European Agency for Safety and Health at Work

Digital technologies for worker management: implications for safety and health. A comparative study of two automotive companies in Belgium and Italy

Report

European Agency for Safety and Health at Work

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Table of Contents

Executive Summary

This study investigates the implications of digital technologies and artificial intelligence-based worker management (AIWM) systems for occupational safety and health (OSH) through a comparative analysis of two automotive companies in Belgium and Italy. The research aims to explore how these technologies influence work organisation, workers' wellbeing and OSH in different organisational settings. By examining the contrasting experiences of a large original equipment manufacturer in Belgium and a smaller Tier 1 supplier in Italy, the study provides insights into how managerial approaches shape the impact of AIWM on working conditions and OSH.

The integration of AIWM systems, which include algorithmic technologies for task allocation, performance monitoring and real-time decision support, has become increasingly prevalent in industrial sectors characterised by complex production processes. While these systems are often adopted to enhance productivity and streamline operations, they also introduce significant challenges regarding worker autonomy, job quality, OSH and psychosocial risks. The findings of the study highlight that the implications of AIWM adoption are highly dependent on the level of worker involvement and the managerial strategies employed. The Italian firm adopts a participatory approach by involving employees in decision-making processes and reports superior OSH outcomes and overall wellbeing compared to the Belgian firm, which follows a hierarchical, top-down management model. However, it is important to notice that the differences in the size of the companies and their positions in the global value chain may significantly influence the choice of management model adopted.

In the Italian case, the active engagement of workers in technology adoption and development has resulted in a collaborative environment that supports transparency and shared responsibility. This inclusive approach mitigates potential negative consequences associated with AIWM, such as increased surveillance and diminished autonomy, and helps in generating a sense of trust and empowerment among employees. Consequently, workers in the Italian firm experience lower levels of stress, higher job satisfaction and reduced exposure to OSH risks, also in the face of increased work intensification. In contrast, the Belgian company's reliance on a rigid, hierarchical approach has led to heightened work intensification, increased psychosocial stress and reduced autonomy. The absence of worker participation in the technology implementation process exacerbated these risks, contributing to a higher likelihood of adverse health and wellbeing effects, including burnout and anxiety.

It is also important to note that the Italian case reports almost zero turnover and has a stable workforce, while the Belgian case exhibits a significantly high level of turnover, with a large proportion of workers employed under temporary contracts. The stability in the Italian case favours better knowledge retention, which benefits productivity and operational efficiency, and improves job satisfaction and strengthens the company culture and workers' commitment. Conversely, the high turnover in the Belgian case and the large proportion of temporary contracts likely lead to greater instability and lower organisational loyalty. This could result in higher recruitment and training expenses, decreased knowledge retention and challenges in maintaining a consistent organisational culture, potentially hindering long-term development and performance as well as the preservation of a healthy workplace.

The study also takes into account the dual role that AIWM systems may play in OSH management. On one hand, these technologies can enhance safety by enabling real-time hazard monitoring, providing ergonomic support and facilitating the delivery of safety training programmes. On the other hand, the use of AIWM systems without adequate human oversight can lead to adverse outcomes, such as the dehumanisation of workers, the erosion of managerial support and the intensification of work rhythms. The Belgian firm's experience illustrates how excessive reliance on automated systems for task coordination and monitoring can undermine worker autonomy and exacerbate the risk of physical and mental strain. In contrast, the Italian company's approach, which integrates AIWM with strong worker participation and support mechanisms, demonstrates how these systems can be deployed to promote a healthier and safer work environment.

The study's findings suggest that the successful integration of AIWM systems requires a balanced approach that prioritises worker involvement and transparency. In order to guarantee a sustainable use of new technologies and safeguard workers' OSH and wellbeing, companies should develop participatory frameworks that actively engage workers in the adoption, development and implementation

of digital tools, ensuring that technological advancements are aligned with the practical needs and insights of the workforce. Indeed, a participatory culture not only fosters job satisfaction and autonomy but also mitigates the risks of work intensification and stress associated with AIWM. Furthermore, structured training programmes, job role rotations, and proactive health and safety measures are essential components of a comprehensive strategy to safeguard worker wellbeing while optimising production processes. Effective data governance is also critical, as it helps maintain trust and ensures a fair and democratic use of digital technologies. Establishing robust data management frameworks that protect workers' privacy and involve workers and their representatives in decision-making processes is crucial for preventing potential misuse and improving worker acceptance and use of AIWM systems. Indeed, transparency in the use and development of data and technologies is fundamental to provide workers with greater agency over the work process and empowering them to exercise control, make decisions and take ownership of their tasks.

Contrasting the findings from the two case studies, the importance of adopting a human-centred approach to digital transformation emerges. While digital tools and AIWM systems can significantly enhance productivity and safety, their success depends on the organisational context and the extent to which workers are included in the process. This study contributes to the debate on the impact of digitalisation in traditional manufacturing settings, emphasising the need for strategies that balance efficiency with worker health and safety to create sustainable workplaces and enhance democratic participation of workers and their representatives in the digital revolution.

1 Introduction

In recent years, there has been growing academic interest in examining the relationship between digital technologies and labour. Although much of the economic literature has emphasised the potentially disruptive impact of Industry 4.0 technologies and artificial intelligence (AI) (for a recent overview, see Montobbio et al., 2023), the anticipated risks of widespread job displacement and significant technological unemployment remain largely unsubstantiated in empirical data (Domini et al., 2021; Autor, 2022). Instead, there emerges a clear trend of declining job quality and an erosion of workers' bargaining power (ILO, 2023).

The integration of digital technologies and artificial intelligence-based worker management (AIWM) systems is transforming traditional workplace environments, particularly in sectors characterised by complex production processes such as automotive manufacturing. AIWM systems, which use algorithmic technologies for automating or semi-automating decision-making, are increasingly employed to enhance productivity, streamline operations and optimise labour management (Calvino & Fontanelli, 2023; Filippucci et al., 2024). These systems can perform diverse managerial functions, including task allocation, performance monitoring and real-time decision support, that is, they may significantly alter the dynamics of work organisation (Mateescu & Nguyen, 2019). Indeed, algorithmic and AI-based systems, by collecting and analysing unmatched amounts of data, are used to plan and organise workloads, the workforce and work processes, make predictions or decisions about workers, monitor and influence workers' behaviours and performance, surveil workers, direct and control working tasks, train or assist workers in their job, or automate working tasks entirely (Kellogg et al., 2020; Wood, 2021). In other words, they are transforming the traditional workplace into a data-driven workplace where data (collection, storage and analytics) are used to assist, augment or automate work, and algorithms and AI are supporting or replacing managerial decisions (Baiocco et al., 2022; EU-OSHA, 2023c; Rani et al., 2024).

In the context of Industry 4.0, the automotive sector has been at the forefront of implementing such technologies, making it a pertinent field for studying both the opportunities and challenges posed by AIWM. On one hand, these systems contribute to increased efficiency and precision in production processes through continuous monitoring and data analysis (Min et al., 2019). On the other hand, AIWM systems can lead to heightened work intensification, reduced autonomy and increased surveillance, potentially exacerbating psychosocial risks and creating a high-strain work environment and raising concerns regarding their impact on occupational safety and health (OSH) (Green et al., 2022; EU-OSHA, 2022a).

Certainly, AIWM has the potential to enhance OSH by providing tools for more effective hazard monitoring, supporting workers' mental health, fostering higher levels of engagement and job satisfaction, and facilitating the design and delivery of OSH training programmes. Nevertheless, the deployment of AI for workforce management also entails reduced worker autonomy and job control, reduced managerial support, the promotion of a competitive and unhealthy work environment with a higher work intensity and performance pressure, a higher risk of individualisation and dehumanisation of workers, and the erosion of transparency and worker power, with significant implications for OSH (EU-OSHA, 2022a). Additionally, AIWM may undermine trust, restrict worker participation, and blur the boundaries between work and personal life. Collectively, these risks have the potential to generate a range of adverse outcomes for workers' physical and psychosocial health and wellbeing, including musculoskeletal disorders (MSDs), cardiovascular conditions, fatigue, stress, anxiety and burnout.

This study explores these dual impacts by examining two case studies in Belgium and Italy (Appendices 1 and 2), focusing on how AIWM affects OSH and working conditions in distinct organisational settings. The research aims to contribute to the growing body of literature on digitalisation and workplace management by providing comparative insights that underscore the need for a participative and human-centred approach to AIWM implementation.

The findings, in line with Rani et al. (2024), emphasise that while AIWM systems offer potential benefits for efficiency and safety, their integration must be carefully managed to avoid adverse outcomes related to worker autonomy, stress and overall health. Two different portraits emerge in terms of OSH implications according to the level of workers' engagement in technology adoption and implementation decisions.

The participatory practices adopted by the Italian company have resulted in superior outcomes for workers' OSH and overall wellbeing compared to the Belgian company's more hierarchical approach. By actively involving workers in decision-making processes and fostering a collaborative environment, the Italian firm has successfully cultivated a culture of shared responsibility and transparency. This inclusive strategy not only enhances job satisfaction but also mitigates potential negative consequences associated with digital technology adoption, such as increased surveillance and diminished worker autonomy. Consequently, workers in the Italian company report lower levels of stress and reduced exposure to OSH risks, highlighting the efficacy of participatory management in safeguarding workers' OSH and wellbeing.

In contrast, the Belgian company's reliance on a top-down management model has increased workers' vulnerability to the adverse effects of algorithmic management, including work intensification and dehumanisation. The absence of worker involvement in the decision-making process exacerbates these risks, contributing to increased pressure, diminished autonomy and a reduced sense of control over their work, ultimately leading to a higher likelihood of negative health and wellbeing outcomes. The differences emerging from the two field studies shed light on the complex interaction between social, technological and organisational features of companies, contributing to the debate on a human-centred use of AI in the workplace (Hermann & Pfeiffer, 2023).

Understanding the interplay between technological innovation, work organisation and OSH is therefore critical for developing strategies that maximise the benefits of AIWM while safeguarding worker wellbeing.

The remainder of the study is structured as follows. Section 2 briefly presents the conceptual framework and the empirical analysis upon which the case studies are built. Section 3 discusses the methodology. Section 4 and section 5 describe the companies under study and illustrate their main features in terms of business models, work organisation practices and relations with stakeholders. Section 6 discusses the main implications of AIWM adoption in terms of OSH, distinguishing between the two case studies, and section 7 concludes with key takeaways. The two case studies are attached in Appendices 1 and 2.

2 Conceptual framework and previous work

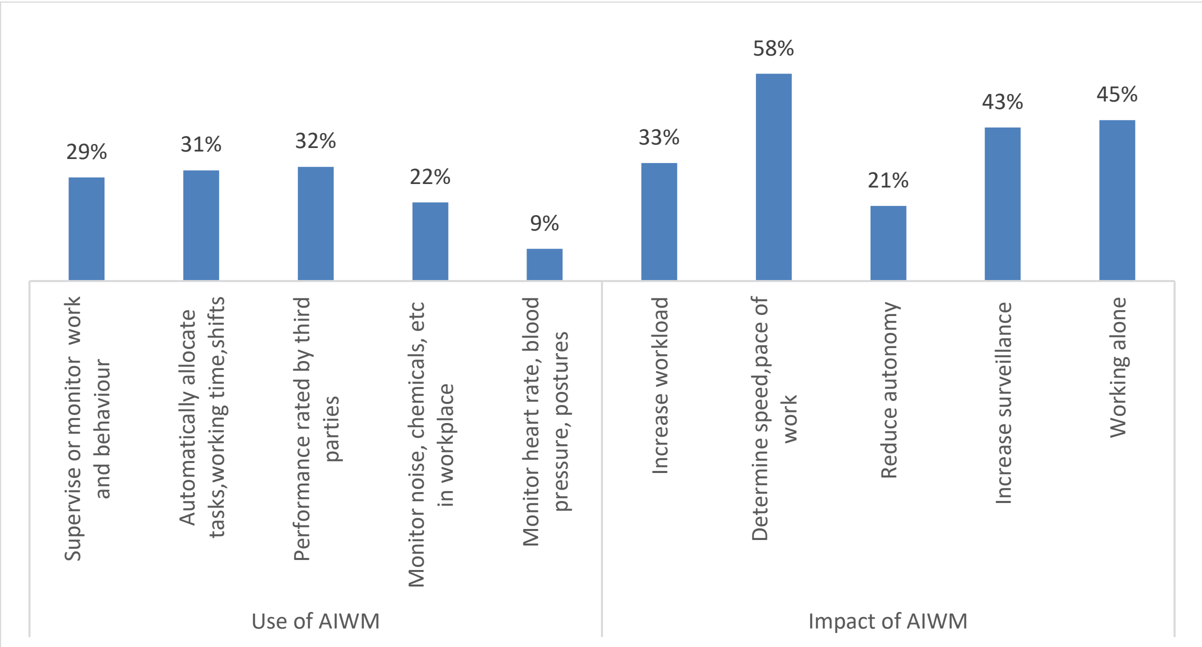
An algorithm is a sequence of instructions for the achievement of a specific output. According to Mateescu and Nguyen (2019), algorithmic management is a 'diverse set of technological tools and techniques to remotely manage workforces, relying on data collection and surveillance of workers to enable automated or semi-automated decision-making' (p.1). Wood (2021) links algorithmic management to the main managerial functions — direction, evaluation and discipline — that draws from the six mechanisms of algorithmic control (the so-called 6Rs: recommending, restricting, recording, rating, replacing, rewarding) defined by Kellogg at al. (2020). Algorithms may be used 'to direct workers by restricting and recommending, evaluate workers by recording and rating, and discipline workers by replacing and rewarding' (Kellogg et al. 2020, p.366). Furthermore, algorithms could be differentiated according to their functions. Based on Parent-Rochelau and Parker (2021), EU-OSHA (2022b) distinguishes three types of algorithms: diagnostic algorithms, used to record past events and analyse their impacts on the present; predictive algorithms, used to foresee the occurrence of future events; and, finally, prescriptive algorithms, used to identify best possible solutions and recommend or implement courses of action.

Algorithms are the backbone of AI technologies; however, not all the algorithms at the basis of worker management systems can be considered as AI-empowered. Following Wang (2019) and EU-OSHA (2022b, p.10), AI can be defined as 'the capacity of an information-processing system to adapt to its environment *while operating with incomplete knowledge*'. That is, AI-based systems are capable of approximating the correct output regardless of the lack of all information needed to correctly measure it. Conversely, non-AI-based algorithms follow predefined list of actions to provide the correct output. The conceptual framework at the basis of this study applies the definition of AIWM provided by EU-OSHA

(2022b) that defines it as 'an umbrella term that refers to a worker management system that gathers data, often in real time, on the workspace, workers, the work they do, and the (digital) tools they use for their work, which is then fed into an AI based model that makes automated or semi-automated decisions or provides information for decision-makers on worker management-related questions' (p.5). The framework combines it with the definition of algorithmic management provided by Baiocco et al. (2022), according to whom: 'Algorithmic management can be defined as the use of computer-programmed procedures for the coordination of labour input in an organisation' (p.6). Hence, this study considers algorithmic technologies, both AI-based and non-AI-based, that are used for the organisation of work and work processes and affect working conditions and workers' safety and health.

