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Production Planning Process Based on the Work Psychology of a Collaborative Workplace with Humans and Robots

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Abstract: This study focuses on discerning how economics, as it pertains to work psychology, is lent a new perspective by the compatibility of humans and robots cooperating in the manufacturing sector. The stability of production plans, flexibility of the organizations, and the management of production constitute the basis for such analysis. In this context, initial findings revealed that steady performance by an individual was significantly influenced by a production plan, while the cycle and lead times in place fundamentally affected the behaviour of employees. Observations were made over five years of 200 workers at 100 manufacturers. Times given over to operations and cycles, and throughput, were primarily defined by the technical cycle of the robot. The secondary element of production planning was the employee, whose operator cycle time was informed by that of the robot. The authors set out to deduce which key factors altered the work psychology in situ in manufacturing environments where collaboration occurred between humans and robots. Prerequisites for optimal psychological conditions were identified (the cooperating human, production planner, collaborative workplace, standardized durations of complete tasks, distance between the worker and robot, and data analytics of production flow). Ensuring circumstances are optimal in terms of work psychology is essential to raising productivity and employee performance. Results showed that the operator was directly dependent on the robot in relation to mutual, continuous production flow. A model of production plan stability was devised, informed by the dependence of specific parameters of the planning model. Research was conducted on the reliance of selected parameters, leading to establishment of prerequisites for an optimal work psychology setting in enterprises with such a collaborative structure.

Keywords: Industry 4.0; human–cobot interaction; job; psychology; process

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1. Introduction

Fundamental to the matter is ensuring the psychological balance of a person in this kind of collaborative workplace. Production planners make a series of trade-offs in schedules every day in the pursuit of maximum production capacity. A robot intended for such an environment must be highly efficient in regards to productivity with minimal risk of failure. In this context, determining an optimal production schedule requires taking the physical and psychological capabilities of the worker collaborating with the robot into consideration.

A key prerequisite for optimal manufacturing performance is having a stable production process, integrated with Operator 4.0. Operator 4.0 is a smart and skilled operator who performs not only 'cooperative work' with robots, but also 'work aided' by machines as and if needed, using human cyber physical systems, advanced human–machine interaction technologies, and adaptive automation towards 'human-automation symbiosis work systems'. Within the setting of a human and a robot being directly part of the collaborative workplace, a paradigm shift occurs in how such a collaborative environment is set up. A traditional approach functions in line with the derived arrangement of machine and human operations, while a digitally controlled system is scheduled according to the cycle time of the robot and the managed technology. However, intelligent production demands a significant alteration be made in terms of the psychology of the worker, since human–human and robot–human relationships change when a robot possesses an equal collegial position as a worker.

Thorvald et al. [1] identify a 'collaborative operator' as a human cooperating with collaborative robots (cobots). This cooperation is based on coexistence in a shared physical space between two agents: human and cobot. The Cognitive Operator 4.0 represents knowledge and cognitive interactions in which it exchanges process information with the help of technologies to symbiotically perform a task. It is an important part of process management by collaborative workplace the relationship between workload and workers' situation awareness [2]. Artkin [3] defines situation awareness as the ability of smart agents (both humans and artificial) to understand what is happening in the surrounding environment. Based on the Endsley definition [4], the human-decision-making process depends on comprehension of a human meaning and the projection of their status in the near future. Our research, conducted in 100 manufacturing companies, confirmed that as long as a person has experience in a given workplace, it is important to transform this into the operational standards of the workplace, and, at the same time, share his experience in the team of colleagues (cobot is the colleague, robot process, and operation standard improvement). This significantly helps reduce stress before and during the implementation of collaborative cooperation. We called this moment 'predictive response ability' and the core content will be analysed in the upcoming months.

The process of production planning and scheduling requires flexibility from a human perspective, in addition to which adhering to a plan must constitute a priority and the general approach remain flexible [5]. When production flows smoothly and in accordance with the plan, the psychological burden on the employee is normal. This balance is upset by any outages that affect a work shift. A serious issue arises if a robot has to wait for the input or output of a human, heightening the psychological demands placed on the latter. A number of system-oriented connections pertain to maximal cooperation between a human and cobot (a "collaborative robot") within a collaborative work environment [6], as currently being investigated by more than 100 SMEs (in the automotive sector); further description of the matter is given in this paper.

