SYSTEMATIC LITERATURE REVIEW: PREDICTIVE SAFETY MANAGEMENT IN THE AUTOMOTIVE INDUSTRY

Sven Vogel, Andreas Brieden, Arman Dehghani, Marc Snell

Abstract

There are various approaches in preventive occupational safety and health management (OSHM) to protect employees in the long run and reduce accidents. Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, 39 articles dealing with the current state of OSHM and preventive models of OSHM were identified through the Scopus, Web of Science, and Google Scholar databases. Furthermore, the emphasis is on how approaches from other industries can be transferred to the automotive industry to reduce accidents over time. Construction, chemical, agricultural, weather forecasting, the stock market, road traffic, and general approaches are among the industries discovered. Long-term successful OSHM was discovered to be a multivariable problem, with no single solution always working. The combination of different approaches appears to be the most promising among the 39 studies. Machine learning methods are best suited to model such a problem due to the complex structures and many influencing factors. Some approaches based on resilience engineering and neural networks can be transferred to the automotive industry based on the data used or taking key figures into account.

Keywords: *Safety management, occupational safety and health management, predictive safety, PRISMA, automotive industry, preventive methods*

1 INTRODUCTION

Approximately 977.070 accidents, including 737 fatal, happen in Germany's wood and metal processing business yearly (DGUV 2020). Heinreich (1931) established the accident pyramid, which allows accidents to be classified because not all accidents have the exact cause (from fatal to near-miss accidents). Bird et al. (1996) showed a correlation between fatal and near-miss accidents (1 to 50.000). They established through their investigation that a series of near-miss accidents lead to moderate to severe accidents.

Risks in some industries can be forecasted using technological advancements and the development of more advanced models. Resilience engineering (RE) is currently used to model these system failures (Brian Thoroman & Salmon, 2020). A system with RE can change to the new circumstances that arise from a problem or failure. Through this adaptability, harmful situations can be anticipated in occupational safety and health management (OSHM), considering the subsequent application of preventive measures. Ranasinghe et al. (2020) investigated the RE method of construction remodelling. The effectiveness of this model was found to be significantly influenced by several RE-indicators from the literature. In addition to the models proposed, Li et al. (2020) present a method for educating construction industry workers that is currently in use. Construction remodelling carries a higher risk of accidents, which is why training methods and their efficacy are discussed. One-time training or teaching had a substantially lower success rate than training that builds on previous training or is repeated frequently.

A literature review on preventive OSHM and the modelling of multivariable problems in the field of OSHM are done using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. The approaches discovered through literature research will then

be applied to the automotive industry to the extent possible, given the available information and framework conditions. More specifically, the paper is structured by the subsequent sections, including (1) introduction, (2) theoretical background, (3) research methodology, (4) results, (5) discussion, and (6) conclusions.

2 THEORETICAL BACKGROUND

The various fields in which the methods used in this study have a place in the literature can be divided. For example, the articles on cross-sectoral work, agriculture, social economics, the stock market, and the chemical and construction industries can be split. The main concern is the long-term protection of personnel, which can be influenced by training (Li et al., 2020) or using a model to identify weaknesses (Zeng et al., 2020). However, some techniques use digital planning to prevent the emergence of a possible problem (Farghaly et al., 2021). Essentially, two methods can be distinguished.

On the one hand, it is necessary to concentrate on the personnel to make them more aware of potentially dangerous situations; on the other hand, computer-based systems can foresee potential threats or shut down the system in an emergency. After then, the computer-based systems can be further split into simple linear models (Yoshitake & Shino, 2018), deep neural networks (Paltrinieri et al., 2019), or a combination of different models (Baker et al., 2020).

According to the current state of the literature, as determined by this PRISMA-compliant literature search, there are only articles in the automotive sector relating to autonomous driving and vehicle safety systems, but not their production. This article included a total of 12 articles on the topics of autonomous driving and vehicle safety systems. In addition to the construction industry, which has nine included articles, the transportation industry accounts for nearly one-third of the total literature.

3 METHODOLOGY

Literature research was carried out using the PRISMA approach described in the first chapter. The objective is to demonstrate the current status of OSHM in significant industries before examining how the different strategies might be applied to the automotive sector. The initial step was to find literature regarding safety management, workplace hazards, accidents, risks, and preventive OSHM. This article was written using systematic literature searches. This benefit is that they summarise the literature, try to be objective in their assessment of the articles used, and have a high standing in the scientific community. This search was then broadened in a subsequent stage to incorporate preventive models and methods in OSHM.