Currently, limited information and data are available regarding the adoption of algorithmic and AI technologies in the workplace. In Europe, the EU-OSHA OSH Pulse survey collects information about the use of digital technologies at work and the health and psychosocial risks related to digitalisation and forms of monitoring and surveillance in the workplace. Based on the 2022 EU-OSHA OSH Pulse survey data, 78% of the total workers interviewed report having digital technologies determining their speed of work, or monitoring and surveilling their work, or assigning them tasks or shifts, or evaluating their work or, finally, monitoring their vital signs. In other words, workers claim to be subject to some forms of algorithmic management (EU-OSHA, 2023c). Figure 1 illustrates the most common uses of AIWM systems in the workplace and their impact on working conditions.

Figure 1: Use of AIWM and impact on working conditions

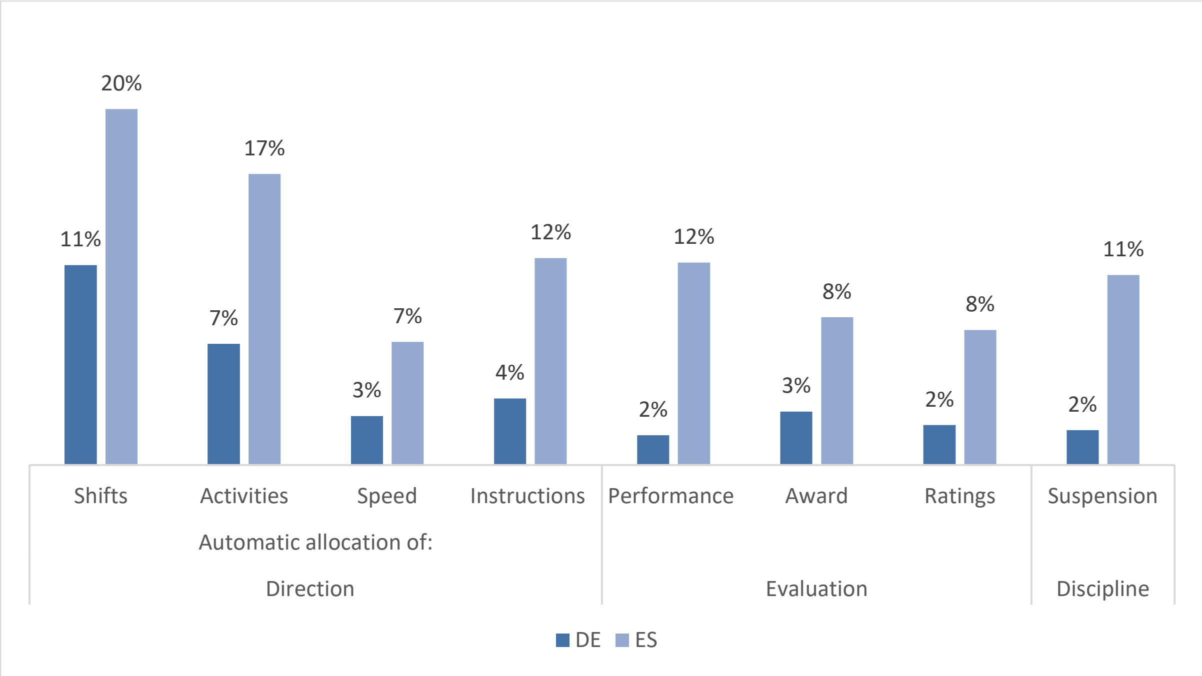


Source: Authors' own elaboration, EU-OSHA OSH Pulse survey, weighted data

More detailed data on the use of algorithmic practices are collected by the Joint Research Centre's JRC Algorithmic Management and Platform Work survey (AMPWork) conducted in 2022. Despite the survey being conducted only in Germany and Spain, some interesting insights emerge and can be briefly illustrated.

As shown in Figure 2, the survey presents data on the percentage of workers who report being under forms of automatic direction, evaluation or discipline defined as follows. Automatic direction includes all those elements that give automatic indications to workers to perform their work. It includes the automatic allocation of shifts, of activities to carry on, the automatic definition of the speed or pace of work, as well as more general instruction on how to perform the task. Automatic evaluation includes the assessment of worker performance by means of a common digital dashboard, recognition of awards or prizes for meeting productivity targets, or customers' ratings. Finally, automatic discipline refers to the possibility of being suspended or fired if parameters and criteria defined by the algorithms are not met.

Figure 2: Algorithmic management indicators by country

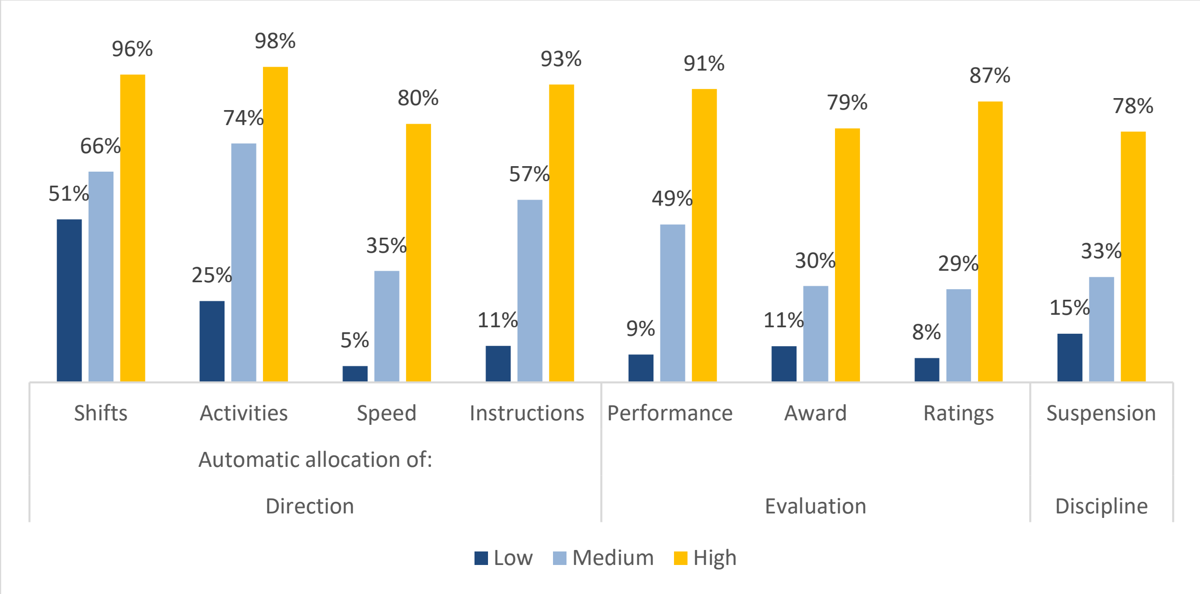


Source: JRC AMPWork, authors' own elaborations

Figure 2 shows how the prevalence of algorithmic management indicators — grouped under the macro categories of direction, evaluation and discipline — varies significantly between Germany (DE) and Spain (ES), with Spain generally exhibiting higher values. Automated allocation of work is the most widespread form with: 11% of German workers and nearly 20% of Spanish workers having their shifts or working time automatically assigned via digital devices; and, similarly, 7% of German workers and 17% of Spanish workers having their specific work activities allocated through digital means. Additionally, 3% of workers in Germany and 7% in Spain have the pace of their work determined by a digital device. Furthermore, a higher proportion of Spanish workers (12%) compared to German workers (4%) follow automated instructions or directions in their workplace. These statistics underscore the more extensive integration of algorithmic management in Spain compared to Germany.

Figure 3 presents the same data no longer aggregated by country but ordered according to the intensity of algorithmic management experienced by workers. The intensity is measured as the sum of the indicators, where 'low' means they are subjected to fewer than three types of algorithmic control, 'medium' is three to five and 'high' is over five algorithmic tools.

Figure 3: Algorithmic management indicators by digitalisation intensity



Source: JRC AMPWork, authors' own elaborations

Figure 3 clearly shows how workers in more digitalised organisations are increasingly subject to forms of automatic direction, evaluation and discipline. Interestingly, the gap of specific indicators varies from a minimum distance of 45 percentage points. in the case of automated allocation of shifts, up to much wider gaps, over 75 p.p., when it comes to the automatic definition of the speed or pace of work, or the use of digital performance metrics and ratings to evaluate workers. A possible reading is that the accentuated use of AIWM systems is associated with work intensification, with higher levels of monitoring and surveillance, and with workers' quantification, which may all have notable OSH implications. Indeed, work overload, along with diminished job autonomy and control, can contribute to increased stress and anxiety among workers. When combined with the pressure to maintain high performance standards, these factors may lead to adverse psychological outcomes, such as burnout and exhaustion, as well as physiological conditions, including back pain, headaches and cardiovascular diseases (EU-OSHA, 2021b; Bérastégui, 2021; Urzì Brancati & Curtarelli, 2022; EU-OSHA, 2023c).

Even though the use of digital devices to algorithmically manage work is still not very frequent, the JRC AMPWork data show that around one in five workers in Germany and one in three in Spain are subject to at least one form of algorithmic management, with one in 10 in Germany and one in five in Spain being subject to two or more, with credible expectations that these figures will increase in the near future.

Alongside data collection through national and cross-national surveys, the development of qualitative analyses and case studies are also contributing to shed light on the diffusion of these technologies in different workplaces. For instance, Rani et al. (2024) conducted case studies on the adoption of algorithmic technologies to coordinate and organise work in the logistics and health sector in four countries,[1] covering both Global North and Global South. The evidence from the case studies shows that algorithmic management is already a reality in all the four countries studied. However, they also report that in many instances, algorithmic tools were implemented for managing aspects and processes beyond work coordination, yet these had direct and important effects on the organisation of work and working conditions.

They found that the implementation of algorithms and digital tools for work management depends on several factors, including the level of standardisation of specific tasks, the accessibility and level of development of the digital infrastructure, the existence of institutional constraints on workplace technology use and the relative cost of labour in comparison to technology adoption. In general, the

[1] France, India, Italy and South Africa.

primary motivation for implementing these technologies across all analysed countries is to enhance effectiveness, increase efficiency and improve service delivery. The case studies reviewed generally demonstrate a positive impact on productivity, achieved through the simplification and optimisation of work processes.

When comparing the results across countries, the authors find mixed results for the adoption of AIWM on working conditions and OSH. They find that workers, mostly in the Global North countries, reported that the adoption of AIWM technologies improved planning and organisation and reduced physical strain, consequently lowering fatigue and stress levels. On the other hand, workers in the Global South reported evidence of work intensification, limitation of autonomy, and increased level of monitoring and surveillance. These differences show that the impact of algorithmic management in regular workplaces appears to be at least partly mediated by the institutional and the regulatory frameworks in place. Indeed, the authors find that public structures in the healthcare in the Global North, with their typically stronger labour protections and union representation, seem to offer some buffer against the negative impacts of algorithmic management. For example, the French and Italian healthcare case studies, characterised by predominantly public hospitals and high unionisation rates, generally report positive outcomes from adopting algorithmic management technologies. This contrasts with the Indian and South African cases, where a stronger focus on profitability and efficiency in both public and private healthcare settings, combined with weaker institutional safeguards, creates conditions for increased monitoring, work intensification and potential erosion of job quality. Nevertheless, the authors, in all cases studied, point to the limited involvement of trade unions in decisions concerning the adoption and implementation of algorithmic management systems and suggest that empowering workers and their representatives requires strengthening the capacity of trade unions to engage with the complexities of algorithmic management. This includes providing training on relevant technical aspects, facilitating access to information, and ensuring their active participation in shaping policies and collective bargaining agreements related to algorithmic management.

Other recent studies on traditional workplaces seem to confirm the emergence of a duality in terms of impact on labour. Krzywdzinski, Evers and Gerber (2024) provide an in-depth study on the adoption of wearables (i.e. data glasses, smart gloves and smartwatches) by conducting a comparative field study in 16 German manufacturing companies in the automotive, electronics, steel and transportation sectors. When the features of the production process — whether capital- or labour intensive — are intertwined with the strength of trade unions in the workplace, interesting differences emerge in the cases studied. Companies adopt heterogenous implementation strategies, characterised by different models of direct worker involvement in the assessment of physical, cognitive and social risks, as well as different degrees of monitoring and surveillance through data collection. While in labour-intensive firms, where most tasks are highly repetitive, the adoption of wearable technologies is aimed at increasing work standardisation and reducing the work content, in capital-intensive companies an opposite dynamic is observed. In this case, workers experience an enlargement of their skill endowment, but coupled with an increasing risk of work intensification. According to the authors, these findings are consistent with firms' differences in terms of strategic goals. In capital-intensive firms, the role of workers mainly consists of monitoring the machines, ensuring a quick and flexible handling of technical problems and bottlenecks. Thus, expanding workers' skills and autonomy in performing their daily activities becomes beneficial to production. In the case of labour-intensive firms, on the contrary, workers are asked to quickly perform highly repetitive tasks, without distraction and exerting physical effort. Here, the development of a pervasive system of worker monitoring becomes a crucial tool to ensure efficiency. In another recent case study on a German logistics company, Krzywdzinski, Schneiß and Sperling (2024) do not find evidence of enhanced surveillance linked to the adoption of algorithmic management. However, mechanisms of knowledge extraction emerge in the phase of data analysis, potentially weakening a more active involvement of workers.

The diverse impacts of technological change on labour and work organisation can be traced to long-standing theoretical debates concerning the complex relationship between technology and labour in the workplace. As early as 1989, Zuboff identified two contrasting patterns associated with the adoption of information and communication technologies (ICTs). On one hand, the dissemination of ICT was viewed as a mechanism for expanding the knowledge base and enhancing workers' skills, while on the other, it served to centralise knowledge and drive extensive process automation. More recently, Vidal (2022) has underscored a significant contradiction faced by managers in lean and digitalised workplaces: they are simultaneously encouraged to ‘empower’ workers by granting greater autonomy and direct involvement to promote continuous process improvement, yet they are also pressured to implement advanced surveillance tools and standardise operations to mitigate inefficiencies and prevent potential worker non-compliance.

According to some scholars, algorithmic management technologies can be flexibly adopted in both scenarios, but only accounting for the institutional, organisational and social contexts in which they are deployed can allow a better understanding of the main factors behind *enabling* or *controlling* patterns (Meijerink & Bondarouk, 2023; Noponen et al., 2023). That is, the economic imperatives driving AIWM technologies — specifically, the profitability derived from standardised behavioural data and simplified personalised profiling — may incentivise their use to consolidate managerial control, shape worker behaviour and minimise uncertainty. Although technological adoption holds the promise of fostering worker empowerment, employers may prioritise efficiency and profitability, and therefore use these tools in ways that conflict with workers’ interests and ultimately undermine their wellbeing.