Production planning and scheduling based on digitally controlled processes have affected the psychology of human labour. Procedures governed electronically are managed by software ("SW", by a "digital manager", as defined later); hence, people react exclusively to the prompts provided by the controlling SW. Industrial enterprises have been endeavouring to find a suitable method of combining such technology with lean production activities, and the introduction of Industry 4.0 has innovated manufacturing processes and the use of equipment [7]. In fact, smart technologies have brought about improvement in production-related performance by affording real-time assessment of it [8]. The basis for electronic management of planning and scheduling in manufacturing is knowledge of interrelationships between the parameters of procedures. Each activity has its own specific variable and interval range, and it is important to collect data on ongoing operations, with subsequent analysis revealing the dependencies of such variables in processes. Performance in this context directly depends on the potential to achieve full capacity by the human, robot, and given technology. Assessing the effectiveness of a person is now possible in real time, as is the evaluation of that of the robot and, maybe, the advanced production technology in place. Though it has been observed that a robot performs work consistently at a planned rate, performance in this regard by an employee will occasionally diminish for various reasons. The requirement to provide comfortable conditions for them is crucial in relation to the aspect of work psychology, since workers frequently experience stress and frustration stemming from their performance of tasks. From this point of view, it is necessary to concentrate on planned and online data gathered from the workplace, with analysis making it possible to predict how the worker shall behave as per the manufacturing schedule. Statistical analysis of production processes shows that the ability to manage data from smart processes permits transformation of them into directives for correct management of employees.

A workplace with collaborative production is typically one where workers are forced to concentrate greatly in cooperation with robots. Practical experience and knowledge of various operational situations that take place routinely are critical, because employees undertake duties which they actively control and conduct repeatedly. In contrast, the robot is subordinate to the lead time designated to it with precisely set cycle durations. The psychological difficulty of human–robot cooperation could eventually result in frustration amongst workers; for example, in the event of an involuntary delay in entering a production-related request, or should the robot be ahead and receive work late, leading to it outpacing the I/O of its human co-worker [9]. Disruptions in production flow on the part of the worker might also occur. A way of avoiding issues like these would be to schedule defined downtimes in the activity of workers, then adapt the cycle time of the robot accordingly.

2. Theoretical Review

Recently, there has been an increased interest in conducting research on work psychology. Factors, such as frequent turnover of staff, instability in work positions, a rise in the coefficient of absenteeism, and an increase in occupational diseases, are behind the trend. One tool that facilitates data analysis of cooperation in a collaborative human–robot environment is dubbed "process mapping", which involves obtaining continuous information on arguments affecting the psychological well-being of workers at a production facility [10]. Investigation has focused on defining the performance of staff, i.e., parameters for quantifying and qualifying human performance, though work psychology was considered by the given author as largely ignored [11]; results therein showed that efficient work systems directly correlated with the psychological state of staff. Arefin [12] stated that a psychologically positive manufacturing environment directly influenced the performance of employees. The literature also reports that organization of work practices through targeted psychological measures affects such performance, while Amor [13] wrote that the latter could be managed by applying work psychology as a basic mechanism. Elsewhere, proper orientation of work psychology brought about benefits in psychological capital and job performance, with an associated reduction in reports of burnout [14].

The current recession, economic fluctuations and circumstances relating to the COVID-19 pandemic have highlighted how important it is to consider the psychological aspects of collaborative work, a constituent part of the rapidly growing trend of Industry 4.0 [15]. Two key concepts exist in psychology, those of the "digital worker", and the "digitally controlled worker" (hereinafter referred to as "DW" and "DCW", respectively). A digital worker is a software-controlled robot or machine directed in its operations by elements of artificial intelligence, whereas a digitally controlled worker is a person who does tasks strictly in accordance with prompts given by software. Such an employee in an environment of collaborative production becomes both an initiator of ethics and work standards, and a user of them [16]. The digitization of work brings people and technology ever closer, enabling staff to implement related operations and voice their opinions in the enterprise. Moreover, it facilitates the management and control of duties performed remotely (e.g., at home), and aids employees in pursuit of their jobs and responsibilities. In essence, the DW acts as the primary support mechanism for the DCW. This advancement has encouraged investigation of psychology of work with respect to improving manufacturing processes and innovating associated technologies [17]. A stable process methodology is required to enable this, and the ratio of the DW to DCW determines the foundation upon which the consequent work psychology is based. An analysis of 100 industrial companies in the automotive sector revealed that the more the DW prevails over the DCW, the greater the amount of attention that has to be paid to the manual labour of staff and organization of their duties; thus, consideration is necessary as to how compatible the competence of a person (know-how and skills) relating to digital technologies is with the given production process [18].

The analysis and monitoring of humans integrated into collaborative workshop operations brought information about the changes in workers that occur in a regular work shift in a collaborative workplace (human–robot combination). Before the definition of the parameters was investigated, the analysis of the production shift plan by 200 selected operators was performed (Figure 1).