The research in this work only covered papers and articles that had already been successfully published. Therefore, grey literature or expert interviews have been excluded. Additionally, free access was a requirement for the articles. Finally, only German and English articles were considered, another restriction. The following flow chart displays the complete literature search results (Fig. 1).

Scopus and Web of Science databases were used primarily for the literature search. Google Scholar was also employed. The keyword for the search criteria includes Systematic literature review (SLR) combining with “safe* management”, “OSHM”, “risk management” “predict* safe*”, “risk assessment”, “predict* health* safe*”, “predict+ hazard assessment”, “predict* risk assessment”, and “hazard assessment”. In June 2022, the last keyword search for the given phrase was performed. The following key terms were used to narrow the search for predictive OSHM models: "predict* models", "predict* OSHM models," and "OSHM modells”. The search string that was employed is given below.

TITLE-ABS-KEY (systematic AND literature AND review AND safety AND management) AND (LIMIT-TO (OA , "all")) AND (LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "HEAL") OR LIMIT-TO (SUBJAREA , "ENVI")) AND (LIMIT-TO (EXACTKEYWORD , "Systematic Review") ORLIMIT-TO (EXACTKEYWORD , "Review") OR LIMIT-TO (EXACTKEYWORD , "Meta Analysis")) AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "German"))

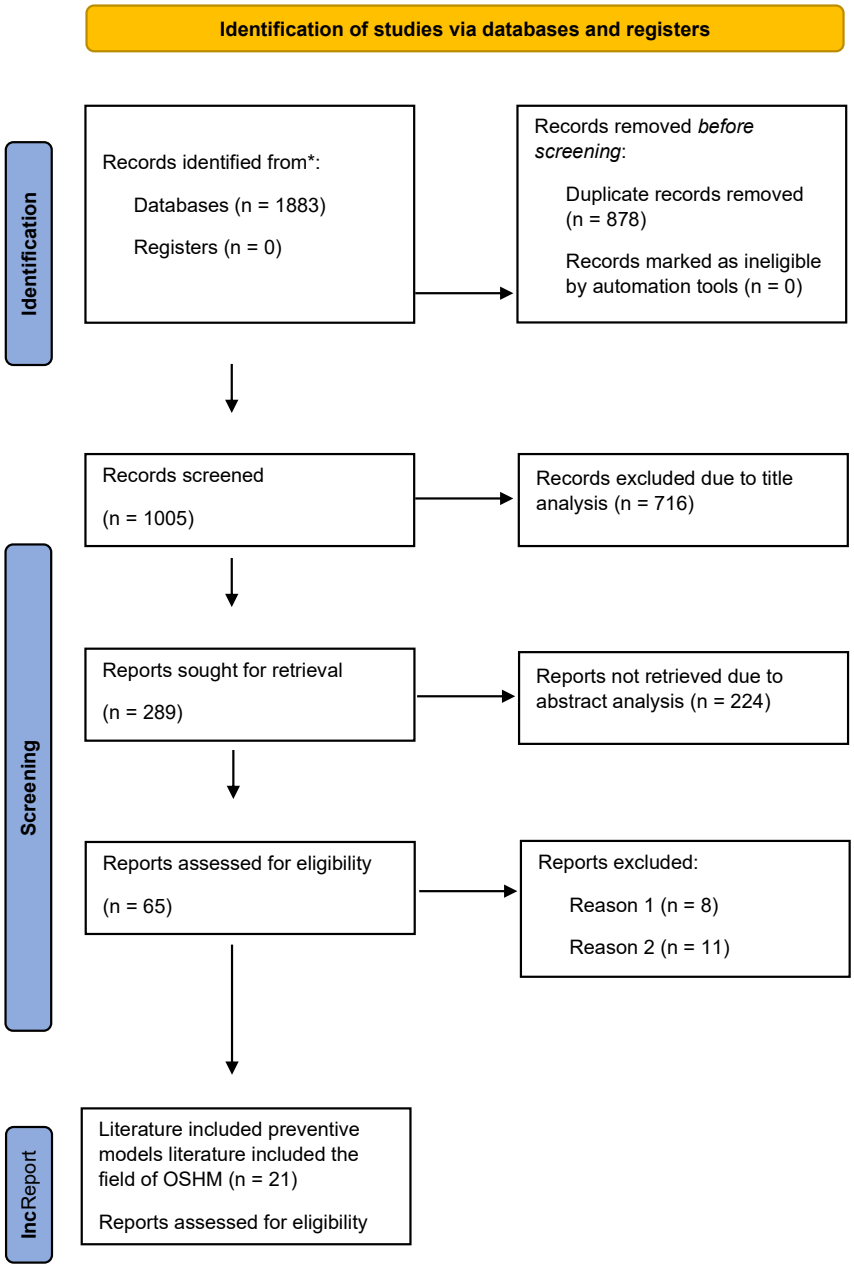

Fig. 1 - PRISMA flow chart for the literature review and the selection of the included paper, own Illustration based on (Pahlevan-Sharif et al., 2019). Reason 1: The source's methodology was inconsistent. Reason 2: The source does not offer a definitive conclusion pertinent to this investigation. Reason 3: Inappropriate topic (medicine).