Furthermore, AIWM technologies are not uniquely defined and present a high level of complementarities among them that prevent the identification of a unique setting and homogenous composition of firms’ digital endowment (Martinelli et al., 2021). That is, several technologies may be implemented at the same time and their effects may be very dependent on the way technologies integrate and interact between them and with the overall setting of implementation.

All this considered and in order to better identify ongoing trends, a broader definition of technologies needs to be embraced, looking not exclusively at algorithmic management systems *per se*, but also at the set of complementary technologies and devices currently used by companies for different purposes than the direct control of the workforce, but contributing to the development of efficient systems of algorithmic management.

For this reason, this study focuses on a large set of technologies, whose degree of integration and interconnection can be moderate, intermediate or advanced. In detail, AIWM includes technologies that allow a totally or semi-automated management of data to make decisions concerning the workplace, through both the application of predefined rules (algorithms) and dynamic models of AI. Examples of these technologies include:

- digital tools and sensors (i.e. barcode scanners, wearables);
- automated machineries digitally connected to companies’ software systems (i.e. thermopresses producing data on temperature, number of final products with defects, etc.); and
- workers’ management systems that allow an automated or semi-automated decision-making process, applying both predefined rules in forms of fixed algorithms and learning models based on AI.

3 Methodology

Given the lack of a unified analytical framework and the still scarce availability of firm-level data, the empirical evidence is quite heterogeneous and still object of a lively debate, as explained in the previous section. In such a context, case study research constitutes an extremely useful methodological tool to investigate the concrete implementation of these technologies and their impact on labour (Yin, 2009; Choudrie & Dwivedi, 2005), eluding a deterministic narrative on technological change (Thompson & Laaser, 2021). Case studies have been increasingly adopted in several research fields, including labour economics, innovation and OSH. They ensure the possibility of moving from abstract reasoning to an in-depth study of firms’ dynamic capabilities in dealing with new technologies (Dosi et al., 2000), by looking more precisely at the interplay between organisational practices, workplace hierarchies and learning regimes (Coriat & Dosi, 1998; Cirillo et al., 2021, 2022) and their impacts on workers’ safety and health.

Based on this perspective, the research strategy used to conduct the two case studies discussed in this report has followed three main steps. First, the research team proceeded with the identification of two European companies meeting the specific requirements. The selected companies, respectively located in Belgium and Italy, were chosen with the direct involvement of EU-OSHA experts, according to the three following main criteria:

- the empirical coverage of the automotive industry, deemed particularly interesting because of the wide adoption of new technologies and the tradition of OSH preventive practices recorded in the sector;
- the implementation of the technology of interest (digital tools, automated technologies and AIWM) at the plant level; and
- the availability of the companies to allow a comprehensive in-depth field study.

A certain diversity between the two companies in terms of size and position in the value chain was sought to allow an informed comparison on the deployment of similar technologies in different institutional and production contexts. Once the choice of the companies was validated, the second stage of the research entailed the collection of several sources and publications concerning the two firms, both through desk research and direct interaction with the managers of the companies. Several preliminary meetings with the companies were also scheduled in this phase to present the project and define the details of the field study (number of interviews, visits to the plants, etc.). Moreover, detailed interview schemes tailored for managers, technology specialists and workers were elaborated by the research team to allow an adequate comparison between the two cases.

The very last step of the research consisted of visiting the plants and conducting interviews. The guided visits to the plants represented a crucial occasion to observe the most important features of the production processes, see in practice the adoption of advanced technologies, interact with the workers and clarify more specific questions about, for instance, work organisation, health and safety practices, and product variety. Semi-structured interviews were conducted mainly at the firms' premises, and only in a few cases remotely, and lasted no more than one hour each. All interviews were recorded, with the declared consent of the respondents, and transcribed by the researchers for a more fine-grained analysis of their content.

A content analysis was then performed on the texts of the interviews, identifying different domains of interest, from the implementation of new technologies, to work organisation models, and management of health and safety risks. Different job profiles were interviewed, including line operators, team leaders, managers and OSH specialists, as shown in Table 2. Such variety in terms of hierarchical positions, competences and specialisations was built to ensure a more comprehensive overview of the multiple existing interlinkages and to detect potential heterogenous impacts of the same technology along the attributes cited above.

Table 1: Overview of interviews by company, role and gender

Role	Belgian case study		Italian case study	
	Number of interviews	Gender composition	Number of interviews	Gender composition
Management	4	4 men	3	2 men, 1 woman
Middle management	2	2 men	3	3 men
Team leader	4	4 men	2	2 men
Operators	3	3 women	3	3 men
ICT specialist	2	1 man, 1 woman	/	/

Role	Belgian case study		Italian case study	
	Number of interviews	Gender composition	Number of interviews	Gender composition
OSH specialist	2	1 man, 1 woman	2	1 man, 1 woman
Total	17	12 men, 5 women	13	11 men, 2 women

Source: Authors' own elaboration on case studies

The interviews followed the specific guidelines defined by the research team in line with those defined by the JRC and the International Labour Organisation in their joint project on the changing nature of work at a global level (Rani et al., 2024). The interviews focus on the one hand on the processes of adoption and implementation of technologies and, on the other hand, on the main impacts in terms of work organisation, psychosocial risks, physical risks and social interactions, as illustrated in Table 2. To facilitate the communication with the workers and ensure a smooth conversation, interviews took place in the absence of supervisors.

Table 2: Domains of analysis in interviews guidelines by job profile (workers, managers and technology specialists)

Domain of interest	Worker	Manager/Tech specialist
Presentation of the interviewee	Presentation by the worker of his/her job profile and description of daily activity, educational attainment, tenure in the company and previous work experience.	
Adoption of the AIWM	Introduction of the technology in the production process and use by the worker in his/her daily tasks, distinguishing between first stages and more recent applications.	Adoption and implementation process, with reference to goals and reasons behind the investment, emergence of bottlenecks, degree of complementarity with other technologies and future investment projects.
Skills and training	Participation in training programmes or involvement in specific initiatives concerning the use of new technologies.	Provision of training courses and promotion of models of internal functional flexibility; overall impact in terms of skills and required competences.
AIWM implications for OSH	Observed, perceived or expected OSH impacts of AIWM on: ▪ work organisation (i.e. productivity, job displacement, control of the process, hierarchical structure); ▪ psychosocial risks (i.e. perception of control and reduced autonomy, performance pressure, insecurity and problems stemming from the use of new technologies); ▪ physical risks (i.e. risks of accidents or repetitive tasks as a consequence of increasing work intensity, ergonomic risk); and	

Domain of interest	Worker	Manager/Tech specialist
	▪ social risks (i.e. reduced verbal interactions and lower support from colleagues in the daily management of problems).	
Relations with trade unions, workers' representatives and other institutional actors	Direct contacts with trade unions and workers' representatives or other institutional actors (i.e. OSH representatives) mainly but not exclusively on technology-related issues.	Negotiation and collective bargaining with trade unions and workers' representatives; consultation procedures with other institutional actors (i.e. university, territorial institutions, OSH actors).

Source: Authors' own elaboration on case studies

4 Overview of the companies

As already anticipated, both companies belong to the automotive sector but covering a different position in the value chain. While the Belgian company is an original equipment manufacturer (OEM) that produces different models of cars, the Italian company is a Tier 1 supplier, namely a supplier that provides car components[2] directly to the final car manufacturer.

The Belgian firm belongs to an international corporation and represents a very large industrial employer in Belgium. The company site, consisting of a paint shop and a welding and final assembly plant, is characterised by a rather high turnover rate. Every week about 20 workers exit from the company, whether for retirement and voluntary leave or because of layoffs and termination of the temporary job contract. Last year, more than 200,000 cars were produced, of which more than one-third were battery electrical vehicles. A trade union is present in the plant, but a certain turmoil among workers occurred a few years ago due to an agreement on increasing working hours.

The Italian company is located in the south of Italy, employs 49 full-time employees and represents one of the south European branches of an international group with thousands of workers. Its main activity consists of producing and selling carbon-coated synchroniser rings to car producers. The process of coating the carbon over the ring is characterised by a combination of manual tasks and automated procedures, together with a series of tasks that can be performed alternately by the operator or by the machine, according to the production volumes required by the client. In 2023, the production exceeded 6.8 million rings. The turnover is almost non-existent, as workers show a strong attachment to the company and tend to pursue their entire career internally, either as blue- or white-collar workers. The company is also involved in an international corporate programme of excellence, where representatives from different plants share their best practices and offer support to other plants that want to adopt similar practices. The company does not have a formal trade union, as Italian labour regulations do not mandate the presence of such bodies in firms with fewer than 50 employees, but two workers are elected as representatives and can participate in discussions with management on specific issues of interest.

To summarise, the two firms present some similarities and differences, highlighted in Table 3. This set-up provides a particularly interesting opportunity to develop a comparative analysis on the impact of AIWM on working conditions and OSH. Indeed, while they strongly differ in terms of size, type of production, turnover and industrial relations, in both cases we observe a combination of lean-oriented practices and quite advanced adoption of digital and automated technologies. Understanding how these

[2] Namely, coated synchroniser rings required by combustion engines gearboxes.

differences and similarities can lead to potentially different outcomes on work organisation, especially for what concerns OSH, will be the object of the subsequent analysis.

Table 3: Synthetic presentation of the two companies

	Belgium-based company	Italy-based company
Type of company	OEM	Tier 1 supplier
Location	Belgium	Italy
Product	Cars	Coated synchroniser rings
Number of workers	7,000 between employees and temporary agency workers	49 employees
Turnover	High turnover	Almost zero turnover
Production volume (last year)	200,000 cars	6.8 million rings
Work organisation model	Lean practices	Lean practices
Technologies	Digital and automated technologies	Digital and automated technologies
Trade union	Yes	No

Source: Authors' own elaboration on case studies

5 Comparative analyses of case studies

The following sections examine and compare the findings of the two case studies. The aim is to identify the common aspects and explain the differences in terms of work organisation and OSH implications that followed the adoption and implementation of AIWM technologies.

5.1 Overview of the two companies: business model, work organisation practices and relations with stakeholders

As briefly anticipated in the previous section, the two automotive companies show important differences in terms of size and position in the value chain. At the same time, they also share similarities for what concerns the adoption of a 'lean' organisation model, aimed at fostering the elimination of time waste, strengthening a process of continuous improvement, and ensuring an efficient and productive use of resources. Inspired by the Toyota Production System, the primary objective of lean production is to maximise value for the customer by streamlining operations, reducing lead times, and minimising costs associated with excess inventory, defects and non-value-adding activities. This work organisation model is now widely adopted in the manufacturing sector and integrates principles such as *just-in-time* (JIT) production, where materials and components are delivered precisely when needed, and *jidoka*, which emphasises automation with a human touch, allowing for the immediate detection and resolution of quality issues (Dombrowski and Mieilke, 2013).

A wide but diverse set of lean practices are currently being adopted in the companies under study, ranging from Andon systems[3] to total productive maintenance, job rotation, teamwork and rapid improvement process (i.e. Kaizen activities). Such heterogeneity, both in the implementation and

[3] Systems that alert operators about an issue on a production line (see Appendix 1).

diffusion of specific work organisation practices, reflects the distinct features of the two companies in terms of business model and employment relationships, as we briefly explain below.

Faced with the production slowdown caused by the global financial crisis of 2008, the Italian company decided to start a process of transition from a traditional production setting, where each worker performs a single task, to integrated workstations where workers can execute all the tasks necessary to produce the final good and develop their multifunctionality and polyvalency, in line with a lean work organisation model. During this experimental phase, the company moved to a larger plant and gradually introduced more advanced digital technologies, achieving a degree of autonomy in designing in-house machinery and equipment to overcome the limitations of the technologies available on the market. The process of technological upgrading relied on the competences and involvement of the whole company. For example, the user interface of SAP (Systems, Applications and Products in Data Processing) was designed in-house by the IT specialist, with the active involvement of workers to ensure an ease of use across all the departments of the company, from production to administration offices.

The Belgian company is also facing major challenges in terms of global competition and transition to electric mobility, and it appears to be strongly oriented towards a process aimed at enhancing its competitiveness, in particular by ensuring constant productivity gains on the assembly line. To keep up the production rhythms (1,000 cars per day and one car per minute) and manage the ongoing conversion to electric cars, several technological innovations and organisational practices have been introduced by progressively integrating digital technologies, advanced automation and data collection. Operators in this company work at a high efficiency rate, given that one car is produced approximately every 60 seconds. This requires a precise synchronisation of all tasks assigned to each workstation and performed by workers or automated machines. With this aim, a digital system is implemented to design both the manufacturing processes and the final product (the car), generating process and inspection instructions for each workstation. The set of instructions, tailored for each specific task, is then transferred to a digital system for assembly line balancing (ALB), which further tests and adjusts the sequence of actions required at each workstation. Each task is assigned a time measurement unit (1 TMU = 36 milliseconds), facilitating workload measurement and management. When the workload of a workstation reaches a critical level, according to the TMU set for that sequence of tasks, the ALB digital system will provide a communication alert (i.e. raise a flag).

Important differences also emerge regarding the employment relationships within the companies. In the Italian firm, turnover is almost zero and workers' average tenure is among the highest recorded in the automotive sector (around 15 years), leading to a kind of 'lifelong employment model'. In the Belgian company, on the other hand, the turnover is extremely high, temporary agency workers account for almost half of the total workforce and the labour force is constantly under renewal. This diversity in the composition of the workforce influences the type of training initiatives put in place by the two companies to ensure the development of a versatile workforce able to rotate and perform different tasks.

In the Italian case, new operators undergo a comprehensive one-month training programme that includes formal instruction on safety and health, quality standards and other essential topics, followed by practical, on-the-job training under the guidance of supervisors. During this period, operators are closely supervised, and their piecework is subject to stringent quality controls until operators consistently meet a zero-defect standard, allowing them to work independently. Highly skilled operators are asked to cover different roles in case of necessity, as they are deemed essential for managing the entire production process and adapting to dynamic constraints across various workstations. This push towards increasing workers' functional flexibility is in line with the organisation's broader strategy, which favours job rotation also among white-collar workers and managers, to facilitate interdepartmental collaboration and process integration.

In the Belgian company, new operators are mostly hired on temporary agency contracts and undergo a training programme that encompasses essential training in OSH, company-specific OSH regulations, basic assembly line operations, lean principles, and the use of digital tools, including AIWM systems. New operators are trained for multiple workstations, starting with two and potentially expanding to four, to ensure operational flexibility and coverage for absent colleagues. However, unlike the Italian company, the Belgian company limits the number of workstations an operator is trained for to prevent a decline in performance efficiency. Because of the high turnover, the Belgian company's human resources (HR) policy is focusing on retaining employees by investing in on-the-job training and using the data collected to address and resolve issues rather than as a discipline measure. Additionally, HR has initiated a campaign to enhance workers' involvement and commitment. A key aspect of this campaign involves having operators occasionally assuming team leaders' responsibilities, such as quality control, to foster a sense of ownership and engagement in their work.