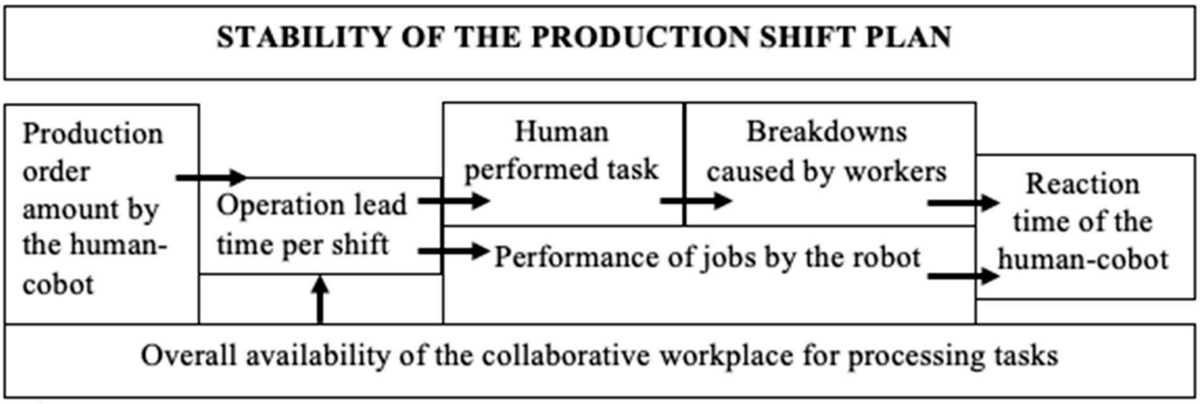

Figure 1. Mutual relationships in the collaborative workplace "human-cobot" (source: author).

The parameters of 'human–cobot collaboration' were identified in collaborative assembly workplaces. Based on the process and ergonomic analysis, the selected workplaces were identified. The selection process was determined by the frequency of the operation, the temporal stability of the operation in the given workload, and the workplace process quality. Continuity with the robot was also important. Herein, information was gained from conducting analysis and field research of people performing operations within a collaborative environment, specifically those on a regular shift at a workplace shared by humans and robots. The following parameters were under study: The following parameters were investigated here:

- the physical load on a staff;
- the psychological stress of a person;
- the stability of a person's workflow;
- the rotation of employees across various workplaces;
- technologically (digitized) assisted monitoring of the performance of individuals;
- the flexibility of workers with regard to downtime in production;
- the proportion of operations undertaken by digital technologies and employees.

The following process-oriented assumptions for optimal work psychology by collaborative workplace were identified:

- flexibility of the employee (settings to ensure a suitable workplace and production flow in real time);
- productivity of the employee (conflict-free, continuous performance of operations with regard to the capacity of the robot);
- set, standardized inputs for processes and manufacturing operations to permit fulfilment of duties by the employee;
- online monitoring of data to aid the organization and management of production;
- horizontal and vertical integration of process data, setting IDs for coded process actions linked to the instigator of an action (employee, machine, robot, information, etc.).

Subsequently, the mutual correlation of the parameters 'human–cobot collaboration' and assumptions oriented to the collaborative process was investigated (Table 1).

Table 1. Mutual correlation of human–cobot collaboration parameters and collaborative process-oriented assumptions (source: own research).

	Process Oriented Assumptions of Work Psychology				
Human–Cobot Collaboration Parameters	**Man Flexibility**	**Man Productivity**	**Stable Standardisation**	**Online Data Monitoring**	**Process Data Integration**
physical load on a person at work	27 M 12 W	120 M 12 W	56 M 9 W	137 M 63 W	7 M 12 W
psychological stress of a person	97 M 43 W	121 M 56 W	95 M 8 W	127 M 45 W	78 M 53 W
the stability of a person's workflow	132 M 63 W	**137 M** **64 W**	137 M 63 W	127 M 61 W	112 M 63 W
worker rotation across multiple workplaces	109 M 57 W	127 M 48 W	37 M 24 W	**137 M** **62 W**	127 M 54 W
digitally set monitoring of a person's work performance	126 M 58 W	**137 M** **660 W**	45 M 27 W	135 M 58 W	111 M 52 W
worker flexibility due to production process downtime	**137 M** **58 W**	110 M 57 W	127 M 56 W	**135 M** **57 W**	97 M 46 W
share of digital and human-driven production activities	116 M 35 W	87 M 54 W	12 M 16 W	35 M 23 W	7 M 13 W

Research was conducted on a sample of 200 operators. Of these, 137 were men (M) and 63 women (W). Each operator was monitored 30 times to objectively assess the static or dynamic load during the job execution. Each row contains the resulting value of the number of operators who had a psychological/stress problem during dynamic changes that were related to random situations at the given workplace and at the given moment of the operation.

Overall, the employees of manufacturing companies became experts at new production technologies and gained experience from digitally controlled production. Should technical conflicts arise, they have the option to discuss and resolve the situation with a colleague or a digital manager. Numerous companies are training employees to adopt a suitable digital and technological perspective.

3. Materials and Methods—Research Limitations

Based on the stability model for the work shift schedule, identification was made as to prerequisites for work psychology and standardized definitions of operations at the collaborative workplace were determined.

