (I1.1); weaker with A2 and uncertain with A4.

Overall, it emerged that the relation between A4 and I2 is the most controversial, needing further investigation. In particular, A4.10, A4.15 and A4.17 resulted the most critical management actions. Moreover, in some cases, it was not possible to define whether the impact on KPI was directly or inversely proportional. This is because the perception of some organizational solutions is subjective, then, strictly related to worker's perception.

3. Case study

The proposed method has been applied in three different Italian industrial contexts: (A) large household appliances (*Finishing and Testing* department of *Laundry* plant); (B) powertrain components and cabs for agricultural machines (*Mechanisms*, *Hubs and Spindles*, *Cover*, *Front Axles* and *Cabs* lines); and (C) rubber and polyurethane soles (*Packaging* area). In total 22 workstations were analyzed. Hereafter, the results of five of them, involving all action categories, are summarized. Company C focused on the social sustainability improvement and implemented all steps of the proposed method [18]; unlike companies A and B that followed only the last three ones, driven by *Cost Deployment* and *Workplace Organization* pillars of the World Class Manufacturing methodology. According to the risk factors identified by company managers and IoT devices (C), the proposed classifications and correlations were exploited to select the most appropriate corrective actions and evaluate their effectiveness (Fig. 3). Different specific indicators have been selected by companies to evaluate short-term benefits, unlike the long-term benefits that have not been quantified yet.

In the first case, the workstation dedicated to product packaging is analyzed. The main problem was given by the excessive quantity of disorganized and bulky packaging material on the line. The operator is forced to make non-ergonomic movements and to walk around to reach the pallets. The re-design of workstation layout (three roller conveyors and four gravity slides organized by packaging material) and workflow allow operators work more within the strike zone (+54%) and golden zone (+20%) with significant benefits expressed by the removal of MURI (overburden) of Level 1 (-71%). Moreover, manual handling was reduced of 20%.

The second case focused on (i) workers training about the most complex assembly operations on *Front Axles* line and step by step support to face the poorer attention paid to simplest operations and (ii) the workload balancing of *Cabs* line, taking into account ergonomic issues (based on ERGO-UAS method [29]). The former allows reducing human error of 60% through the implementation of visual management tools, user friendly instructions (One Point Lesson) and real-time feedback (colored LED). The latter allows increasing the line productivity of 2% and reducing time of 7%.

The third case focused on the company area that comprises most of workers. From the data collected by the IoT framework resulted that the PET foil separation for sole packing entailed a high work demand and the near painting area negatively affected the indoor air quality. The implemented actions allowed to obtain the following short-term benefits: peaks elimination in the EOG graph and airborne pollutants constantly below recommended levels.

COMPANY A	R1.2	R1.3	R1.4	R2.1		I1.1	I2.2	I2.5	I2.7	I3.1	I3.2	I3.5	I5.1
	x	x	x	x	A1.9	x	x	x	x	x	x	x	x
				x	A2.12		x	x	x	x	x	x	x
				x	A4.5		x	x	x	x	x	x	x

COMPANY B	R4.4	R4.14	R4.16		I1.1	I1.2	I2.1	I2.2	I2.4	I2.5	I2.6	I2.7	I3.6	I4.2
	x			A4.8	x		x	x		x		x	x	
			x	A5.7		x	x		x		x	x	x	x
		x		A5.8	x			x		x		x		
			x	A5.9		x	x		x		x	x	x	x
			x	A5.10		x	x		x		x	x	x	x

COMPANY C	R4.4	R5.3	R5.5		I1.5	I2.1	I2.6	I2.7	I3.3	I3.6	I3.7	I3.8	I4.1	I5.1	I5.2
	x			A2.2		x	x	x		x				x	
		x		A3.7	x										x
			x	A3.8	x				x		x	x	x		x

Fig. 3. Correlations between risks tackled, actions implemented and KPIs involved.

3.1. Discussion

The method experimentation in three different industrial realities evaluated its transversality, generating important findings. On one hand, all identified risks found an effective solution in the proposed list. No item has been added to the classification. All companies selected a subset of actions-related KPIs because some of them were not significant for the specific case (e.g. no complains related to identified risks were registered before (I1.5) or nobody has reduced work capacity (I3.9)). A new correlation between actions and KPIs (A3.8/I4.1) was proposed: the implementation of an ergonomic solution can be seen as indirect training.