Other important distinctions emerge with respect to the industrial relations setting. Given the size of the Italian company, there is no legal requirement for a formal union representative body. However, two workers are elected internally to represent the entire workforce on specific issues, such as setting criteria for the production bonus. Despite the lack of a formal trade union, other participatory practices are adopted in the company. For example, employees are encouraged to make suggestions for improvements (via digital devices) and, if implemented, are rewarded with a lump sum, which is doubled if the improvement addresses an OSH issue.

In contrast, in the Belgian case trade unions exist in the company and collective bargaining and unionisation are in place. Unions are regularly informed and consulted by the management before the introduction of digital tools and advanced technologies in the workplace. Despite the widespread use of these technologies, the field study reveals that a general level of acceptance emerges among trade unions. The use of digital technologies and consequent increasing datafication of the entire production process is interpreted both as a necessity in a context of strong competition among global players and as a useful tool that allows a more objective evaluation of workers' performance.

Both companies show a proactive attitude in their relations with stakeholders, especially concerning OSH and managerial best practices. The Italian company has launched a project with the support of a local hospital on the adoption of smart shirts aimed at detecting the most strenuous movements executed by the operators in the workstation. Although all workstations are well below the minimum target that would require an intervention, increasing attention is paid to these issues, considering the workforce's ageing. In addition, the company started a collaboration with the Italian National Institute for Insurance against Accidents at Work to promote and develop best practices that facilitate communication and the creation of periodic opportunities of dialogue between all the members of the company.

The Belgian company uses an 'external service for prevention and protection at work' that consists of a risk management and a health supervision section. The service deals with occupational safety, occupational medicine, ergonomics, industrial hygiene and psychosocial aspects of work. The health supervision section is managed by an occupational physician and includes the nursing and administrative staff necessary to carry out health supervision. External ergonomists can also provide additional professional guidance in case their evaluation is required by the team leader and the prevention advisor while defining the ALB process.

5.2 Adoption of AIWM and the role of data analytics

Digital technologies and AIWM are widespread in both companies under study and affect all the hierarchical roles and production stages. Algorithmic systems and AIWM are used indeed by production, maintenance and logistics departments and, in line with the principles of lean manufacturing, provide support for the JIT delivery of materials and components and coordination of the workforce in different departments.

Despite some distinctions in terms of intensity and degree of integration, AIWM systems are used in both companies mostly for the following purposes:

- *Task allocation:* Automated daily assignments of operators' work via screen devices, and real-time alerts regarding required statistics to be compiled before and during work.
- *Monitoring processes and worker performances:* Providing feedback to management on solution-oriented strategies and alerts on preventive measures.
- *Quality and safety controls:* Validation of batch packaging and machine temperature monitoring to ensure compliance with quality and safety standards.

- *Planning and maintenance strategies:* Adjustments to production plans in response to changing requirements and alerts for preventive and predictive maintenance based on breakdown frequency.
- *Logistics management:* Real-time updates on raw material deliveries, final product picking, warehouse management and batch composition validation.[4]

The broad diffusion and integration of digital technologies in the production process requires continuous data collection and processing in both companies. The availability of a wide amount of data is in fact integral to managing and optimising production processes, although both the implementation and the workers' perception on data collection interestingly differ.

In the Italian company, data are available throughout the entire hierarchical structure, at varying levels of detail. When starting their shift, operators log into the system and access information on work schedules, personal protective equipment (PPE) requirements and feedback from the previous shift; maintenance operators consult data to address both current and past maintenance requests, with detailed cost information automatically shared among relevant personnel. The production manager, as well, receives detailed reports at the end of each shift on production, target compliance and quality issues directly via email. In the Belgian case, it emerges clearly that the system is capable of tracking performance down to the millisecond, providing a highly detailed view of operational efficiency, quality control and strict guidelines for the execution of tasks to reduce deviations and further standardise the entire process.

In both field studies, interviewed workers do not report a negative attitude towards the extensive use of data, but an important distinction emerges in their overall assessment. In the case of the Belgian company, workers see data as an objective standard for evaluating their performance and as a helpful guide in their daily tasks, consistent with the firm's main goal of monitoring and controlling all stages of production, with data serving as an objective benchmark for performance evaluation. Conversely, in the Italian case, workers perceive data collection as a tool for collective transparency and communication, leading to a sense of empowerment, as they feel entitled to actively intervene in the process, reporting issues of quality, ergonomics and, more generally, working conditions.

Such diverging perspectives are confirmed also by the different degree of workers' involvement in the process of technological upgrading. In the Italian company, a gradual and participative learning strategy was put in place to favour a tailored implementation of digital tools and AIWM, with only minimal formal training on the use of digital tools. This approach continuously relies on learning by doing and the collection of iterative feedback from operators to address challenges and improve processes. On the contrary, the Belgian company has integrated a formal training on digital tools and AIWM systems as part of the initial training process, with no possibilities for workers to interact with the hierarchy or contribute to the definition of the implementation and adoption of the technology. However, the relative company size difference must be considered. Indeed, the limited size of the Italian supplier allows it to focus on organic, adaptive learning whereas the larger size of the Belgian car producer rather favours a more top-down approach with adoption of a formal and comprehensive training at the very beginning.

In conclusion, the differences observed in work organisation, the use of advanced technologies and the availability of data should be interpreted considering the structural differences between the two companies in terms of size, position in the value chain and managerial practices. While the Belgian company focuses its attention on ensuring high production volumes through a strict and highly monitored allocation of tasks, the Italian supplier is driven by the need to satisfy the clients and efficiently deal with unexpected changes in their orders. Indeed, even though both companies employ lean organisation models and digital technologies to enhance productivity, two different models emerge. While the Italian company focuses on worker versatility and in-house technological development, with significant worker involvement in the implementation of digital systems, the Belgian company emphasises efficiency through precise task synchronisation and workload management on the assembly line, using detailed

[4] While the adoption of AIWM in the assembly line to ensure task allocation, monitoring, management and quality control is largely found in both the Italian and Belgian companies, the implementation of these technologies in the maintenance and logistics departments was observed in the Italian firm.

digital instructions and ergonomic assessments to maintain high productivity levels. Consistent with this, also the adoption of new technologies has followed different patterns and results in distinct configurations. In the Italian case, the process of technological upgrading is quality-oriented, entirely driven by the needs of the company, and follows a bottom-up pattern with departments sharing needs and constraints in a collaborative way. On the contrary, the adoption of digital technologies and AIWM in the Belgian case seems to be mainly cost-oriented, aimed at ensuring the highest degree of standardisation of production, through a top-down process that does not directly involve workers but strictly defines technical and time constraints for the performance of tasks in a context of high workload saturation.

6 The implications of AIWM on OSH

OSH risks in manufacturing are diverse and present substantial challenges. These risks include physical and mechanical risks associated with machinery, such as injuries from moving parts, cuts, burns and crushing incidents. Chemical risks are also prevalent, with exposure to solvents, oils and other hazardous substances posing risks of chemical burns, respiratory complications and potential long-term health effects. The environment of manufacturing facilities often involves significant noise and vibration, which can result in hearing loss and other physical ailments. Furthermore, the presence of dust and airborne particulates can pose serious respiratory threats. Ergonomic risks are also notable, as repetitive movements, the manual handling of heavy materials and awkward postures frequently leads to MSDs. Addressing these OSH risks requires a holistic and systematic approach, including the employers´ obligation to perform rigorous risk assessments and to eliminate or, should it not be possible, to reduce the risks to the minimum following the hierarchy of control measures [5], the implementation of comprehensive safety and health protocols, and continuous employee training.

Technological and organisational solutions are pivotal to reduce the incidence of these risks and their reach. Indeed, the automotive industry is increasingly incorporating AIWM systems to ensure safety within complex manufacturing environments. These systems, by leveraging large datasets collected from workers and machinery, provide insights into productivity patterns, identify potential risks and streamline workflow management. For example, AIWM can enhance risk monitoring since AI technologies can be employed to continuously monitor workplace conditions, track workers' activities, and analyse behavioural and work patterns in real time, thereby enabling a more accurate assessment of potential OSH risks (Min et al., 2019). AI-based tools can also identify whether workers are maintaining appropriate postures and therefore reduce the likelihood of MSDs (Katwala, 2017). In addition, AI systems can detect, for instance through wearables technologies, compliance with PPE requirements, minimising the risk of occupational accidents and health-related issues (Palazon et al., 2013).

Another significant advantage lies in mental health monitoring. AI systems can evaluate workers' stress levels (Doki et al., 2021; Zel & Kongar, 2020), providing early indications of burnout or exhaustion and enabling the implementation of pre-emptive measures to mitigate these conditions. Furthermore, AI can assist in identifying incidents of workplace bullying and harassment by analysing communication patterns among workers, which may inform targeted interventions aimed at improving the psychosocial work environment (EU-OSHA, 2022a).

AI can also support customisation of workstations and routines, tailoring these to individual workers' needs. This personalised approach can optimise ergonomic conditions, thus promoting a safer and more efficient work environment. For instance, AI can facilitate the adaptation of workstations for employees with specific needs, such as older workers or those with disabilities, and therefore enhance inclusivity and reduce physical strain (Segkouli et al., 2021; Soter Analytics, 2023; EU-OSHA, 2022a).

In addition to customisation, AI tools can contribute to the design of safer work environments and roles. They can be integrated into safety training programmes or inform the development of effective health

[5] As per Council Directive of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (89/391/EEC) (OSH "Framework Directive") available at: https://eur-lex.europa.eu/eli/dir/1989/391

and safety strategies. AI can generate individualised risk profiles for workers based on health surveillance data, current risk levels and the probability of future health risks, in this way enabling a more tailored approach to risk management (Chamorro-Premuzic, 2020; EU-OSHA, 2018).

Despite the potential benefits for workers and OSH, the integration of AI systems into the workplace may also have adverse effects on worker safety and health and wellbeing. The principal risks are related to the functioning of those systems. Indeed, one major factor contributing to these adverse outcomes is the use of poorly trained, biased algorithms. If the data used to train AIWM systems are biased or incomplete, the resulting algorithms may perpetuate existing biases and lead to discriminatory decisions that disadvantage certain groups of workers (EU-OSHA, 2022a). For instance, older or disabled workers may be less likely to receive a production premium if health or age differences are not considered.

Another critical issue is the lack of human oversight. AIWM systems should not operate independently without human supervision, as this is essential for ensuring that the system functions as intended, and for identifying and mitigating errors or biases. Insufficient oversight can exacerbate risks, particularly if AIWM systems inadvertently direct workers into hazardous situations or disproportionally intensify the rhythms of their work (EU-OSHA, 2022a).

Furthermore, the opacity of AIWM systems presents a significant challenge. The lack of transparency in AIWM systems poses a critical issue in their implementation, as these systems must be designed to be fully comprehensible for both workers and employers. Workers need to have a clear understanding of how their personal data are collected, processed and utilised, as well as how the decisions that impact their working conditions are made. Moreover, transparency should extend beyond mere visibility of the decision-making processes to include mechanisms that enable workers, or their representatives, to influence, negotiate, and, if necessary, contest or prohibit the use of such systems. Thus, effective transparency should empower workers by giving them agency over how these technologies shape their work environment. In addition, a failure to provide adequate transparency can foster distrust and anxiety among workers, negatively impacting the quality of relations with hierarchy and undermining the overall effectiveness of AIWM systems (EU-OSHA, 2022a; EU-OSHA, 2022b).

Over-reliance on AI tools is another factor that can negatively impact worker wellbeing. The use of AIWM systems should be proportionate and appropriate to the context. Excessive reliance on these technologies, such as automatic response systems, can lead to over-monitoring, reduced worker autonomy, and increased frustration if workers receive unclear or insufficient guidance from AI-based systems.

In addition, as discussed in EU-OSHA (2022a), the deployment of AIWM systems can negatively affect OSH by directly impacting workers' working conditions and their autonomy over task performance. Indeed, these systems may contribute to:

1. **Work intensification:** AIWM systems can be used to increase work intensity by pushing workers to perform tasks at a faster pace, for extended periods and with fewer breaks. This increased pressure can elevate levels of stress and fatigue and thus raise the risk of workplace injuries.
2. **Loss of job autonomy and discretion:** AIWM systems may reduce workers' autonomy by controlling the content, pace and scheduling of work, which can lead to frustration, higher stress levels and decreased job satisfaction, and expose workers to greater risk of burnout.
3. **Dehumanisation:** AIWM systems, if not designed with a human-centred approach, may treat workers as mere cogs in a machine rather than as individuals, leading to a sense of dehumanisation. This can diminish motivation, reduce engagement and negatively impact overall worker wellbeing.

To prevent these risks, the Italian company has conducted an extensive risk assessment process in collaboration with OSH specialists, successfully reducing the incidence of these risks to well below the minimum legal thresholds for intervention. This achievement has been largely attributed to the implementation of technological and organisational solutions. For instance, the installation of closed workstations equipped with air conditioning and cleaning systems has significantly decreased workers' exposure to noise and biochemical risks. In terms of ergonomics, several technical interventions have been introduced to minimise the frequency and intensity of physical movements, along with a notable increase in automation, which, according to workers, could be expanded further.

Additionally, in response to increased productivity associated with the use of AIWM systems, in recent years the company has introduced an additional daily break to provide operators with more time to rest and socialise. Given that workers typically spend most of their time in isolated, enclosed workcells, management has recognised the importance of enhancing social interactions and collective breaks to mitigate the risk of isolation and improve psychological wellbeing, particularly in the context of significant organisational and technological changes.

On the other hand, the Belgian company appears to struggle more with balancing productivity and OSH risks, often favouring immediate efficiency gains over long-term OSH considerations.

6.1 AIWM and ergonomic risks

Both companies utilise digital technologies and AIWM to manage ergonomic risks and enhance productivity, by integrating technological solutions into their operations. However, significant differences emerged in both their approaches and outcomes.

In the Italian company, the implementation of AIWM has led to significant improvements in managing ergonomic risks across all departments. The reduction in the number of physical movements necessary for communication and task execution has decreased physical strain on employees. For instance, operators can now initiate assistance requests directly from their workstations, eliminating the need to leave their posts and walk across the plant, thus saving time and reducing physical exertion. Maintenance workers also benefit from this system, as they can arrive at workstations fully equipped with the necessary tools based on information provided in online requests, and therefore minimising unnecessary physical effort. In logistics, the improvements are even more visible. The ‘milk runner’, responsible for delivering materials, no longer needs to return to the warehouse in cases of incomplete or incorrect lists, thanks to streamlined digital communications. Additionally, the process of picking and validating final products has been simplified using barcode scanning systems, which automatically record and transmit data to the warehouse. This technological integration reduces the need for manual checks and the physical strain associated with them. Furthermore, packaging operations are less physically demanding due to the virtual warehouse system, which accurately tracks the composition and location of batches.