With a digitized process at its core, the concept described herein encompasses the aspects of the employee, robot, and digital technology; the flow of data is controlled by a SW algorithm. Key support variables pertain to the extent of digital literacy on the part of the employee and robot, although they obviously differ widely in actual content and procedure, and in relation to applicable work psychology. Cobots are designed to be more akin to co-workers than mere tools, and fluent interaction between operators and their robotic counterparts is critical to the "task and high performance" of the former [19]. Important facets include technological factors (e.g., occupational safety), appropriate configuration of the cobot, employee-centred matters (e.g., fear of redundancy), and gaining an appropriate level of trust with the robot [20]. In the context of work psychology, the link between efficiency and employee satisfaction is crucial, since it represents a function of how much control the worker has over their role in the human–cobot manufacturing team [21].

Based on rules for production planning and scheduling, the following pillars of a collaborative environment were identified:

- human–cobot cooperation is directly dependent on there being sufficient standardized processes in place;
- a production planner is able to identify key parameters for ethical human–cobot cooperation;
- a standardized workplace ensures optimal ethical conditions to achieve the desired level of performance from a human–cobot workforce;

- compliance assessments adhere to the same regulations for humans and cobots, with respect to the duties conducted;
- workplace processes and environment standards are governed by principles of eliminating waste and benefiting from efficacy on the part of the robot (minimization of e-waste);
- all crucial responsibilities of the employee and competences of the cobot are identified and applied as a basis for standardization.

The author conducted interviews with production managers at selected industrial enterprises, the primary topic being work psychology in collaborative workplaces. The following parameters were specified in the production operator's research: the operator controls the communication options with the robot, the robot gives feedback to the human about the performance at the workplace, and the human–cobot conflict resolution process is standardized. As a part of empirical research, we focused on in-depth interviews with assembly operators. Each operator had at least one year of job experience in the given collaborative workplace. The age structure of the operators was between 35 and 52 years old. Empirical research was conducted during 2021–2022. To evaluate the results, we used qualitative research, where we identified and investigated the effects on work psychology at the operator's workplace. Subsequently, we defined significant parameters for the human–cobot collaborative workplace through a comparative analysis from 2 operators, at minimum, by workplace (shift change view on problem). Analysis revealed that up to 86% of the respective employees were affected by psychological stress stemming from the production process; a crucial finding in the opinion of the authors (Table 2). The robot, acting as a colleague in the collaborative process, has the capacity to recognize when an issue arises that impacts the psychological state of the worker during human–cobot cooperation, and respond to it accordingly. The efficiency with which this kind of relationship functions is reliant on the mental well-being of the human and their degree of trust in cooperative endeavours with the robot. These two aspects were seen to be decisive in the research conducted at industrial companies. Manufacturing productivity and ergonomics issues brought extensive opportunities for cobot safety, workplace design, and task scheduling [22].

Table 2. Analysis of the human–cobot collaborative workplace (source: own research).

Human–Cobot Workplace Analysis: Factors Affecting Work Psychology Relating to Planning and Scheduling Practices					
Factor of Work Psychology	**Aspect of Human–cobot Cooperation (Share in % Labour Undertaken by Human and Robot for a Planned Task)**	**Number of Collaborative Workspaces Monitored at 200 Selected SMEs**	**Stability of the Production Plan in Collaborative work (% of Mutual, Planned Tasks Conducted)**	**Number of Psychological Conflicts That Arose between the Human and Robot**	**Acceptable Lead Time of Collaborative Workplace (% of Plan Completed during Actual Lead Time)**
Job definition	70/30 40/60 30/70 20/80 10/90	134 27 18 17 4	80 60 70 70 90	(1–3) (6–8) (2–3) (3–5) (2–6)	(90–95) (80–85) (90–95) (80–85) (90–95)
Production inputs (availability)	90/10 80/20 75/25	176 23 1	90 75 80	(8–10) (7–12) (0–1)	(80–85) (85–90) (80–85)
Continuous production flow before and after collaborative endeavours	80/20 85/15 90/10 95/5	147 34 17 2	80 85 85 90	(5–7) (4–6) (2–3) (0–1)	(80–85) (90–95) (80–85) (90–95)
Technological support provided by staff	YES NO PARTIALL	170 27 3	95 80 85	(2–8) (15–20) (14–17)	(85–90) (75–80) (80–85)

Comment: Total monitored, 200 SMEs—collaborative workplace; of this, 130 SMEs—standardised rules by hybrid workplaces (balanced cooperation human-cobot); 180 SMEs—standardised human performance in a flexible production time; 114 SMEs—production planning and scheduling of digitised processes in cooperation with humans, and according to the reflection on the ethical rules based on actual shop floor conditions.