The studies were evaluated using the PRISMA approach's various analysis steps, with articles excluded at each stage. Before doing a deeper analysis, all duplicates were eliminated after the literature review. All paper titles were then evaluated. The abstracts were examined after that. The final number of included articles was determined by completing a full-text analysis and excluding additional articles (Fig. 1). Predictive methods used in medicine (illness treatment) and sports medicine (disease prevention) were not included. Only studies that directly addressed OSHM in the industry and preventive models in the OSHM were comprised; the sector was not, however, given additional consideration at this time.

It can be concluded that scientific databases (Scopus and Web of Science) and the strict inclusion criteria in these databases are suitable for sound research. Furthermore, considering comprehensive literature searches were actively done, it may be expected that at least one of the included reviews contains information on all notable articles from recent years.

The articles were split into the categories (Road traffic, Chemistry, General, Agriculture, Socioeconomics, Weather and Stock Exchange) indicated at the beginning and given to a sector for the final evaluation (field of OSHM and preventive models of OSHM). The findings are discussed in the next chapter, along with potential changes to individual methods of preventive OSHM in the automobile sector.

4 RESULTS

The outcomes of a comprehensive review of the literature and a meta-analysis of the literature are reported in the ensuing chapters. In addition, a review of the literature on OSHM was conducted. Furthermore, preventive models in OSHM were investigated. In the following chapter, the two approaches will be examined separately. Since the search was restricted to publications published between 2000 and June 2022, it became evident from the literature that most publications were published in the recent few years.

The year 2021 represents 41% of the 39 sources used in this review. 2020 has a 20% increase, with 2019 coming in second with a 15% increase. In 2022, 10% are already present, with 7.5% of these attributed to preventive OSHM models. The annual publication count for both search strings is shown in Figure 2.