On the other hand, Company A adopted only direct observation methods, Company B carried out a manual analysis to identify risks and executed a preliminary evaluation of KPIs in a virtual simulated environment and Company C exploited the IoT framework for all analyses. It emerged the following benefits deriving by IoT: reduction of time and resources; more objectively identification of risks; real time monitoring favoring the continuous improvement; monitoring of workers' biometric parameters enabling personalized analyses and encouragement of proactive workers' behaviors.

4. Conclusions

The paper deals with the social dimension in manufacturing companies. It proposes a method to analyze the workers' experience, focusing on the risk factors management. They are identified and classified in order to draw up a list of corrective actions that allow preventing or reducing them. In order to create a holistic supporting tool for human-centered manufacturing, different human-related domains have been investigated: physical, cognitive, environmental, organizational and HMI. It allows increasing the companies' attention to workers' well-being and satisfaction by bridging the current gap between social, economic and productive relapses. Indeed, a correlation between risks, corrective actions and KPIs have been created.

The proposed approach has been tested in three different real industrial contexts with significant benefits from an ergonomic, productive and qualitative point of view. In the next future, also long-term benefits will be quantified.

Future works will focus on the empirical validation of correlations, involving a significant sample, and the development of a tool that automatically suggest the most proper actions and allow simulating the achievable results based on machine learning algorithms.

Appendix A.

Table A1. Classification of risks, corrective actions and KPIs

Risk	Corrective action	KPI
R1. Awkward posture R1.1 Neck R1.2 Back R1.3 Upper limbs R1.4 Lower limbs R2. Workspace R2.1 Workstation layout R2.2 Reach distance R2.3 Work height R3. Work activity R3.1 Standing up at same position for a long period of time R3.2 Sitting down for a long period of time R3.3 Repetitive movements R3.4 Forceful movements R3.5 Precise and fine movements R3.6 Manual lifting R3.7 Manual carrying R3.8 Manual pulling R3.9 Manual pushing R4. Work organization R4.1 Task variety R4.2 Task repetitiveness R4.3 Work rhythm R4.4 Work demands R4.5 Shift management R4.6 Breaks management R4.7 Work scheduling autonomy R4.8 Decision-making autonomy R4.9 Work relationships R4.10 Lack of support from supervisors and/or co-workers R4.11 Role conflict R4.12 Work/life Balance R4.13 Lack of incentives R4.14 Lack of awareness about health and safety risks R4.15 Lack of skills R4.16 Lack of expertise R5. Work environment R5.1 Lighting R5.2 Noise R5.3 Smell R5.4 Microclimate R5.5 Agents exposure R6. Tools and devices R6.1 Lack of work equipment R6.2 Functionality of work equipment R6.3 Lack of tools supporting healthy body posture R6.4 Lack of training tools R6.5 Vibration load R6.6 New technologies R6.7 Lacking or complex work instructions R6.8 Lacking or complex user interface	A1 Equipment A1.1 Cart or platform truck A1.2 Hand truck A1.3 Pallet truck A1.4 Forklift A1.5 Stacker A1.6 Tilter A1.7 Lifter A1.8 Hoist or crane A1.9 Conveyor, slide, or chute A1.10 Carousel A1.11 Turntable A1.12 Use an airball table A1.13 Weightless positioning balancer A1.14 Reaction arms A1.15 Industrial manipulators A1.16 Collaborative material handling robot A1.17 Collaborative assembly robot A1.18 Collaborative quality inspection robot A1.19 Collaborative machining robot A1.20 Exoskeleton A2 Design A2.1 Reduce the weight of the load A2.2 Packing containers to increase handling A2.3 Tag the load to alert workers (heavy, fragile, unstable, etc.) A2.4 Provide multiple grip points to facilitate lifting and transport of loads A2.5 Provide gloves that increase grip stability A2.6 Store loads so that they can be handled within the worker's power zone A2.7 Avoid manually lifting or lowering loads to or from the floor A2.8 Slide, push, or roll instead of carrying, when appropriate A2.9 Avoid carrying large or bulky loads that limit or obstruct your vision A2.10 Arrange spaces to improve access to materials or products being handled A2.11 Use team lifting as a temporary measure for heavy or bulky objects A2.12 Minimize the distances loads are handled A2.13 Provide appropriate shoes to avoid slips, trips, or falls A2.14 Improve access to containers (angled shelving, side-opening door, etc.) A2.15 Design easy gripping components A2.16 Workstation layout allowing operators work within the strike zone/golden zone A2.17 Adjustable work surface A2.18 Provide ergonomic workstation accessories to increase workers' comfort (footrest, armrest, headsets, etc.) A2.19 Ensure a proper sitting posture A2.20 Ensure an appropriate lighting on the work surface A2.21 Configure the workstation to allow easy cleaning and maintenance A2.22 Provide equipment promoting reaching (hook, portable work platform or steps, etc.) A2.23 Consider using powered equipment when forces are excessive A2.24 Prefer lighter-weight equipment A3 Workplace A3.1 Avoid or display wet floor and obstacles A3.2 Ensure a safe and comfortable transit of vehicles and people A3.3 Installing barriers to reduce risk of accidents A3.4 Ensure thermal comfort A3.5 Ensure adequate lighting A3.6 Reduce noise A3.7 Eliminate or reduce bad smells or odors A3.8 Reduce exposure to biological and chemical agents A4 Management A4.1 Definition and adoption of a Code of Ethics or of Conduct A4.2 Plan meeting between executives/managers and workers for communication, feedback, idea sharing, problems solving, etc. A4.3 Improvement of company communication standards/methods A4.4 Provide sufficient information to enable workers to perform tasks competently, including adequate support and resources A4.5 Optimize the workflow A4.6 Definition and description of the roles and responsibilities of each worker A4.7 Plan realistic and feasible deadlines A4.8 Workload balancing A4.9 Redistribution of workload, even temporarily for critical periods, or extra work A4.10 Limit giving workers tasks that under-utilize their skills A4.11 Task allocation according to workers' skills A4.12 Task allocation according to workers' physical characteristics	I1 Factory performance I1.1 Productivity I1.2 Quality I1.3 Organizational incentives I1.4 Employee turnover I1.5 Employee complains I2 Perceived workload I2.1 Mental Demand I2.2 Physical Demand I2.3 Temporal Demand I2.4 Performance I2.5 Effort I2.6 Frustration I2.7 Job Satisfaction I3 Work-related diseases I3.1 Absenteeism I3.2 Accident rate I3.3 Sickness absence I3.4 Vacation I3.5 Musculoskeletal disorders I3.6 Stress and mental health disorders I3.7 Work-related cancer I3.8 Work-related diseases due to biological agents exposure I3.9 Reduced work capacity I4 Knowledge I4.1 Risk control I4.2 Operations skills I4.3 Technology skills I5 Workplace I5.1 Ergonomic workstation I5.2 Ergonomic environment I5.3 Human-Automation collaboration I5.4 Human-Human collaboration