In the Belgian company, considering the high workload, speed and repetitive nature of tasks combined with the use of assembly lines and AIWM, rotations and workload adjustments are implemented to manage high-intensity work. The frequency of these rotations is determined by a collaborative process involving team leaders, team members, senior management and OSH advisors, as part of the ALB process. Unlike the Italian company, the Belgian company uses digital tools within the ALB framework to fine-tune workload settings, allowing for operations at, above or below 100% capacity. A workstation’s workload setting of more than 100% will obviously have more impact on workers (e.g. increase of ergonomic risks) and will give rise to more frequent rotation.

Furthermore, the system’s reliance on scientific management principles, such as methods-time measurement, introduces the concept of a ‘virtual average operator’. This statistical construct does not accurately reflect the physical capabilities of all operators, resulting in unequal workload distribution and potential ergonomic risks for certain workers, which are not systematically monitored by the company. Technically, additional ergonomic considerations can also be embedded within personal identification information datasets, potentially indicating mandatory requirements for PPE. However, this application is seldom utilised. Instead, a critical role in assessing ergonomic conditions is played by team leaders and prevention advisors, particularly in the final stages of the ALB process. These stakeholders are responsible for conducting thorough evaluations of the ergonomic aspects of each workstation, ensuring that the distribution of tasks does not pose risks to worker health and complies with safety regulations. Specific ergonomic risks are also associated with particular workstations; for example, ‘pick-to-voice’ logistics operators may experience discomfort from prolonged headset use and the continuous operation of handheld or finger-attached scanners.

6.2 AIWM and psychosocial risks

AIWM systems and algorithmic technologies are used by both companies to optimise productivity and operational efficiency. However, the impact on working conditions varies significantly across different dimensions, including worker autonomy, the intensification of work and opportunities for personal development, and so do work-related psychosocial risks in the two cases examined.

Worker autonomy has been impacted to varying degrees by the adoption of digital technologies and AIWM systems in the Belgian and Italian companies. The Italian company's approach allows for a greater sense of autonomy and professionalism among workers, facilitated by access to comprehensive process information and a more flexible task structure. Indeed, despite the stringent quality controls that manage the production process, there is evidence of some autonomy and discretionary management of daily tasks. For example, operators report a sense of greater autonomy when they can view their work assignments on monitors without needing to consult with supervisors. This perceived autonomy includes independently checking the assigned workcell and related tasks, even though the decisions on work assignments are made by the production manager. In logistics, real-time access to updated information about each workstation enables milk runners to better organise their delivery schedules based on current priorities. Similarly, maintenance workers benefit from receiving detailed assistance requests and having access to historical data on previous operations and potential breakdown risks, which increases their confidence in the decision-making process. Both middle managers and operators report an amplified sense of 'empowered professionalism', attributed to the system's validation of their skills and the standardisation of processes, which minimises unexpected events and enhances their overall knowledge of the production process.

The case of the Belgium company differs in terms of degree of workers' autonomy, as the highly streamlined production processes afford operators at the assembly line minimal autonomy. Indeed, the ALB process involves breaking down tasks into individual movements and actions, each timed to the millisecond. The sequence of these movements is strictly dictated and closely monitored by the AIWM system, leaving little room for deviation or improvisation. Consequently, the work becomes highly repetitive, particularly for production operators. Slightly different is the case for operators in the logistics department. For instance, while tractor drivers in logistics receive task allocations from the AIWM system, these tasks are not strictly sequenced, allowing for some autonomy in determining task order. Nonetheless, all tasks must be completed within the prescribed timeframe, especially those marked as urgent, which do not permit any deviation. With respect to other workers, team leaders in the Belgian company enjoy more autonomy due to their diverse set of responsibilities, although the extent of this autonomy is contingent on the specific nature of their workstation.

In general, the lack of worker autonomy usually related to the use of AIWM systems has significant implications for OSH. Reduced autonomy is frequently associated with increased stress levels, diminished job satisfaction and a higher risk of burnout, as workers have less control over their work pace, scheduling and decision-making processes (Marmot, 2015; EU-OSHA, 2022b). Increased stress and lack of control over one's work can also heighten the risk of psychosocial risks, which may manifest as anxiety, depression or other mental health issues. Furthermore, when workers have limited ability to make decisions, they feel incapable of influencing their work environment, leading to disengagement and decreased motivation that can, in turn, reduce situational awareness and the capacity to react appropriately to hazardous situations, therefore increasing the likelihood of workplace accidents and injuries.

Moreover, a lack of autonomy often coincides with work intensification, where AIWM systems impose strict productivity targets or continuously monitor performance metrics. In both the Italian and Belgian companies, the implementation of digital tools and AIWM systems has resulted in significant productivity gains as well as work intensification, but with different implications.

In the Italian company, digitalisation and AIWM have enabled workers to perform their tasks more efficiently, leading to substantial time savings. This efficiency gain has allowed workers to engage in a broader range of activities, thereby enriching their individual task portfolios and allowing them to dedicate more time to other tasks. Indeed, the instantaneous availability of digital data and improved communication channels have facilitated a shift in focus for supervisory and technical roles towards activities that support the company's innovative capabilities. For instance, production managers can allocate more time to developing new technological solutions, maintenance managers can enhance operator training, and logistics managers can adjust schedules in response to changing demands. Although there is a potential risk of deskilling among operators due to the dominant role of AIWM, this risk is mitigated by their active involvement and sophisticated use of these technologies, fostering, in reverse, an upskilling effect.

Conversely, in the Belgian company, digital technologies and AIWM have led to increased workloads and work intensification, characterised by the instantaneous and precise allocation of tasks under strict time constraints, guided by the AIWM system. Operators experience upskilling primarily in general skills, such as operating efficiently under high pressure and maintaining quality standards. However, the nature of their tasks remains strictly organised and highly repetitive, with no time dedicated to different activities. For team leaders and higher-level managers, the use of digital tools and applications encourages the development of transferable skills that are applicable both within and beyond the company. This role differentiation highlights a divergence in skill development outcomes between different job levels.

In both companies, worker training, skills and performance are closely monitored by human supervisors with the support of AIWM systems. In the Belgian company, for example, the AIWM system flags situations where an operator has not worked at a specific post for an extended period, prompting team leaders to reassign them to maintain proficiency. This continuous monitoring ensures that workers remain skilled and capable of meeting the demands of their roles.

Another aspect relevant for workers' wellbeing is cognitive stress. Continuous tracking and system-driven task instructions can lead to cognitive overload and 'techno-stress', resulting in anxiety, fatigue and impaired decision-making (Graveling et al., 2020; Samek Lodovici et al., 2021). This stress negatively affects mental wellbeing and increases the risk of errors and accidents. To mitigate these effects, AIWM systems should be designed to support worker autonomy and provide constructive feedback, helping maintain a healthy balance between productivity and workers' wellbeing.

Depending on how it is designed, implemented and managed, AIWM may help reduce cognitive workload and improve task management by offering benefits such as real-time oversight and error reduction, but it may also introduce stress factors and potential issues related to over-reliance on technology. In the Italian company, the way AIWM technologies have been adopted has significantly enhanced mental and cognitive wellbeing for both managers and operators by improving task management and the autonomous handling of quality constraints and emergencies. Managers benefit from reduced mental stress through the system's ability to facilitate preventive interventions, advanced risk assessments and immediate responses to unexpected issues. Operators experience a lighter workload due to AIWM tools such as statistical alerts for production, checklists set up for maintenance and batch validation for logistics. These tools reduce the cognitive burden by automating task reminders and minimising interruptions that previously contributed to stress. However, there are concerns that reliance on AIWM may lead to a degradation of essential basic skills such as memory and prompt reflection, which are critical for adapting to dynamic job demands and ensuring high performance and productivity.

In contrast, the Belgian company presents a different scenario where AIWM and digital technologies impact workers' stress and workload differently. Team leaders, who are mostly affected by these technologies, experience varying levels of stress based on the nature of their tasks and team performance. The AIWM system, including the Andon system, provides real-time status updates, which improve time efficiency and offer greater oversight and autonomy, particularly in less critical workstations. However, some team leaders face high stress due to task overloads and time-sensitive issues, particularly when managing escalated Andon calls or technical malfunctions. Logistics operators using pick-to-voice systems may face frustration and stress if the system fails to recognise their inputs, resulting in task delays. Despite this, operators report that quality monitoring mechanisms are beneficial for job performance. Additionally, while pick-to-voice and 'pick-to-light' systems are perceived as helpful in reducing errors, excessive reliance on these systems may lead to decreased attention and potential mistakes. The Belgian company addresses this issue through workstation and post rotations to mitigate stress and maintain engagement.

Finally, the most significant divergence between the approaches adopted by the two companies regarding technology implementation is evident in its impact on social relations and work–life balance, which also depends on the different size and internal structure of the two firms. The integration of AIWM and digital tools in the Italian case has led to improved social relations and work–life balance, characterised by better communication, and fewer conflicts, therefore reducing also stress levels, while in the Belgian case, workers report little to no time for social interaction and some difficulties, particularly for a pick-to-voice logistics operator and team leaders, in managing work-related stress outside working hours.

Moreover, in the Italian company, in particular, the benefits associated with the deployment of digital tools and AIWM span to all roles and the hierarchy. Operators perceived a reduction in social distance, and a better quality of verbal interactions as technical urgencies are managed by the system. These technologies are seen as facilitating seamless communication across departments and hierarchical levels, fostering a sense of social involvement and better coordination among workers. Improvements in work–life balance are also evident particularly for managerial roles. The availability of detailed and updated data has streamlined the management of emergencies and unforeseen problems, such as unplanned worker absences and machine breakdowns, thereby reducing the frequency of out-of-hours disturbances. For operators, the system's alerts and validation processes ensure that all tasks are completed correctly when the shift is finished, allowing workers to focus on their personal lives without concerns about unfinished work and reducing work-related stress after working hours.

Overall, both companies use digitalisation and AIWM to enhance productivity and efficiency, but different strategies emerge. The Italian company focuses on broadening and enriching job roles, particularly in supervisory and technical areas. Conversely, the Belgian company looks at maintaining high efficiency and quality in a more tightly controlled and repetitive work environment. These variations are indicative of the diverse ways in which AIWM can shape workplace dynamics, potentially enhancing worker engagement and health and safety in some contexts while exacerbating control and work pressure in others. Thus, the implications of AIWM for OSH are highly context-dependent, necessitating a nuanced approach to implementation that considers the specific needs and conditions of the workforce and the organisational setting.

Indeed, the implementation of AIWM to foster greater worker autonomy may offer multiple benefits. It enhances job satisfaction, reduces stress levels and supports mental health. Furthermore, workers who retain control over their tasks and decision-making processes experience increased motivation and a stronger sense of ownership, resulting in a healthier work environment and lower psychosocial risks. Moreover, autonomy allows workers to manage their work pace and workload more effectively, which reduces the risk of work intensification and may balance the negative effects of excessive control of AIWM adoption.

On the contrary, the adoption of AIWM to further centralise control and optimise processes at the risk of a higher intensification of work may induce workers to prioritise speed over their health and safety, compromising their mental wellbeing, as well as ergonomic practices — hence deteriorating workers' mental health and increasing the risk of MSDs and injuries. In fact, diminished autonomy not only impacts psychological wellbeing but also has direct physical health repercussions, underscoring the need for a more balanced approach in the implementation of AIWM systems that fosters greater worker involvement and control over their tasks (Roquelaure, 2019; EU-OSHA, 2021b).

Addressing these implications requires adopting a human-centred design in AIWM deployment, ensuring that systems are transparent, support worker empowerment and allow for worker participation in decision-making processes, thereby safeguarding both mental and physical health (EU-OSHA, 2022a, 2022b).

7 Conclusions and key takeaways

In the last decade, the empirical literature has widely studied the adoption of algorithmic management in the context of digital platform work (Pesole et al., 2018; Brancati et al., 2020; Wood, 2020), highlighting the role of algorithms in reshaping work organisation and power dynamics within the platform economy and the potential implications for OSH (EU-OSHA, 2021a). Similarly, the digitalisation process, the increasing adoption of algorithmic technologies in workplaces (Rani et al., 2024; Krzywdzinski, Schneiß

& Sperling, 2024) and the advent of the Industry 4.0 revolution (Cetrulo & Nuvolari, 2019) have reignited interest in the ongoing transformations in more traditional workplaces, such as the manufacturing industry, although their OSH implications are less studied.

This study on the adoption of algorithmic and AIWM technologies in two automotive companies located in Belgium and Italy aims at contributing to a better understanding of the overall impact of digitalisation on working conditions by focusing on the implications in terms of OSH. Developing a comparative perspective, the two case studies highlight both the OSH opportunities and challenges posed by the integration of AIWM systems.

The adoption of AIWM technologies by both companies occurred within the broader context of integrating advanced digital and automated systems as part of a lean production model aimed at enhancing productivity and minimising waste. However, significant divergence in managerial approaches and outcomes emerged, attributable to variations in their organisational structures, workforce engagement strategies and the distinct nature of their technological applications.

The Italian Tier 1 company supports worker versatility and in-house technological design and development, with substantial worker involvement in the implementation of the digital systems. This participatory approach has encouraged a sense of ownership and engagement among workers, contributing to low turnover rates and a collaborative work environment. The gradual introduction of digital tools, supported by on-the-job learning, has allowed workers to adapt and provide feedback, thus improving the processes iteratively.

On the other hand, the Belgian OEM focuses on efficiency through precise task synchronisation and workload management. By implementing detailed digital instructions, the company has streamlined its production process to achieve high output rates and stay competitive. However, this has rather favoured high turnover and consequently led to a significant proportion of temporary agency workers, highlighting the additional potential downsides of a less inclusive approach to technological adoption.

The case studies also highlight how digital technologies and AI can enhance OSH by preventing injuries, taking off routine and repetitive tasks from workers, and facilitating complex operations through reminders, quality and safety automatic controls.

Again, different strategies are identified in the two companies. In the Italian case, the collaborations with research institutions and national organisations on health and safety underscore a proactive attitude towards a continuous improvement of working conditions and OSH, taking advantage of the more advanced technological solutions, such as sensors and wearables, developed within the company. The participatory culture and lean work organisation model further reinforce a safe working environment by integrating workers as active problem-solvers.

In the Belgian company, the use of digital systems for ergonomic assessments and workload management indicates a structured and corporation-based approach to OSH. However, the emphasis on productivity enhancement through workload saturation and continuous monitoring suggests an underlying tension between the pursuit of competitiveness and the substantive improvement of working conditions. Furthermore, the high turnover rate of employees as well as of temporary agency workers indicates potential deficiencies in effectively addressing worker wellbeing in a comprehensive manner.

Finally, from the case studies it clearly emerges that the level of worker engagement in the adoption of digital technologies significantly influences their impact on OSH and overall job satisfaction. The participative approach followed by the Italian company by involving workers in decision-making processes and continuous improvement initiatives contrasts sharply with the Belgian company's top-down approach with consequences for workers' overall wellbeing and OSH. In addition, the findings of the study suggest the importance of developing a participatory culture in order to mitigate the potentially adverse effects of algorithmic management, such as increased surveillance and reduced autonomy.