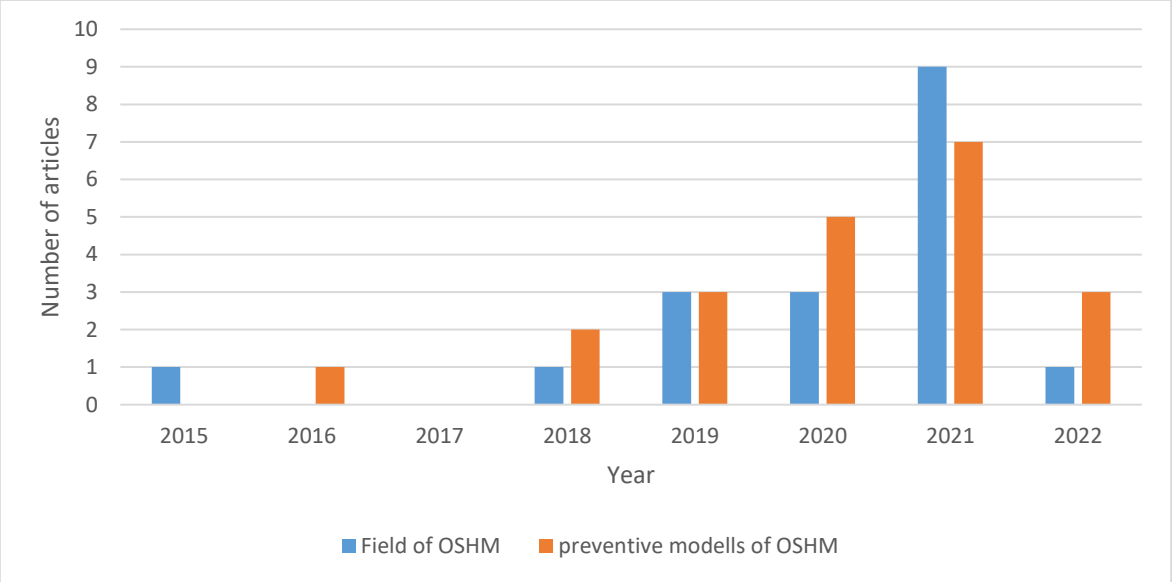

Fig. 2 - Display the publication through the years for each search direction.

The sources used can also be broken down into sectors that are specific to each subject. For example, table 1 shows that 44% of construction companies are related to the field of OSHM. On the other hand, the road transportation sector takes the top spot in the preventive OSHM models with 47%. The oldest article included in this research was written in 2015. This demonstrates that OSHM has significantly grown in relevance over the past few years and that specific hot spots can be found depending on how the search is interpreted.

Both searches returned the same number of articles in the category of general articles. Chemistry comes second in preventive models, with 19%, after traffic. Models may be made more quickly in this field than in others due to the descriptions of particular processes and defined goals (Schmitz et al., 2020).

18 of the 39 articles in this article are systematic review searches. The remaining 21 sources are topic-specific and address a particular issue (Tab. 1). The fact that 11 of the 18 evaluations followed the PRISMA methodology suggests that the paper seems to be of higher quality. In addition, 6 followed the guidelines set forth by Kitchenham et al. (2007). In essence, this entails the creation of specific research questions, the acquisition of data, the extraction of data, and subsequent analysis. The method described by Kitchham et al. (2007) can be derived from the structure of a paper, although no detailed information on the methodological approach was provided.

For the topic-specific publications, the research was always dependent on already-existing data, which was frequently unavailable to a sufficient level. Two methods of the procedure can be identified. On the one hand, the method addresses a current or ongoing issue before attempting to discover a solution considering the information at hand. The strategy of creating something preventively to avert issues in the future is a second option. The second strategy excels in the road transportation industry, where proactive action is done to reduce collisions or enhance intersection safety. About 80% of solutions to a given problem depend on artificial intelligence (AI) or machine learning techniques due to industrialisation and technological advancement. The growth of training opportunities and employee communication accounts for about 15% of all methods, whereas general approaches - which are techniques that are not categorised in either category - account for about 5%.

Tab.1 - Sector-specific division of the included literature for each of the two search directions.

Category	Field of OSHM	Preventive models of OSHM
Road traffic	2	10
Chemistry	2	4
Construction	8	1
General	3	3
Agriculture	1	0
Socioeconomics	2	0
Weather	0	2
Stock Exchange	0	1
Sum	**18**	**21**

The methods used to create the model are shown in Table 2. There are no combinations, and only the original model is listed. Table 2 lists six distinct modelling approaches and their associated functionality. The uses in the literature column show that linear regression and neural networks are the most used. The ARIMA model and the hierarchical model demonstrate that models are combined, implying that both model approaches are derived from the same source.

Tab. 2 - An overview of the models used in the included literature

Model	How the model works	Literature
First-Principle-model.	The process of reducing a significant unity to its smallest possible unit	Ahooyi et al., 2016
Linear Regression	A dependent variable is attempted to be explained by independent variables	Yoshitake & Shino, 2018; Paltrinieri et al., 2019; Baker et al., 2020
ARIMA model	Time series description and analysis	Xiong et al., 2021
Neuronal networks	A model with multiple variables that can represent dependencies and complex issues	Liu et al., 2022; Wang et al., 2021; Farid, 2021; Kim et al., 2021; Skuratov et al., 2020
Markov model	is a stochastic method for changing systems at random	Ma et al., 2020
Hierarchical model	A model with branches but a distinct origin	Xiong et al., 2021

5 DISCUSSION

The SLR in OSHM will be discussed first. The different models and methods of preventive OSHM were then considered, and the extent to which they can be adapted to the problems in the automotive industry was determined.