Descriptive statistics were generated to determine correlations between the given factors for work psychology. Analysis of the data showed that the primary issue affecting production planning and scheduling in a collaborative environment was the availability (i.e., readiness) of the workplace to perform tasks. When such circumstances are favourable, a positive physiological state (satisfaction) prevails amongst staff. The lead time of the employee is dependent on the frequency of continuous production flow, which corresponds with performance per shift (in relation to lead time).

The analysis of the collaborative environment was conducted to verify the scientific hypotheses below:

Hypothesis 1 (H1). *The psychological well-being of a person directly relates to a defined work task.*

Hypothesis 2 (H2). *The production plan and associated schedule are conditioned by availability at the collaborative workplace (in the context of achieving the desired level of performance).*

Hypothesis 3 (H3). *The time taken to react to an issue at a collaborative workplace is a controlled process.*

The following findings were arrived at from investigation of the 200 industrial enterprises:

H1: 183 SMEs ("yes"), 10 SMEs ("no"), and 7 SMEs ("partially"—conflicts arose through changes in production priority).

H2: 165 SMEs ("yes"), 29 SMEs ("no"), and 6 SMEs ("partially"—conflicts arose from production standards).

H3: 120 SMEs ("yes"), 22 SMEs ("no"), and 58 SMEs ("partially"—conflicts arose based on the technologically related cause of unavailability at the collaborative workplace.

The robot performs and undertakes tasks according to precisely defined instructions. It can continue in its duties with adherence to the given production schedule, and has exactly determined functionality for jobs, in addition to which it is able to operate in flexible modes to react to changes in arrangements. The employee represents the immediate co-worker of the robot. Unforeseen circumstances may invoke stress in the worker through having to adapt to alteration in production flow; hence, possessing a state mental readiness is crucial in a collaborative environment. Since the concentration of the worker is affected by the factor of availability (in connection with tasks), attention should be paid to how such tasks are prioritized. The associated learning curve plays an important role, too, especially regarding the application of skill sets of the worker for the performance of operations.

4. Results

Research was conducted in cohort comprising 100 industrial companies and 200 operators. Of these, 130 were men (65%) and 70 women (35%). Almost 85% of the operators had a graduated from secondary school, while 15% possessed a university qualification. The collaborative robots were primarily products by KUKA, FANUC, and ABB.

The correlation of human–cobot collaboration parameters and collaborative process oriented assumptions (Table 1) showed that the key factors of work psychology are connected with the stability of a person's workflow/man productivity, worker rotation across multiple workplaces/online data monitoring, digitally set monitoring of a person's work performance/man productivity, worker flexibility due to production process downtime/man flexibility, and worker flexibility due to production process downtime/online data monitoring. A critical parameter of work psychology is the stability of the work process, which is why the research of collaborative workplaces was first focused on the stability of the production shift plan (Figure 1). Similar arguments are presented in various research papers, such as [23], fluent interaction between the operators and their robotic counterparts; by [24], "resiliency" and "flexibility" capabilities of humans; or by [25], shared workspace for human and robots. Flexibility, cognitive skills, and dynamic thinking by humans are most important parameters of effective work psychology by collaborative workplaces.

The main objective of research was to obtain data on work psychology in a collaborative environment, with investigation of staff employed in such a facility in relation to the following parameters (Figure 1):

1. Amount of production orders for the human–cobot collaborators per shift (POA_{hc}).
2. Operation lead time per shift (OLTs).
3. Cycle time of the human (CT_{man}).
4. Human-originated breakdowns (BD_{man}).
5. Reaction time of the human–cobot arrangement (RT_{hc}).
6. Stability of the plan for modifying production (S_{sp}).
7. Overall availability (capacity) to process production tasks (OAC).

The structure of the proposed indicators corresponds to the production planning indicators. Workload efficiency is based primarily on a stable production plan and a technologically acceptable work schedule. The objective of the empirical research was to determine the stability of the work process in the collaborative workplace. These parameters were chosen as they are a constituent part of planning and scheduling. From a human point of view, a technological acceptable work schedule dictates the stability of a production plan, and such a schedule is a precondition for realizing optimal work psychology in a collaborative environment. A total of 20 repeated observations were made for each employee, the priority being to discern parameters crucial to their cooperation with the robots, since data analytics revealed that the latter did not deviate from the given schedule within the period of a month. Only two companies experienced variance in performance by the robot through unexpected downtime, i.e., 3% of their planned lead time (Table 3). On the contrary, the humans showed several deviations from the planned production time. Therefore, we investigate deviations in work performance by humans, which are related to work psychology.

Table 3. Production flow analysis in a collaborative workplace: sample analysis and calculation of basic variables (selection) (source: author).