In conclusion, involving workers in the development and implementation of digital technologies can enhance workers´ acceptance and adaptability, job satisfaction, and overall workplace safety and health. This approach ensures that technological advancements are aligned with the practical needs of the workforce and promote a sense of better understanding of the entire production process, increasing workers' level of engagement. While digital technologies can optimise production processes, it is crucial to balance efficiency with worker safety, health and wellbeing. Engaging workers in the development and implementation of digital technologies allows to “design out” the risks to workers from the digital processes, hence supporting “prevention through design” and a human-centred approach. Adequate structured training programmes, job role rotations, and proactive health and safety measures are essential components of a comprehensive approach to digital workplace transformation. Effective and transparent management of worker data are critical to maintaining trust and ensure a fair and democratic use of digital tools. Companies must establish robust data governance frameworks to protect worker privacy and use data responsibly and they must share relevant information with workers’ representatives to support shared decision-making processes. Implementing continuous improvement mechanisms that incorporate worker feedback can lead to more sustainable outcomes in terms of process efficiency and workplace safety and health.

On a final note, the successful integration of algorithmic management technologies and AIWM systems in the workplace requires a balanced approach that prioritises workers’ involvement and their safety and health. By encouraging a participatory culture and ensuring robust data governance, companies can harness the benefits of digitalisation while preventing its potential risks.

7.1 Key takeaways

1. **Participatory and human-centred implementation of digital tools:** Involving workers in the development and implementation of digital technologies can improve and reinforce their acceptance and adaptability, job satisfaction and overall OSH. This approach ensures that technological advancements are aligned with the practical needs and insights of the workforce.

2. **Balancing efficiency and wellbeing:** While digital technologies can optimise production processes, it is crucial to balance efficiency with worker safety, health and wellbeing. Worker participation, prevention through design, adequate structured training programmes, job rotations, transparency of information, and proactive OSH management are essential components of a comprehensive approach to digital workplace transformation.

3. **Data governance and privacy:** Effective and transparent management of worker data is critical to maintaining trust and ensuring a fair, participatory and democratic access to and use of digital tools. Employers must establish robust data governance frameworks to protect workers’ privacy and use data responsibly. Furthermore, they must share relevant information with workers’ representatives to support shared decision-making processes.

4. **Continuous improvement and feedback loops:** Implementing continuous improvement mechanisms that incorporate worker feedback can lead to better outcomes in terms of process efficiency and workplace safety and health. Iterative learning and adaptation are key to successful digital integration.

5. **Holistic assessment of OSH risks related to digital technologies:** The increasing interaction between workers and digital technologies, due to the widespread diffusion of advanced robotics, wearable tools and digital assistance systems, requires the performance of a sound, comprehensive and dynamic risk assessment of all risks - physical as well as psychosocial risks, including those of organisational, cognitive and social nature - faced by workers while performing their job.

Appendices

Appendix 1 – Belgian case study

Introduction

This report presents a case study on the implementation and use of worker management systems using artificial intelligence/algorithms (AIWM) and the implications for workers' occupational safety and health (OSH) in a company operating in the automotive sector in Belgium. The aim of this report is to produce evidence on the risks, challenges and opportunities of digitalisation of the workplace, and to highlight examples and practices of the design and implementation of digital technologies in a healthy and safe way.

As the case study shows, the introduction of AIWM in the automotive sector is a progressive and logical step considering the evolution of manufacturing. Importantly, AIWM is not just one digital tool but rather a process involving a plethora of digital tools and applications that all together process large amounts of data. In order to get a thorough understanding on the implications of AIWM systems on OSH, the case study focuses on those workers who are most exposed to AIWM in the company under study: operators and team-leaders working in production and logistics on or near the last stages of the assembly line, where all parts are assembled to the freshly painted car bodies. In the company, this is the production stage (or part of the plant) with the highest use of AIWM systems, in comparison to other parts of the plant, and so the impact on OSH is expected to be highest there. Moreover, in this part of the plant, more than half of the total number of workers of the company are employed.

Methodology

Methodologically, this research builds on a combination of desk research and field work, which included 10 study visits at the company's premises, 17 semi-structured interviews and numerous informal talks with different actors: operators, team-leaders, (middle) management, people responsible for production, logistics, IT staff, occupational safety and health representatives and trade union representatives. Company visits often included observation, while interviews usually included demonstrations, for instance of the use of (digital) tools.

Business model and work organisation

Brief presentation of the company

The company under study is a car manufacturer located in Belgium. The company is part of an international group employing 45,000 workers in multiple plants in different locations in Asia, Europe and the United States. In Belgium, the company employs some 7,000 workers, about 10% of which are temporary agency workers. Each week about twenty workers leave the company due to retirement, voluntary leave, non-renewal of the employment contract or layoffs. The company's Belgian branch in essence comprises of several shops where the bodies of the cars are first welded together, painted, and where finally all remaining parts are added to the car body. At the time of study, the company had a production rate of well over 200,000 cars per year, or on average over 1,000 cars are produced per day or approximately one car every 60 seconds. Both the rate of production, needed to keep the company competitive in a global market, and the focus on quality demand efficient and highly streamlined production processes, which also involve the use of AI-based worker management (AIWM) systems to optimise and coordinate human input into the production processes. As a result, during the two preceding decades, production increased by almost a third.

The adoption of a lean organisation model and advanced technologies

Manufacturing at the company studied is streamlined using an **assembly line** that consists of consecutive workstations performing different tasks and processes. The higher the rate at which products are moved along the line, the more important the throughput of each individual workstation and the timing of the different tasks, considering that the line is set to produce one car approximately every 60 seconds. That is, even minor setbacks or an excessive allocation of time to the performance of tasks can lead to significant drops in productivity and large losses in revenue.

Smooth throughput thus requires the **synchronisation** of **all** tasks performed by both workers and automated production processes on **all** workstations. At the company studied, a digital system is used for both the design of a car and the processes needed for its manufacturing, resulting in a digital description of the different workstations making up the assembly line and of the essential task(s) that must be performed at each workstation. These digital descriptions, called **Process & Inspection Instructions** (**PIIs**), are subsequently transferred to another digital system that is used for the so-called assembly line balancing (**ALB**). In the company studied, ALB is the process of the actual implementation of the digitally designed process(es), which consists of testing, and adapting if needed, **the sequence of all actions** or operations needed **to perform the task(s)** allocated to a particular workstation as described in the PII. For instance, tasks performed by workers (operators) consist of different movements and actions (taking a step, picking up a part, or moving an arm), which must be performed in the sequence determined during ALB. Hereby, every action is automatically assigned a Time Measurement Unit or **TMU** (1 TMU = 36 milliseconds), whereby the total sum of all TMUs in function of the assembly line's throughput will result in a score representing the total workload for one operator working on that workstation or work post. PIIs can also indicate a need for ergonomic aids and what PPE is mandatory (or in some cases forbidden). However, this option is not automated, and reportedly it is not always used. The company's ALB digital system allows for the setting of workstations' workload at exactly (or higher or lower than) 100% of its capacity and will automatically raise a flag when the workload on a post is reaching or exceeding critical levels (measured in terms of TMUs). In the final stages of the ALB of a workstation, the station's team-leader and the prevention advisor are involved, who can decide to ask (external) ergonomists for advice about the ergonomic implications of the workload (e.g., on the need for ergonomic aids).

In addition to the workstations along the assembly line, and supporting them transversally, the on-site logistics function in the company and the related workforce is dispersed throughout the plant, in line with **just-in-time** principles of lean manufacturing.

Workers' functional flexibility, skills and training

New operators joining the company are mostly hired as temporary agency workers. All new workers first participate in a training programme where they are taught the basics of OSH and OSH risks prevention, company-specific OSH regulations, as well as the basics of assembly line work, lean principles, and the basics of the use of (digital) tools and of AIWM (e.g. Andon), the company's principles and company culture. New operators are trained for two workstations or posts, which allows them to rotate workstations or posts as well as fill in for colleagues who are absent. Subsequently, operators will be trained on the job to allow them to work at more work posts. Operators are trained for up to four posts, as allowing operators to work on too many different workstations or posts is considered counterproductive as they would not be able to perform at peak efficiency at all workstations or posts.

AIWM and its implications for the workforce

In the company under study, production is completely data driven and controlled by digital tools continuously collecting, storing and processing a tremendous amount of data related to production and also to worker performance. These data are used to control and steer the assembly line and on-site logistics, quality control, and in many cases, the allocation of tasks to workers. On the assembly line, digital data from different sources are combined and used to assure the timely arrival of parts and overall workstations' timely and required quality throughput. Below, we briefly discuss the main AIWM processes affecting operators and team-leaders and how said processes do so.

Adoption of AIWM

In the company studied, all workers badge in and out when entering and leaving the company premises. Operators, however, also log in and out when entering or leaving a workstation or post via a **Personal Digital Assistant** (**PDA**) dedicated to each workstation. When logging in or out of the workstation, operators scan the code of the car they will start working on or have last worked on. This allows **tracking** which operator worked on which cars and when, as the location of the cars on the assembly line is known and logged using **RFID**-tags and **RFID**-readers. When an operator uses connected tools or generates data by other means (e.g., through scanners) while working, performance of tasks is monitored to the (milli)second.

Operators working in production mainly add parts (upholstery, electric cables, bumpers, wheels, lights and so on, depending on the workstation) to the car bodies in a **predetermined sequence**, as described in the PIIs. Such sequence of selecting the right parts and, where needed, using the right tools at the right moment to assemble them is guided by the AIWM system that allocates tasks to the production operators as described below. In what is called ‘a 60 second world’, operators typically have **only a few seconds** to perform each task. Operators working in logistics, performing the tasks allocated to them by the AIWM system as explained below in further detail, typically move parts to the line driving small electric tractors pulling carts. In addition to that, under the guidance of the AIWM system, at certain work posts logistics operators merely load the carts or transfer parts from the packaging they arrived in into other boxes or carts, while at other workstations, logistics operators combine preparing carts and driving them to the designated workstation on or near the assembly line.

Team-leaders are responsible for the **timeliness and quality of the production and throughput at their workstation** and thus for the functioning of their team. Team-leaders, both in production and in logistics, are operators that have been promoted to this role. Team-leaders play an important role in the ALB process of their workstation and in the daily assessment of OSH-related matters. Finally, team-leaders are responsible for the swift resolution of all issues affecting production and teamwork as such.

The allocation of tasks to workers by the **AIWM** system **can be considered ‘implicit’ or ‘explicit’**.

‘Implicit’ allocation of tasks by the **AIWM** system regards mostly production operators and happens, for instance, when a certain car model arrives at the workstation and the worker – having received training as described above – is expected to know which tasks need to be performed on said model. In any case, as already mentioned above, the tasks are described in the **PIIs**, while the timing and sequence of tasks to be executed on the line to build a car is decided **algorithmically** even before production starts.

‘Explicit’ allocation of tasks by the **AIWM** system consists of tasks allocated directly to the production operator concerned by either **audio** signals (for instance 'pick-to-voice' where the AIWM system issues voice commands via a headset) or **light** signals (for instance ‘pick-to-light’ which indicates when to pick up, assemble or use which parts or tools), in which case task performance can be acknowledged (and monitored) by the operator using his voice (voice recognition software), barcode scanners or light sensors. Explicit allocation of tasks can also take place through **screens**, for instance on PDAs for some logistics or maintenance operators or for some machine operators assisting or supervising industrial robots or other automated processes. As is discussed below, many operators working in production state such explicit forms of task allocation, e.g. by voice or light, are helpful in the performance of their job and help them to avoid making mistakes by indicating the sequence in which parts or tools need to be picked and used within the limited time tasks need to be performed.

Quality is monitored digitally, via sensor-equipped tools (e.g., nutrunners, i.e. connected wrenches, will report time, torque, number of revolutions and inclination) and via error proofing (e.g., of electric and electronic systems) at designated workstations, or by operators performing quality checks and reporting issues via the digital quality control system. Quality and other production issues (e.g., lack of parts at workstations) are **monitored, logged, controlled and signalled** via both dedicated quality management **digital tools** and an **Andon**-system (a system to alert operators about an issue on a production line), which are part of the wider AIWM system. **Andon alerts** or **calls** can be triggered either manually by an operator (e.g., by pulling the Andon cord, pushing an Andon button, or issuing an Andon call via the workstation's PDA), or automatically by sensor equipped tools (e.g., a nutrunner) or by the AIWM system. An example of the latter case is where the **AIWM** system keeps track of the logistics flow and will issue an Andon call (e.g., if a logistics task was not performed in time). Andon calls can be signalled via Andon **lights**, a **sound** (typically a fragment of a piece of music, usually a pop song) and **automatically generated messages** that are sent via **SMS** and/or via **email** to the team-leader and the supervisors concerned, the level of escalation being determined algorithmically by the AIWM system.

Team-leaders must address and resolve any issue flagged by an Andon call as soon as possible. If an issue is not resolved within a designated time, or in case a number of Andon calls are generated within a certain period of time, the team-leaders' supervisor is **automatically** notified. Subsequently, if the issues are not resolved, the superiors of the supervisor are notified. The last in line to be notified is the CEO (six to seven **degrees of escalation**, depending on the type and number of issues). These notifications are automatically generated based on a **predetermined set of factors and rules**.

Digital screens are also part of the AIWM system, providing information allowing mainly team-leaders and their superiors both a quick but comprehensive overview of the status of their workstation(s) and the rest of the assembly line (such as **targets** set and reached, **level of supplies**, the **number and type of issues**). Andon calls are thus actually tasks allocated to operators and/or their superiors.

Psychosocial and organisational factors at play in the use of AIWM

The pervasive level of digitalisation, and use of data and digital technologies within the company, does not only impact productivity and efficiency, but also affects job quality, including occupational safety and health, on different levels. Below, we briefly discuss the impact of AIWM on worker's autonomy, on work intensification and skill use, and the use of data for monitoring purposes.

Workers' autonomy

Given the high rate of production and the heavily streamlined processes at the company, operators working at the assembly line have **little to no autonomy**. As described above, during ALB, tasks that need to be performed are broken down into each separate movement and action needed and are timed to the (milli)second. Furthermore, the **sequence** in which movements and actions must be performed by the worker is **stringently described** and most often monitored by the AIWM system. There is little to **no room for deviations or improvisation**. As a result, work performed at workstations or posts on the assembly line by production and logistics operators in the company studied is **highly repetitive**. Some operators working in **logistics** do have **a little more autonomy**. For instance, although tasks are allocated to tractor drivers by the AIWM system, these tasks are not part of a predetermined and binding sequence, allowing for some degree of autonomy in deciding which tasks to perform first. Nevertheless, it is understood that all tasks must be completed within the **limited timeframe** set by the system automatically, and that **tasks marked as urgent do not allow for any autonomy**. Team-leaders have a more diverse set of responsibilities, allowing for more autonomy in the performance of their job, although as discussed below, much depends on the specifics of their workstation.