Risk	Corrective action	KPI
	A4.13 Team building according to workers' skills and characteristics	
	A4.14 Dynamic scheduling of shared human-robot operations	
	A4.15 Rotate tasks and schedules	
	A4.16 Redefine work breaks according to specific needs/activities	
	A4.17 Give workers some control over the way they do their work	
	A4.18 Flexible work arrangements	
	A4.19 Promote a work-life balance and encourage workers to take annual leave or holidays	
	A4.20 Strive to make working hours regular and predictable	
	A4.21 Avoid encouraging workers to overwork	
	A4.22 Rehabilitation and/or reinstatement programs	
	A5 Training	
	A5.1 Health and safety training	
	A5.2 Training to ensure the safe use of working equipment	
	A5.3 Training programs according to workers' skills	
	A5.4 Training about new technologies	
	A5.5 Cross-training programs	
	A5.6 Pairing with expert workers in the event of new roles/tasks	
	A5.7 Simple step by step work instructions	
	A5.8 Provide best-practices to better execute tasks	
	A5.9 Real-time feedback	
	A5.10 Use visual management to convey messages more effectively	
	A5.11 Digital assistant	
	A5.12 Use AR/VR technologies to support workers during the task execution	
	A5.13 Use AR/VR technologies or interactive methods to improve training experience	
	A5.14 Educate workers about the early warning signs of stress and fatigue	
	A5.15 Training on work time management with regard to tasks and/or objectives	
	A5.16 Provide training to workers on how to develop relational skills	
	A5.17 Provide training to workers on how to cooperate, diffuse difficult or manage conflict	
	A5.18 Make psychological/medical support available to workers who are directly and indirectly involved in a traumatic event or in other emotionally demanding work	
	A5.19 Rehabilitation and/or reinstatement training programs	

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