5.1 The SLR of OSHM analysis

Vigoroso et al. (2021) approach to introducing digital games in various work areas is a very complex task. The article focuses on agriculture and the potential for computer games to positively influence safety awareness, behaviour and machinery handling and aid in the long run. The findings of this study demonstrated that game-based safety training was efficient. On the other hand, there are detractors because, in the case of implementation, high costs result from the necessary technical equipment and ongoing maintenance and servicing costs (Craig, 2013). There are also expenses for necessary new developments and expansions. Aside from cost considerations, there are also motivational concerns. The structure of such a safety game must be such that it can be repeated as often as desired in the event of failure. However, the player's motivation should always be maintained so that the association with security management remains positive (Kwegyir-Afful & Kantola, 2020; Kamkuimo et al., 2020). The issue with video game-based safety training is that the number of participants for effectiveness testing is rarely greater than ten (Kuindersma et al., 2017; Golovina et al., 2019). Gender research would be interesting to pursue further. Women account for approximately 42% of all video game users. Based on this, it would be necessary to investigate the efficacy and increase of women in male-dominated jobs to bring everyone up to the same level, if possible (Din & Gibson, 2019; Gallagher, 2016). Video games' approach could be transferred to the automotive industry as digitalisation and virtual reality advance.

Craig et al. (2019) systematically identified security vulnerabilities and key features within socioeconomic systems. Based on these key features, an adaptation model was created and built. The problem with this identification is that it was done by expert teams and thus cannot be entirely subjective. Furthermore, identifying weak points is difficult because they are optimally determined by the system rather than before.

Li et al. (2020) presented a review of educational measure effectiveness. The first issue was that education effectiveness was measured using surrogate measures rather than actual injury outcomes. The literature review supported this conclusion. The results of the 35 included studies revealed significant heterogeneity. However, the bias in the individual articles under consideration was moderate. As a result of the research, it was determined that while educational measures are beneficial, they do not prevent accidents sufficiently in the long run. To improve the validity of these measures, it was proposed that they be tested with placebo measures to ensure the long-term effectiveness of the defined measures. The automotive industry employs a wide range of educational measures, the efficacy of which has been demonstrated. The placebo method could be used to put existing measures to the test to obtain more sustainable key figures and advance safety management.

Risk acceptance criteria (RAC) could be used to assess the risk of a process, extending the training metrics developed by Li et al. (2020). Panagiotis and Koulouritotis (2021) conducted an SLR on this topic and discovered a wealth of literature on Poisson distribution RAC. As a result, it was discovered that RACs are extremely important, particularly in the field of industry. Furthermore, it was recognised that the scientific community's acceptance and motivation to develop new RACS has significantly increased. There are numerous key figures and RAC in the automotive industry. However, new RAC development is complex because they should ideally be identical across manufacturers for better comparability.

Through this literature review, three approaches in the construction sector were identified. First, the modern design approach, for example, aims to prevent accidents during construction and subsequent remediation work (Farghaly et al., 2021; Costella et al., 2020). Second, there are approaches to behavioural safety measures to reduce injury rates and promote employee health (Mullan et al., 2015; Muñoz-La Rivera et al., 2021), and finally, the RE approach mentioned earlier (Ranasinghe et al., 2020). All the approaches identified aim to keep employees safe in the long run.

Farghaly et al. (2021) initiated a program to motivate architects to pay attention to safety gaps that arise during construction or maintenance work during the planning phase and to eliminate them as best as possible. The behaviour change approach was not identified as a viable option in the construction industry. Based on the literature review, it was discovered that the approaches used were inadequate. Possible explanations included changing working conditions and a language barrier. This example demonstrates the importance of having a safety management system in all languages. This language barrier exists in the automotive industry, among different nationalities and international operations, but it has already been overcome. A new method for high-risk workplaces was developed as part of the RE approach presented by Ranasinghe et al. (2020). First, building rehabilitation indicators were identified and then evaluated. Top management commitment, awareness, learning, and flexibility were identified as the top four indicators. Because research in this area is still in its early stages, there is still much potential in this field. This method could be used in the automotive industry as well. A large amount of data allows for identifying key indicators and subsequent evaluation.