Amount of Production Orders Fulfilled Collaboratively per Shift	**Lead Time of Operations per Shift**	**Cycle Time-Human**	**Human-Originated Breakdowns**	**Reaction Times**	**Overall Availability for Realization of Production Tasks**	**Stability of Shift Plans**
POA_{hc} [min]	**OLT_s [min]**	**CT_{ma} [min]**	**BD_{man} [min]**	**RT_{hc} [min]**	**OAC [min]**	**S_{sp}**
420	420	12	21	3		1.00
	$OAC = OLT_s - CT_{ma} - BD_{hum} - RT_{hc}$				384	0.91
410	420	9	10	6		0.98
	$OAC = OLT_s - CT_{ma} - BD_{hum} - RT_{hc}$				395	0.96
400	420	4	12	2		0.95
	$OAC = OLT_s - CT_{ma} - BD_{hum} - RT_{hc}$				402	1.01
420	420	3	5	5		1.00
	$OAC = OLT_s - CT_{ma} - BD_{hum} - RT_{hc}$				407	0.97
395	420	7	9	6		0.94
	$OAC = OLT_s - CT_{ma} - BD_{hum} - RT_{hc}$					1.01

The setting for volume of production crucially affects work psychology, as a prerequisite for this to be optimal is workplace stability from the perspective of staff; after all, they have all the inputs necessary for continuous performance during a shift. It was seen that work psychology benefited from greater stability (consistency) in performance as per workflow, and a higher level of quality in this respect was observed. Table 1 illustrates how such stability in a collaborative environment was dependent on reactions given to instances of downtime.

POA_{hc} = 420 min	OAC 384 min	S_{sp} = 0.91
POA_{hc} = 410 min	OAC 395 min	S_{sp} = 0.96
POA_{hc} = 400 min	OAC 402 min	S_{sp} = 1.01
POA_{hc} = 420 min	OAC 407 min	S_{sp} = 0.97
POA_{hc} = 395 min	OAC 398 min	S_{sp} = 1.01

Subsequent attention was paid to intervals of permitted limits for the parameter S_{sp} for stability. Data on 200 collaborative employees revealed a dependence in the connection between productivity (OAC) and available performance (S_{sp}). The causes of instances of downtime were also analysed, highlighting a correlation between the human and robot as per the times required to fulfil tasks. The instant a mutual task commences is key, and work psychology influences matters at this point within a sequence of collaborative, connected stages (time for initiating a task + time taken to do a task + time for finalizing a task). It is important for a person in such a collaborative team to be situated in front of the robot or perform duties behind it within a clearly defined time frame.

The collaborative robot has the ability to spot when a problem will occur, and send a pre-emptive signal to the operator, followed by a recommendation on rectifying it, thereby lending psychological support to the person. Work psychology is affected by various situations involving the operator:

- staff may intuitively react and decide to tackle an issue with regard to their physical and psychological safety, potentially conflicting with process management;
- the operator follows recommendations given by the robot, diminishing their emotional state, and increasing the chance of errors being made in decision-making and duties;
- the employee chooses to solve a matter in their way, based on personal experience, rather than taking the advice of the cobot, and the human could feel a sense of accomplishment or disappointment in subsequent performance.

In addition to planning and scheduling, achieving a state of work psychology is reliant on solid preparation of all attributes involved in managerial processes (Figure 2). Important elements relating to production flow that affect the psychological well-being of staff include the types of components incorporated in products, assembly tolerances, and time constraints for resetting machinery, and preparatory or final operations. These fundamentally impact the productivity of staff and place emphasis on performance. In the context of an assembly line, for example, the employee is expected to function with a high degree of flexibility, prioritizing it over the aspect of time.

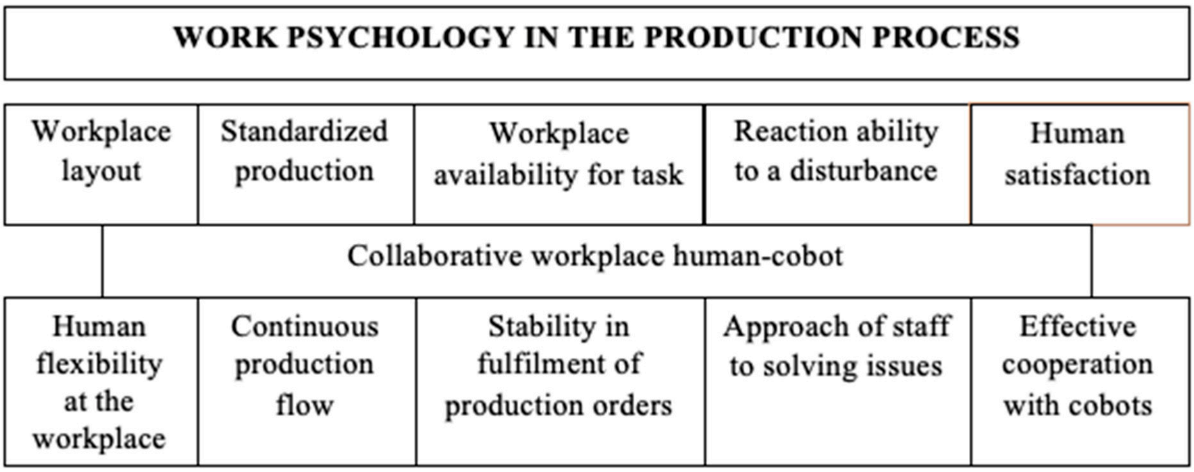

Figure 2. Work psychology in the production process—basic pillars (source: author).