Work intensification and impact on skills

The use of **digital technologies and AIWM** in general lead to **work intensification and higher workloads**, for example the more direct, often **instant and direct allocation of tasks**, to be executed in the assigned timeframe and under guidance of the AIWM system, which determines the sustained pace of work. For operators, the intensification of work and the use of digital technologies and **AIWM seems to be accompanied by an upskilling effect on general skills** such as, among others, being able to work on an assembly line faster and being able to perform continuously under high pressure while maintaining a high level of efficiency and quality. For team-leaders and their superiors, this is different as they are encouraged and expected to use the digital tools and applications available to them. This allows them to **develop skills** that in many cases are transferable to other professional roles, functions and activities, both within and outside the company.

Workers' training, skills and performance are monitored regularly by team-leaders, but are also **monitored by the AIWM system**. For instance, if an operator logs in to a workstation or post after not having worked there for very long, the system will raise a flag. The system also raises flags if operators are reaching the limit of time they were not assigned to a post, allowing team-leaders or supervisors to assign them to that post within a set time so as to maintain their level of training.

Data availability, control, and surveillance

Data on all workstations' and on workers' performance and throughput are processed continuously, resulting in **vast amounts of historical data** stored in data clouds and data lakes. The data processed are primarily used to control and monitor the company's production and quality related processes. However, the level of data processing allows for the **monitoring of workers at all levels** of the company's organisation up to the millisecond. On the upside, such monitoring – per managerial decision – is at present mostly used to monitor workers' performance in order to identify and resolve quality related issues. Surprisingly, none of the operators interviewed seem to mind the pervasive collecting and processing of data: on the contrary, they apparently welcome the gathering and use of data as an **objective standard of evaluation** of their work, a guide to help them in the performance of their job.

The implications of AIWM for OSH

Brief overview of OSH risks

As in all companies manufacturing cars, workers in the company are confronted with various health and safety risks. However, for this case study report, we will only look at the implications of AIWM systems on the health and safety risks that operators and team-leaders are faced with, which we briefly discuss in the next sections.

AIWM and ergonomic risks

Due to the **high workload and speed**, and the **repetitiveness of movements** involved, which are the result of the use of an assembly line and AIWM, most operators working at the company are **rotated** between different workstations and posts **to avoid physical, but also mental strain**. The frequency of rotation depends on the workstation and is decided by the team-leader in concurrence with the team members, the team-leader's superiors and the OSH prevention advisor, as part of the ALB of said workstation.

The use of digital tools for ALB not only allows to set workstations' workload at exactly 100% of their maximum capacity, but also allows their workload to be set above or below the maximum capacity. A workstations' workload setting of more than 100% will obviously have more impact on workers (e.g., increase of ergonomic risks) and will give rise to more frequent rotation.

In addition, as the ALB relies on some of the **principles of scientific management** (i.e. Methods-Time Measurement) and thus on the use of statistics, it makes reference to a (non-existing) '**virtual average operator**' when calculating the workloads. The result is that being a statistical artifact, this 'virtual average operator' thus does not apply correctly to all operators equally, meaning that a certain workload will be harder to handle for a number of operators and easier for others, which is not taken into account by the system. The impact thereof is not monitored, or at least not systematically at the company studied.

Furthermore, the setting of the workload on the assembly line in general and on specific workstations is a **managerial decision** in which variables on production and efficiency are weighed against OSH risks, where safety is more easily measured than long-term health concerns.

Apart from the ergonomic risks described above that almost all operators face, there are those which are specific to specific workstations: 'pick-to-voice' logistics operators, for instance, can experience **physical unease** due to the prolonged wearing of the headset and due to the continuous use of handheld or finger-attached scanners.

Cognitive stress

In many ways, **team-leaders** are company workers who are **most impacted** by the use of AIWM and digital technologies, with their workload and levels of stress depending on the nature of the tasks performed at their workstation and on the performance of their team. On the **upside**, AIWM allows team-leaders to have **more oversight** of their workstation and their team's performance, which **can support stress management**. The Andon system, for instance, provides team-leaders with **(quasi) real-time status updates** resulting in **time efficiencies**, allowing those responsible for 'calmer' workstations to have **more control** and, to some extent, **more autonomy**.

However, some team-leaders face a high number and even an overload of tasks, most of which are critical and extremely time-sensitive and assigned by AIWM, especially in situations resulting in an **escalation of Andon-calls** (e.g., when multiple issues arise simultaneously, or when a faulty sensor or tool continuously generates Andon calls), which can lead to high levels of stress.

'Pick-to-voice' logistics operators can experience **frustration and stress** in cases where the AIWM system does not acknowledge the operator's voice inputs (e.g., due to ambient noise or the need for recalibration of the voice recognition system), resulting in the operator not being able to finish the task and losing precious time. On the positive side, most operators report that the quality monitoring mechanisms **helps** them in the performance of their job and the assessment thereof.

Furthermore, logistics operators using 'pick-to-voice' and 'pick-to-light' systems claim such systems help them to **avoid making mistakes.** Nevertheless, some team-leaders and other superiors indicate that operators relying too much on such systems experience a **lack of attention and alienation**, which may result in mistakes or even accidents. One way the company aims to tackle this issue, is through workstation and post rotation of operators.

Social relations and work-life balance

Outside team meetings or other meetings, the vast majority of operators at the company under study have **little to no time for social interaction** during work hours. One of the only exceptions being logistics operators (e.g., tractor drivers) who move through the plant and thus have some possibilities to (briefly) talk to colleagues. Depending on the workstation, team-leaders have somewhat more opportunities to interact with colleagues, aside from weekly briefings with their colleagues and superiors. Furthermore, where there used to be two 10-minute and one 25-minute breaks in every shift, this was recently changed to three 10-minute breaks, leaving even less room for resting time and interaction among colleagues. Said change was unrelated to the use of AIWM and decided via an online referendum among workers, with some workers contesting the results thereof.

The majority of operators interviewed did not report experiencing work-related stress symptoms outside the workplace, although a pick-to-voice logistics operator did report **hearing the AIWM's voice after working hours** and having **trouble sleeping when first starting the job**, while a team-leader reported **taking home work-related stress and frustrations** caused by, among others, the AIWM system to the point of having trouble sleeping when being at their previous workstation. The operator subsequently stated the situation at their previous workstation had not changed and felt sorry for the person who had replaced them, knowing all too well what said person was experiencing every day.

Social dialogue

Industrial relations

Relationships between workers, trade unions and management seem to be good at the company studied, and trade union representatives reported being fully allowed to play their role. As mentioned before, interviewed workers both in production and logistics do not seem to mind the level of digitalisation and monitoring in the workplace. However, it is worth mentioning that this could be the result of a 'selection bias', with workers who do feel affected by the extensive use of digital technologies not being available for an interview (for instance because they are on sick leave or left the company). Trade unions at the company – which are informed and systematically consulted by the management before the introduction of digital technologies and tools – seem to have accepted the extensive and pervasive digitalisation of the workplace as a necessity in a highly competitive global market, and in some cases, even as a more objective means of evaluation of workers' performance. However, it is worth noticing that the use of data is not equally accepted at all plants of the group that the company is part of, as reported in the interviews.

Participatory practices

Investment in on-the-job-training, shortages in the Belgian labour market and the company's culture and traditions are some of the main reasons that the company's human resources (HR) policy is to retain workers as much as possible and not to use gathered data as a 'stick' but rather as an occasion to address and resolve issues. Furthermore, HR launched a campaign to improve workers' involvement and commitment at work. One part of this ongoing campaign is to have operators from time to time take over team-leaders' responsibilities (for instance quality control).

Relations with institutional stakeholders

Of relevance to OSH is the use of an ‘external service for prevention and protection at work’. As established by Article 40 of Act of 4 on August 1996 on the wellbeing of workers in the performance of their work in Belgium, an external service for prevention and protection at work always consists of a risk management and a health supervision section. The first dealing with occupational safety, occupational medicine, ergonomics, industrial hygiene and psychosocial aspects of work. The health supervision section, on the other hand, is managed by an occupational physician and includes the nursing and administrative staff necessary to carry out health supervision. This service is an independent third party who, in the company under study, is consulted and provides advice on OSH-related issues and, among other tasks, deals with workers who are on long time sick leave. However, due to the legislation on data-protection and professional secrecy of health-care providers, data on the reasons for reportedly high number of long-term absenteeism cannot be shared with the company.

Key takeaways

The introduction of **AI-based worker management** (AIWM) systems in the studied company represents a significant advancement in manufacturing, building upon concepts like assembly lines, scientific management, lean manufacturing and automation. AIWM promises increased productivity, but also brings forth challenges and risks particularly concerning OSH. At the studied company, the **pervasive adoption of digitalisation and AIWM** has been largely accepted with minimal resistance, possibly due to a superficial understanding of the extent of the data collected and the ways in which it could be (mis)used among workers and their representatives, and in spite of the information and consultation strategies put in place by the management. Another factor at play could be the extensive use of **temporary agency workers** and the fact that procedures for such workers (including mechanism of representation, consultation and participation) differ from those that apply to workers directly employed by the company.

While AIWM is primarily used to achieve better monitoring and optimisation of production and quality processes, its **extensive data processing capabilities** also enable detailed monitoring of workers. This monitoring is crucial for performance evaluation but raises concerns about worker privacy and the potential for **increased workload and stress**. Despite the company's emphasis on OSH, the negative impacts of AIWM on workers’ wellbeing and its potential for preventing or mitigating OSH risks (e.g., reducing stress and enhancing control) seems not to have been sufficiently addressed by the company. The company's management **prioritises productivity but acknowledges that the demands of the job are not suitable for everyone**, physically or mentally. This selective acceptance may create a bias where dissenting voices either leave voluntarily or are unable to join in the first place, potentially skewing perceptions of AIWM's impact.

Moving forward, there is a **need for further research into the implications of AIWM on OSH** and worker wellbeing, as well as **consideration of more integrated data processing systems that balance productivity gains with ethical and OSH concerns**. Additionally, initiatives aimed at **improving worker involvement and commitment** such as the HR campaign described above highlight attempts to mitigate risks stemming from extensive digitalisation and AIWM, although these efforts require further refining, adapting and extending such initiatives to address issues effectively.

Appendix 2 – Italian case study

Introduction

With the development of advanced and highly integrated digital technologies, new models of management have been progressively introduced in the workplace. Until now, most of the attention has been devoted to platform workers, given their new socio-economic and institutional characteristics. However, increasing evidence highlights how worker management models based on AI and algorithms have also been spreading in more traditional contexts, such as the manufacturing industry, calling for further research. In fact, rather than showing a uniform and deterministic pattern, important heterogeneities emerge concerning the deployment of these technologies and their impact, both on the production process and on job quality. The goal of this report is to provide novel evidence on such topics, through a case study of an automotive company located in Italy. Being part of a broader campaign of EU-OSHA aimed at identifying opportunities and risks behind the adoption of new worker management models, this study tries to combine the analysis of the organisational, technological and social characteristics of the firm. The main assumption is that health and safety issues do not represent separate dimensions, but rather are at the intersection of all the domains under study and need to be addressed in a comprehensive and interdependent way.

Methodology

Data have been gathered through the combination of multiple sources, from official documents shared by the company, field observation and interviews with workers, held both at the firm's premises and remotely. Several job profiles were covered to ensure an adequate representation of the workforce composition, from line and quality operators to workers with managerial responsibilities in the departments of production, logistics, maintenance and human resources. Additionally, external occupational safety and health (OSH) experts were also involved as key informants on the specific practices adopted by the company. Interviews followed a specific template agreed upon with EU-OSHA and were conducted both in the form of individual interviews and focus groups.

Business model and work organisation

Brief presentation of the company

The firm under study is a company with 49 full-time workers, located in the province of Naples, in the south of Italy. The company sells carbon-coated synchroniser rings to automotive firms, mainly original equipment manufacturers (OEMs). The ring is an important component of manual and dual-clutch gearboxes of internal combustion engines and hybrid cars, trucks, and similar vehicles. Despite a relative uncertainty in the sector due to the conversion to electric vehicles, which do not require this component, the company has been recording a stable production level, with more than 6,825,000 rings produced in 2023. The company's core production activity – the coating of synchroniser rings – is carried out through three different processes: coating the carbon and applying the glue on the ring; coating the carbon without applying the glue (already present on the carbon); molybdenum thermal spray coating of the ring. These processes show important differences. They include manual tasks performed by the operator (i.e., visual inspection after sandblasting), automated tasks performed by the machines (i.e., sandblasting, glue spraying) and tasks that can be performed alternately by the operator or the machine (alignment of the carbon strip). In fact, the degree of automation is not fixed and can be modified by the company according to production volumes and customers' requirements. The firm is part of an international group headquartered in West-Central Europe, which employs 12,704 people worldwide and is present in 38 different countries. Among the coordination mechanisms adopted at international level, a program of excellence is held every month for representatives of each local unit to discuss improvement proposals. On this occasion, best practices can be applied to different plants with the support of the firm that first introduced them.[6]

[6] The company under study already provided support to other plants, given its experience with lean work organisation models.

The adoption of lean organisation model and advanced technologies

An important process of renewal aimed at increasing productivity, efficiency and quality started once the company, founded in 1998, moved to its current 4000 m^2 factory in 2008, with the idea of radically changing the structure of the company's processing layout. In the context of the financial crisis, which strongly hit the automotive sector worldwide, the company was supported by a consultancy firm, expert in lean organisation models. The main goal was to move from a traditional production process, where each worker performs a single task, to integrated workstations where the worker is able to perform all tasks and produce the final good. During the initial experimental phase, the company quickly became autonomous in such a transition process. In fact, while introducing automated solutions to enhance productivity and improve working conditions, the company began to design in-house machinery and equipment tailored to its needs, to overcome the technical constraints of technologies available in the market.[7] Digital technology was also gradually introduced, mainly through the adoption of Systems, Applications and Products in Data Processing (SAP) – an enterprise resource planning software – whose user interface was developed in-house by the company's IT specialist. To ensure an easy and efficient use of SAP by the whole company (from production to administration), the implementation process actively involved workers through the collection of their suggestions.

Workers' functional flexibility, skills and training

To operate efficiently, the company relies on highly functional operators who can manage the entire process and cope with changing constraints when moving from one workstation to another. Indeed, given a certain variety in the production process, each workstation is characterised by a different set of tasks and specific matrix of competences. Consequently, a one-month training program is provided for new operators. The course includes first formal training (covering health and safety, quality, etc.) and then specific training on the job, where the operator is supported by the supervisor in performing working tasks. During this initial period, the pieces produced go under stricter quality controls. Once the zero-defect standard is reached, the operator is allowed to work autonomously.[8] To a different extent, administrative workers and managers also rotate among different roles. Such functional flexibility and internal job mobility is indeed perceived as a learning practice that enables a better understanding of the entire process and enhances a smooth interaction among departments. With respect to the adoption of the lean model, the entire workforce was actively involved in workshops and training courses, provided by the consultancy firm. Meanwhile, no specific training was devoted to digital technologies, including the more recent application of AI-based solutions to manage workers – that is, AI-based worker management (AIWM)[9] tools. Rather, a strategy of 'learning by using' was pursued by the management, as technological innovations were introduced step by step and tested directly on the line with the operators. During this transition phase, workers were indeed encouraged to share their feedback about difficulties and bottlenecks encountered in dealing with the new devices.