To make autonomous driving even safer, it is necessary to make an accurate behavioural prediction based on other road users. Kolekar et al. (2021) conducted an SLR on this topic and discovered that artificial intelligence-based solutions are up-and-coming for making road traffic safer. Figure 3 depicts the various models used to predict behaviour. The problem with this prediction is that it does not account for weather conditions, reflections, poor network quality, and other factors. Furthermore, there is still a lack of data, which is critical for modelling and the quality of the final model. This method demonstrates that large amounts of data must be available to develop a reliable model for complex problems. However, this model's approach can only be applied to the automotive industry to a limited extent because handling personal

data is a significant challenge and, thus, too complex at the moment. Furthermore, cameras are also not an option because the data would have to be stored, reintroducing the data protection issue and violating the employees' privacy.

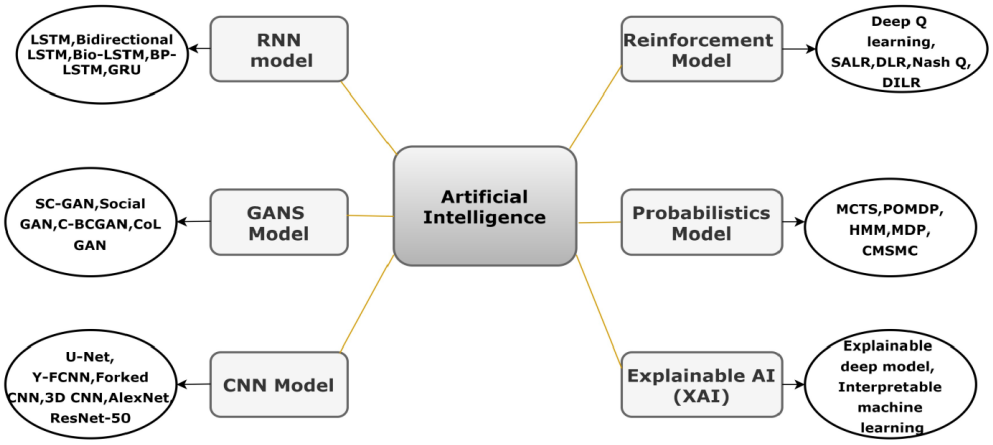

Fig. 2 - ”Behavior prediction using different artificial intelligence-based models” (Kolekar et al., 2021; P.: 10).

5.2 The preventive models of OSHM analysis

In the field of weather forecasting, two approaches are being pursued. The first is an event prediction approach (Wang et al., 2021), while the second is a Kuban-region-specific approach that deals with damage (Plyuschikov et al., 2019). Both studies demonstrate that deep learning methods can simulate complex problems. However, because both works are particular and tailored to a specific problem, they cannot be applied to the automotive industry. Furthermore, specialised databases, such as GIS, would complicate transfer. Nevertheless, this work has demonstrated that deep learning methods are appropriate for the automotive industry's complex OSHM problems.

There are accident prevention models of OSHM. These are related to the prediction of road traffic accidents (Ma et al., 2020), the design of intersections and roundabouts (Gallelli et al., 2021), and the analysis of driving behaviour (Nouh et al., 2021; Yoshitake & Shino, 2018), and accident prevention or, at the very least, injury reduction (Leledakis et al., 2021). A deep-learning method for analysing driving behaviour is developed by Nouh et al. (2021). Using this model based on historical data sets obtained from the driver, the system can perform a risk classification divided into high, medium, and low. If the system detects a medium or high level of danger, it should intervene and take control of the vehicle. A total of 15% was kept verifying the training data on which the final model was tested. However, the presented model has a flaw in that not enough practical experiments were conducted to improve recommendation accuracy.

Further experiments could reduce the error rate, making the model more scalable. Also, because only five drivers were chosen, the amount of data was minimal. In theory, the possibility of behavioural analysis in the workplace is a good idea. However, being an employee is not enough to implement long-term safety management. The nature of the job and other environmental factors would have to be considered in the evaluation. However, on the plus side, these methods can create a predictive model that makes accurate predictions and thus currently protects road users. Oh et al. (2018) developed a method for reducing the risk of excavator accidents on construction sites in the construction industry. The excavator driver had several blind spots on the construction site, so these areas were covered by using two laser scanners. Two safety indices were developed, which determine the time until the calculated collision, and a perception index, which intervenes in the system to varying degrees depending on the safety

level. This approach has already been tested and implemented in the field. This approach would only apply in the automotive industry to the safety of fully automated robots. As a result, this application would be particular.