Optimizing working conditions in a collaborative environment for employees necessitates that the latter are suitably qualified for their positions. Stabilizing the production schedule during a shift (to fulfil quotas) around specific lead times is currently a major issue in the industrial sector. In relation to this, significant stressors in a collaborative unit comprise the mismanagement of material and insufficiency in the skill sets of workers. Staff need to feel a sense of confidence about conducting duties and giving good performance, and their mental state can be impacted in the event an issue arises and complicates matters. Continuous control procedures determine the relevant actions to deal with incidents.

The digital literacy that workers possess plays an important role in work psychology. In the given context, it relates to the capacity to collaborate with the digitally controlled machine and presupposes certain cognitive skills, abilities, and attitudes [26]. Reports in the literature have highlighted that digitization exerts a knock-on effect on psychosocial risk at work [27]. Tasks that require physical or manual skills and basic cognitive awareness shall be automated first, whereas more demanding jobs necessitate social, emotional, and technological skill sets instead [28].

5. Discussions and Social Implications

Working in front of a robot leads to a rise in the level of stress experienced by the human, making the situation less stable and altering readiness for performance. In effect, the person is psychologically drawn in to align with the actions of the robot, hence their immediate surroundings are crucial, and it is necessary to ensure all inputs are present and correct prior to the commencement of work. The stress level was investigated by empirical research. The core inputs were human–cobot cooperation and process collaboration. According to the results presented in Table 1 and the results achieved by the research, we distinguish by human factors, such as stability, rotation, and flexibility, as a principal stress factors. The level of risk associated with these factors increases proportionally with the requirements on the digital process monitoring and the productivity index by human working in a collaborative workplace. Therefore, the intentions (diagnostics) in the field of the work psychology should lead to the optimisation of workload in given lead time. The production plan for the work shift determines the optimal production schedule. This fact is essential for a stable work environment and, at the same time, for an optimal psychological adjustment of the human being. De Longis [29] refers to the fact that burnout syndrome may affect the temporal dynamics of negative emotions at work, making them more persistent over time and resistant to change. Due to the use of ICT, workers can be accessible, even after standard working hours, preventing adequate recovery and psychological detachment [30].

Collaborative workplace inputs are technological production sources (material, machine standards, job instructions, etc.), they are necessary components for the production performance as an output. Eliminating stress by human and the improvement of the work psychology setting by collaborative workplace is necessary before the performance. It is conditioned by optimal setting of the parameter "Reaction time of the human–cobot arrangement (RT_{hc})". This variable additionally encompasses the aspect of mental concentration applied by the operator to their labours. The less disorder they have around them before undertaking duties, the more stable their resultant performance. The authors intend to conduct further research on this matter. In our research, we investigated the stress level using an indicator 'Stability of the production change plan' (see Table 3). The presented stability value below 1.0 means an increased level in human stress. The value under 1.0 represents the stability of the production planned tasks completion. In our next empirical research, we want to give attention to the effective psychological collaboration between artificial intelligence and human stress by process task realization in planned throughput time in a collaborative workplace. Artkin [3] stats that the failure detection, quality inspection, enhancing workplace safety, and people concentration on performance are important elements of workplace optimization by a human. Therefore, our further research in this area will focus on the analysis of the interruption parameter by the worker before the robot (Table 4).

Table 4. Work psychology process approach schema (source: author).

Work Psychology at the Collaborative Workplace: Key Processes for Future Research	Specification for Research Purposes
Structure of the planning and scheduling process	Detailed structure of production flow; controlled process for enumerating customer orders; digitization of procedural steps in the cycle of planning, scheduling, and production flow.
Automatization of the production process	Lead-time coordination between production planning and logistics processes, and actual workplace performance and lead times.
Maintenance	Actual, relevant knowledge and skills pertaining to processes and related issues involving technology and workplace practices.
Organization of tasks and their realization	Competence and skill sets of collaborative staff pertaining to actions for actual production and potential disruption, application of KPIs for monitoring performance and eliminating performance wastes.

The robot has the ability to identify technical circumstances that could give rise to disruptions or other issues and respond immediately should the matter have been correctly diagnosed by it. Nevertheless, staff single out processes and deal with problems by drawing on their personal knowledge and experience. The decision-making process they apply transpires differently from that of the robot, since the person finds a solution on the basis of whether they had caused the disruption or not. Past research conducted revealed that people usually relied on the robot to provide a suitable reaction, only seeking the best solution afterwards. This aspect contributes to how arrangements are set for the worker, primarily since the collaborative environment is managed by technology. The person becomes, in essence, a component within the digitally controlled workplace, subordinate to how processes are managed, and the responses of the robot.