AIWM and its implications for the workforce

Adoption of AIWM

Digital technologies and AIWM are now widespread in the company, affecting all hierarchical roles and production stages. To better assess their impact, it is crucial to identify their main applications. The table below provides a synthetic overview of the tasks performed through digital technologies and AIWM, distinguishing among production, maintenance and logistics departments.

As the table below clearly shows, the main (and in some cases overlapping) areas of application of AIWM concern: **allocation of tasks, communication and information tools** (i.e., automatic daily assignment of operators' workbook via a screen device, alerts on statistics to be compiled before starting to work and during the process); **quality and safety controls** (i.e., validation of batch packaging, control of machines temperature); **planning and maintenance design** (i.e., updated change in the production

[7] A machine designed by the company was recently installed at another plant of the group located in Italy.

[8] In terms of quality, the company records only 2.5 pieces with defects per one million products.

[9] AIWM identifies technologies that allow the totally or semi-automated management of data to take decisions concerning the workplace, both through the application of predefined rules (algorithms) and dynamic models of artificial intelligence.

plan of specific products in case of changing requirements, alerts on preventive maintenance interventions based on breakdown frequency); **logistics management** (i.e., updated delivery of raw materials and final product picking, warehouse management and validation of batch composition).

Table 4: Main applications of digital technologies and AIWM across departments

	Production	Maintenance	Logistics
Main tasks performed through technologies (i.e., SAP, barcode scanners, sensors)	Collection of data on production targets, raw materials, quality requirements, workstation productivity, etc. Provision of technical sheets and virtual configurations of products and machines present in each workstation. Communication tool for assistance and support.	Communication tool for requesting maintenance intervention and assistance (classified by urgency). Collection of data on all maintenance operations (time required, workstation, type of components used, type of failure, total cost, etc.).	Collection of data on available stock and raw material consumption at each workstation. Integrated collection of data on batches to be sent to customers (from raw materials used to final product) and stored internally for agile consultation. Virtual representation of the warehouse and inventory management.
Main AIWM applications	Workbook assignment to operators via the monitor when they log in with their personal badge. Set-up of the workstations (after the launch of a new production order by the production manager) based on the features of each product and associated process. Preliminary checklists on quality, safety and production requirements to be validated by the operator to start working. Alert system for the collection of specific statistics on the product (on average every two hours).	Preventive maintenance warning system based on optimal intervention frequency (derived from data analysis on machines failures and directly modifiable by the maintenance manager). Workstation set-up checklist (to be completed by the maintenance operator).	Real-time updating of material consumption at each workstation (while the operator produces the final product, the system automatically computes the amount of material used) and generation of delivery programmes every two hours. Control and validation of the final product packaging. Generation of transport documents with complete traceability of the entire process. Automatic risk assessment in case of quality claims on other products with similar characteristics.

Source: Author's elaboration based on workers' interviews and field visit at the plant

Psychosocial and organisational factors at play in the use of AIWM

Given the extensive use of these technologies within the company, the impact on job quality needs to be assessed in a multidimensional way, considering both the different domains of job quality and the hierarchical role covered by the workers.

Autonomy, standardisation and professionalism

A first job dimension strongly impacted by these technologies is the degree of autonomy that workers exert while performing their tasks. Even though the production process is subject to strict quality controls that must be respected carefully, evidence is found of a more discretionary management of daily tasks, both in formal and informal ways. For instance, the possibility of looking at workbook assignment on the monitor without interacting with any supervisor is perceived by the operator as a form of enhanced autonomy in managing own job (i.e., checking alone the assigned work cell and related tasks), even if he knows that the decision was taken by the production manager. In the case of logistics, the availability of updated information on each workstation allows the milk-runner[10] to better organise his delivery schedule, according to the actual priorities that he faces. As for maintenance, the possibility of receiving detailed requests for assistance and the availability of stored data on previous operations and risks of breakdowns, increase the worker's self-confidence when making decisions. Generally, both middle managers and operators report a feeling of higher entitlement in performing their tasks, as the system provides a validation of their professionality. This sense of 'empowered professionalism' is also due to the perception of having a comprehensive and broader knowledge of the entire process, which becomes more standardised and methodical, and less prone to unexpected events.

Work intensification but also enrichment of tasks and upskilling

The use of digital tools and AIWM has led to an overall increase in productivity, as all workers confirm they can perform their daily tasks more quickly, with considerable time saving and enhanced efficiency. At the same time, such work intensification has also translated into an enrichment of the individual set of tasks. Given the extensive and instantaneous availability of digital data (previously stored only in paper form), as well as the ability to communicate with the rest of the company (without physically moving), workers confirm dedicating more time to other tasks. This results in an upskilling effect, especially in the case of supervisory and technical roles. Indeed, they can focus on activities less linked to the production process, but that are still crucial to fostering the innovative capabilities of the firm. For instance, while the production manager can devote more time to designing new technological solutions, the maintenance manager can provide more training to operators, while the logistics manager can more easily adapt his daily program, anticipating or postponing activities according to changing customer demands or business needs. In the case of operators, the potential risk of deskilling due to the pervasive role of AIWM seems to be counterbalanced by their direct involvement and advanced individual use of these technologies.

Data availability, control and surveillance

Data collection is continuous and covers all stages of production. For example, at the end of each shift, the production manager receives an automatically generated email, providing detailed data about final products produced per workstation, compliance with targets, an overview of any problems encountered and the solutions adopted. Previously, this data could only be collected on paper or by talking directly to the operators, with clear costs in terms of unsolved asymmetric information and time waste. The operator, when logging into the system at the start of the shift, can see on the monitor – together with a message from OSH awareness campaigns about the use of personal protective equipment (PPE), etc. – the workbook (weekly shift, workstation, specific PPE required) together with detailed information about any issues that occurred the day/shift before at the same workstation. The maintenance operator also relies extensively on data in the daily work: not only does the operator deal with on-going intervention requests, but it is possible also look at the operations made during the previous day/shift.

[10] The milk-runner is the logistics operator in charge of delivering raw materials and picking up final products from workstations.

Once a maintenance intervention is completed, information on its total cost (in terms of working time, price of components, production loss) is automatically displayed to all the workers involved. However, rather than being seen as a tool of surveillance, such intensive collection and broad availability of data is perceived as a communication channel. It becomes a tool of collective transparency that increases the sense of commitment of workers in performing their tasks efficiently. Even the emergence of unexpected bottlenecks seems to be handled more calmly by the operators, first because they feel the 'authority' of directly signaling the problem and secondly, because they know that everything is recorded by the system. Indeed, by having a comprehensive overview of the entire production process, workers feel that such data is not used to control them, but rather to increase efficiency, to support them and in this way to even improve their working conditions.

The implications of AIWM for OSH

Brief overview of OSH risks and management strategies

The type of production carried out in the company under study exposes the workforce to a wide array of health and safety risks. Macro hazards include the risk of explosion due to the storage and use of flammable gases (i.e., acetylene, oxygen), solvents, machine and coating oils. Occupational risks include exposure to vibration and noise (caused for instance by the sandblasters); bio-chemical risks and dust exposure (caused by the coal and molybdenum processing); accidents related to the use of automated machines (i.e., injuries, dragging damages, burns); manual handling of loads and repetition of tasks. Over time, an in-depth process of risk assessment was initiated by the company together with OSH specialists to reduce the incidence of these hazards, which are now well below the minimum legal threshold for intervention. Technological and organisational solutions were pivotal to reach this outcome. First, the creation of closed workstations, equipped with air conditioning and cleaning systems, has drastically reduced both workers' exposure to noise and the incidence of bio-chemical risks. Concerning ergonomics, several technical solutions have been introduced to lower the frequency and intensity of movements, together with a significant adoption of automation that, according to the workers, could be further implemented.

More recently, given the higher productivity recorded in the last years, an additional daily break has been scheduled to give operators more time to rest and socialise.[11] Indeed, workers usually spend most of their working time alone in closed work cells. Thus, increasing moments of interaction and collective breaks was deemed by the management as crucial to mitigate the risk of isolation and to improve workers' psychological wellbeing, especially in the presence of radical organisational and technological innovations. Indeed, the impact of AIWM on health and safety is also relevant, especially in the area of physical and mental stress, as briefly illustrated below.

AIWM and ergonomic risks

In the case of ergonomic hazards, a positive impact of AIWM is found in all departments, both because of the diminished number of physical movements needed to communicate with other colleagues and the reduced physical effort required to perform specific tasks. For instance, the possibility of opening a request for assistance from the workstation translates into an important saving of time and physical effort for the operator, since instead of exiting from the workstation and walking across the plant, the operator can continue the work. The maintenance worker also reports a decrease in physical effort, as it is now possible to reach the workstation with all the necessary tools, according to the information provided by the operator in the online request. In the case of logistics, the improvement is even larger. In fact, the milk-runner can more efficiently deliver the materials to the workstations, without having to go back to the warehouse in case of an incomplete or incorrect list. Moreover, while picking up the final product from the workstation, the operator is not required to visually check all the products' codes and to manually record them on a paper, thanks to the barcode scanning system that validates his operations and transmits the information directly to the warehouse. In addition, the packaging of deliveries for

[11] Apart from a 30-minute lunch break, operators have a 10-minute break every two hours. Working time is organised into morning shifts (from 7 am to 3 pm), evening shifts (from 3 pm to 11 pm), or central shifts (from 8 am to 4 pm) for coordination roles.

customers is less physically demanding, thanks to the availability of the virtual warehouse through which the internal composition of batches can be validated while their exact location is recorded.

Cognitive stress

A better management of the time available to perform different tasks and the more efficient and autonomous handling of quality constraints and emergencies result in a general improvement of mental and cognitive wellbeing, both for managers and operators. In the case of managerial roles, the reduction in mental stress is strictly related to the capability of better dealing with unexpected problems, through preventive interventions, advanced risks assessment and immediate response. For operators, AIWM is perceived as a tool that lightens the workload, whether in the form of statistics alerts (for production), set-up checklists (for maintenance) and batch validation (for logistics). In all these applications, the worker is not asked to remember all the necessary steps, but the system reminds him what to do and ensures that everything is done in the correct way. Previously, the risk of being interrupted and consequently forgetting some tasks represented an important source of stress for the operators.

Social relations and work-life balance

In terms of social relations, the way digital tools and AIWM have been deployed in the workplace ensure that each worker can contact the rest of colleagues when needed. This fosters a sense of social involvement and better coordination. More precisely, evidence is found of a perceived reduction in the social distance across departments and hierarchical levels: an improvement in the quality of verbal interactions as they result in being ‘freed’ from the technical urgencies (handled by the system); and a general reduction in conflicts and tensions, previously due to misunderstandings and unclear communication. Important improvements are also recorded in the domain of work-life balance, both in direct and indirect ways. In the case of managerial roles, the impact is direct since the availability of detailed and updated data has facilitated the management of emergencies and unforeseen problems (i.e., the unplanned absence of a worker or machine breakdowns), drastically reducing the frequency of calls outside of working hours. In the case of operators, the effect is indirect, as the certainty of having correctly respected the entire sequence of tasks required (through the system of alerts and validation) gives the workers the serenity to focus exclusively on their private sphere once at home, without worrying about having left something unfinished.

Social dialogue

Industrial relations

In the company, no formal union representative body exists, although two workers have been elected internally to represent the entire workforce on specific issues, such as the definition of production bonus criteria. The company is covered by the most representative sectoral collective bargaining agreement in the automotive industry.[12]

Participatory practices

Despite the lack of trade union and firm-level bargaining, workers report a strong sense of belonging to the company. Indeed, the average tenure is 15 years, such that many operators feel to have ‘grown up’ together and tend to use the plural when talking about the history of the firm. The adoption of a lean work organisation model has been a key driver in activating this participatory mechanism, in line with the assumption that workers do not simply execute tasks, but they act as problem solvers. At this stage, digital technologies seem to further strengthen such a path. The most important and successful participatory practice is the possibility for workers to make proposals for improvements concerning any sphere of the production process. The worker can send the proposal using his personal device or

[12] We refer to the *‘Contratto Collettivo Nazionale di Lavoro per le lavoratrici e i lavoratori addetti all'industria metalmeccanica privata e alla installazione di impianti’* (National Collective Bargaining Agreement for workers in the private metalworking and plant installation industry) signed by the three national trade unions: FIOM-CGIL, UILM-UIL, FIM-CISL.

through the tablet available at work. If the idea is implemented, the worker gets a monetary reward that is doubled if the improvement concerns health and safety issues.[13]

Relations with institutional stakeholders

The company is also very active in forging relationships with institutional actors on specific projects, especially concerning health, safety and managerial best practices. Among the collaborations recorded in the last years, it is worth to cite the on-going project with the ICS Maugeri on the adoption of wearable shirts aimed at detecting the most strenuous movements executed by the operators in the workstation. Increasing attention is paid to these issues, given the aging of the workforce. Another important collaboration started last year with INAIL aimed at developing best practices at the workplace, especially through the improvement of communication and the creation of periodic moments of dialogue between all the members of the company.[14]

Key takeaways

Several interesting conclusions can be drawn from the presentation of this case study. First, the strong **interaction between work organisation models and adoption of new technologies** (AIWMs in this case) is strongly confirmed. What is pivotal, however, concerns the virtuous circle emerging from the adoption of advanced technologies aimed at both **optimising the production process and improving working conditions**, highlighting the interdependence between the two. Putting **labour at the centre of value creation** implies, in the case of this company, a **solid commitment to health and safety goals and prevention programmes**. In fact, given the tight quality standards and the strong competition faced by the supplier company in the global automotive market, a complex strategy of **technological upgrading, learning dynamics and participatory practices** has been put in place to pursue the goal of **continuous improvement** in all spheres of the production process. In such context, a **wide and transparent collection of data**, as allowed by AIWMs, does not only increase the productivity of the entire plant, but it also **enhances a strong sense of responsibility among workers**, who feel entitled to intervene and make suggestions, while becoming **more prone to accept the pervasive use of these tools**.

[13] The list of ideas implemented includes: the automatic bench height adjustment system; the adoption of a round disc, rather than rectangular, to allow uniform treatment of the ring surface; the automated positioning of the ring in the thermopress to reduce the risk of burns; and the distinction between a general request of assistance and a request of maintenance.
[14] The ICS Maugeri is a scientific clinical institute, while INAIL stands for National Institute for Insurance against Accidents at Work.

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