There are many different approaches to preventing accidents in the chemical industry. Some approaches deal with process safety (Schmitz et al., 2020) and alarm systems that predict material failure (Ahooyi et al., 2016; Liu et al., 2022). Schmitz et al. (2020) use a retrospective data example to show how information from organisational factors could have prevented the near miss from developing prematurely. Organisational factors influence the quality or trustworthiness of barrier systems, which indirectly affects the occurrence of accidents. Management systems, such as management, communication, and coordination, may also be regarded as "performance-influencing factors" or "error-causing conditions". The issue is that there are too many communication adjustments, especially in larger companies with multiple management levels. The problem is that each manager comes from a different background, meaning certain things are valued, making it easier for a problem to be perceived differently. In the automotive industry, the possibility of identifying factors influencing process safety is provided, and the review of individual departments and processes is controlled, including through external audits. Furthermore, whether this approach is truly a long-term way to prevent accidents or merely one component of a more extensive safety management system.

Skuratov et al. (2020) developed a method for stock market analysis based on data analysis and anomaly detection. A neural pattern detector searches for the exact boundaries of technical analysis figures to detect patterns. Trading decisions in any market can thus be significantly improved. Pattern evolution can be automated by estimating their duration in time and amplitude values. The parameters used to determine the trend and create patterns are customisable and can be changed to meet the analyst's or trader's needs. This neural network could be adapted for data analysis in the automotive industry. New starting points for preventive OSHM could be discovered by analysing the data and detecting anomalies.

Finally, non-industry-specific approaches should be regarded. Baker et al. (2020) developed a model that indicates the severity of the injury, the type of injury, the part of the body affected, and the type of incident by combining various models. This model is based on over 1000 accident reports that eight independent experts reviewed. A total of 80 attributes were evaluated based on the results of this evaluation. Because this evaluation was demanding and time-consuming, Tixier et al. (2016) refined and modified their approach (model with a 95% success rate) to make extraction faster and easier for future industries. Baker et al. (2020) presented approaches for the construction industry, testing the following model approaches, XGBoost and linear Support Vector Machines (SVM) and Natural Language Processing (NLP). The SVM model had a marginal advantage over the XGBoost model. This SVM model is currently used in work scheduling to predict safety. Because the model's results are based on accurate data, the detected vulnerabilities can be considered. The problem with this model is that it can only predict about half of the accidents in the construction industry because of the inhomogeneous nature of the working conditions. Working conditions in the automotive industry are more uniform, which improves the identification of relevant attributes and the model's reliability.

Based on this research, the number of different articles clearly shows that neural networks are used much more frequently than other methods and are thus more suitable for the complex problems of OSHM. Furthermore, the articles are up to date and have a wide range of applications. Neural networks are used in everything from material failure to stock market prices to meteorological forecasting and autonomous driving. The increase of publications on preventive models demonstrates the advancement of technology and the continued development of models, approaches, and opportunities.

6 CONCLUSION

The purpose of this article was to present the current state of OSHM and the preventive models in OSHM, with a focus on the automotive industry or the possibility of transferring the approaches used to it using the PRISMA method. Different approaches could be identified based on the literature review. It was discovered that OSHM is always a combination of different systems rather than a single method, approach, or model. The current machine learning methods best represent the complexity of existing problems. Baker et al. (2020) have the most promising approach, which is most applicable to the automotive industry based on the method used and the underlying data.

The main limitations of this work stem from a lack of specific literature in the field of automobile manufacturing. Literature is scarce in both German and English on this subject. Because this topic is generating increasing interest, as evidenced by the results, this knowledge gap should be filled in the future through additional research. The purpose of this paper was not to include factors other than those mentioned in the study. Other factors may become relevant in the future. Further research can determine how various factors gain or lose relevance over time. Furthermore, the available data could be expanded, and a uniform system implemented, resulting in higher quality and reliability data.

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Contact information

M.Sc. Sven Kevin Vogel
BMW / Universität der Bundeswehr München,
Faculty for controlling, finanz- und risk management
Werner-Heisenberg-Weg 39, 85579 Neubiberg, faculty building 36
E-mail: sven-kevin.vogel@bmw.de
ORCID: 0000-0002-2662-0545

Dr. Arman Dehghani
BMW, Moosacher Str. 51, 80809 Munich
E-mail: arman.dehghani@bmw.de
ORCID: 0000-0002-6317-8741

Dr. Marc Snell
BMW, Moosacher Str. 51, 80809 Munich
E-mail: marc.snell@bmw.de
ORCID: 0000-0001-9101-6400

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