In contrast, it is more comfortable to work behind the robot. Staff there are not "feeding" the robot but take items from it. The associated work psychology differs from having to feed it with input, as the primary concern is to keep up with the output rate of the robot. The employee to the front of the robot is under pressure at the start of the operation, whereas the emphasis for the one situated behind it is the duration of its output. This means two different variables exist in relation to the setting of work psychology, and these "push" and "pull" actions are crucial for an optimal work psychology setting; therefore, an enumerated specified order is needed for proper scheduling of production.

In our research, we dealt with the concept of 'push' production (data analysis in Table 3), which is connected with the production planning and scheduling system in the investigated industrial companies. The reason of the push system preference was the human experience in a mass repetitive production. The data from the workplaces provided us with relevant outputs to understand the essence of the psychology of work in a collaborative workplace. The reason for the reliability of the data was the volume and the repeatability of the production. Thus, workers gain relevant experience and knowledge to manage and improve work psychology. Based on this experience, we will start similar research in 2023 in companies oriented to the pull production concept. It is characterized by the piece or small series production. We will try to generalize the results of our research so far, and develop a methodology for managing work psychology in pull production companies.

The goal of future research is to set parameters for "reaction times for productive workers", where the position the operator holds (in front of or behind the robot) is important to analysis. The results of such research shall subsequently be linked with a methodology for planning and scheduling production at the enterprises under study. Distinguishing between planned and actual production capacity is crucial to implementing correct planning and management. As can displayed in Table 1, safeguarding processes are in place to counteract as a stabilizing element of work psychology. Though stability is reduced, and the psychological well-being of the operator is negatively affected, and the level of work psychology diminished. Results prove that correctly enumerating orders for manufacturing goods is crucial to projecting a sense of work psychology, since it represents the impulse for setting the latter. The role of the planner in this is to make sure the production schedule of allotted time slots takes into consideration the capacity of staff for output. Any such plan is informed by the activity of the robot, so it follows that the duties of the employee are scheduled to align with the robot.

6. Conclusions and Recommendations for Future Study

The psychology of a workplace closely relates to a sense of having ownership over human labour. Advances in collaborative environments and related procedures have emphasized the need to consider the staff employed in such a digitally controlled domain [9], which presupposes aspects of hybrid research are applied in evaluation of such a site. Problems stemming from reduced performance by a worker that collaborates with a robot could give rise to psychological disorders [6].

Items for future research have been identified in relation to the limits of this study. The first shall be to analyse to what extent agreement prevails in human–cobot feedback in the event of an unforeseen issue in production. It will then be necessary to discern the dependence of the consequent revision process in real time and psychological readiness of staff for performance. Identifying psychological factors affecting employees in terms of motivation for performance, or barriers that diminish it, would be the overarching purpose of the investigation. Findings shall inform how a stable production plan is set up in a collaborative environment. It is known that a correlation exists between production planning and the effectiveness of human performance in this context. Hence, emphasis shall be placed on the actual content of processes governing production planning and scheduling. The following research questions have been formulated to this end:

- RQ 1: Tasks undertaken at a collaborative workplace are clearly defined in structure and content at a system-wide level.
- RQ 2: The lead times in a collaborative workplace adhere to a flexible schedule and stable plan for production.
- RQ 3: Work psychology is crucial to achieving the desired level of performance in a collaborative environment.

A collaborative work environment creates prerequisites for integrating the employee into a manufacturing line with digitized technology, within which they have the opportunity to improve and refine the digitally controlled process, promoting a sense of positive work psychology. Fruitful human–robot cooperation at sections of the manufacturing facility benefits production, and settings of planning and scheduling processes [31].

Data analysis herein focussed on gaining a comprehensive understanding of the human–cobot relationship, and results were applied to define parameters for optimizing operations in hybrid workplaces. Standardization of the manufacturing environment, as laid out in a production plan, and realized on human–cobot assembly lines, necessitates relevant scheduling of procedures based on the capacities of the human and cobot, in turn influencing the real-time schedule, which is primarily informed by the durations of cobot activities [32].

The authors consider one of the greatest challenges of current research on work psychology in a collaborative environment to be ensuring a process for stable production, the flexibility, skill sets and rotation of workers, and the technical and technological compatibility of the operator and robot. It is a realistic to assume that another year of research shall increase comprehension of the tolerance of reaction time on the part of the operator to restarting an interrupted process. Work psychology is primarily about the satisfaction of employees, and, herein, about a sense of satisfaction stemming from good cooperation with a cobot. In the future, knowledge of the requirements of human and robot colleagues will constitute an important field of research for industrial engineers, especially with regard to managing efficient and effective processes.

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