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Relative Risk (RR) Analysis and Prediction as Part of Assessing Occupational Safety and Determining Priorities for Action in Occupational Health and Safety in the Construction Industry in Poland

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Abstract: Risks are associated with every human activity. Accidental events are recorded in enterprises in the construction industry every day. Those events differ among themselves in the severity of consequences and the number of victims. It is important to reduce them effectively based on the conclusions of accident rate analyses. The study outlines the process of relative risk (RR) analysis and carries out a process of quantitative data prediction to determine priorities for action in the area of accident risk reduction. For the construction industry, being the subject of the analyses, statistical data on the number of persons injured in accidents at work in 2006–2021 were compiled, the relative risk (RR) was determined, and a prediction process using the Brown model and Winters' model was performed. The relative risk analyses allowed for determining priorities for action in occupational health and safety. Based on the analyses, it was concluded that it is possible to adapt econometric models in the area of relative risk prediction, and the obtained forecast values may be the basis for taking actions regarding occupational health and safety.

Keywords: occupational health and safety (OHS); relative risk (RR); construction industry; accident at work; forecasting

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1. Introduction

Shaping safe and hygienic working conditions is an essential and topical issue of scientific research. The hazards present in the work environment depend on the working conditions and the way work is organized and carried out [1,2]. Accidental events, which generate social and economic costs for business stakeholders, are recorded in the economy of every country [3]. Methods and tools aimed at improving safety and the ergonomics of working conditions are still being sought. Legal regulations, technical and organizational solutions, audits of working conditions by state authorities, and social organizations have a significant impact on work safety. However, the human factor has some influence on the occurrence of events that can adversely affect employees' lives and health.

The issue of studies on accidents in the literature relates to various economic sectors of every country: among others, agriculture [4–7], education [8,9], mining [10–15], the steel industry [16–18], construction [19–27], and the shipbuilding industry [28]. The conducted analyses related to accidents also apply to various forms of transportation, i.e., air [29], road [30], and rail transport [31–33], as well as to everyday life and sports [34]. When considering accidental events, it should be noted that not all of them are treated as accidents at work because not all of them are connected with the performance of work. It is therefore possible to divide those events into occupational and extra-occupational accidents.

As regards the legal definition of an accident at work adopted in Poland, a sudden, externally-caused event connected with the performed work that results in injury or death is deemed to be an accident at work. Consequently, only those events [35] for which the characteristics indicated in the definition (sudden nature of an event, external cause, injury or death, connection with work) co-occur are considered accidents at work. In turn, the definition laid down in the EU legislation provides that an accident at work is a discrete occurrence during the course of work which leads to physical or mental harm [36]. The definition of an accident at work is not uniform in all countries. The similarity refers only to the fact that an accident at work is a sudden, externally-caused event, and the occurring differences refer to damage, harm, or loss. They consist of such views that an accident is identified with an injury, an accident is an injury with its preceding situation, and an injury is one of the possible consequences of an accidental event [37]. The standard 45001:2018 [2] refers to injury and health ailments understood as an adverse effect on the physical, mental, or cognitive condition of a given person. Adverse effects may be related to occupational disease or health problems of the employee, or his death. It is also referred to as an incident, i.e., an event related to work, which may cause injury or health problems. An incident causing injury or health problems may also be treated as an accident at work [2].

This study pays particular attention to the issue of accidents at work in the construction industry in Poland. The selection of the scope of the analyses is justified by the specific working conditions and hazards, the number of recorded accidents at work, the extent of damage, the machinery and equipment used, and the type of work performed. A literature review of selected bases, such as Web of Science, Scopus, PubMed, Google Scholar, and ResearchGate, as regards the construction industry, made it possible to establish the subject of studies of the analyses in occupational health and safety in the construction industry across the world.

The conducted studies [19–27,38–48] focus on the identification of a group of employees who have been victims of an accident at work, taking into account the injured person's age, sex, length of service, and location of injury [20,21,23], the identification of causes of accidental events [23,48], the identification of factors causing accidents [24], causes of accidents (e.g., a fall from a roof or a scaffolding, contact with falling objects), any lack of elements that reduce the likelihood of the occurrence of an accident [26], and socio-economic factors [40]. Accident rates—accident frequency and accident severity—are also determined [25]. They may help to compare enterprises and evaluate the effectiveness of the adopted preventive measures. Attention is also paid to the impact of implementing a system of occupational health and safety management on the number of accidental events occurring and the improvement in OHS in enterprises in which that system is certified [27]. Currently, the applicable requirements and application guidelines are specified in the ISO 45001:2018 standard [2] for an organization's responsibility for the health and safety of employees and other persons who may be affected by its actions. The responsibility relates to the promotion and protection of physical and mental health. The main objective of an implemented system is to prevent work-related injuries and health ailments. In the case of an implemented and maintained management system, attention is also paid to aspects related to top management involvement, communication, and co-operation with employees [2,49]. It must be borne in mind that leaders set the tone; it is therefore necessary to involve the management in OHS actions, particularly in the construction industry.

The conducted studies relating to the construction industry [38,39] also apply to the safety climate (safety culture) and the need to shape it at the level of an organization and the level of groups. The conducted analyses also point to the existing problems connected with the following, among others: conflicts between production logics and safety, cost compromises in relation to other competing project priorities, and the acceptance of a low level of safety as its norm [39]. The occurring problems impact the shaping of the safety climate and require the effective implementation of solutions to reduce or eliminate the occurring problems.

At the same time, the studies point to an analysis of the connection between innovation efficiency and the perception of the existing OHS regulations [41], the identification of key elements related to the safety programme [42], the impact of migration on the number of recorded accidents at work [43], training in OHS [44], an explanation of employees' behaviour related to risk-taking [45], the practices of HR departments in the area of the effective safety management in construction projects affected by workplace accidents, the use of modern solutions to assess the technical state of scaffoldings, and the use of drones [47]. A summary of research topics in the field of occupational health and safety in construction is presented in Table 1.

Table 1. Selected areas of conducted research—literature review.

Authors/Year of Publication (Country Where the Research Was Conducted)	Scope of Conducted Research
Hoła, B.; Szóstak, M., 2017 (Poland) [20]	Determining the profile of the injured persons on the basis of characteristics such as: employment status, occupation, age, length of service, preparation of the employee to perform work, and the size of the company for the number of accidents
Camino López, M.A.; Ritzel, D.O.; Fontaneda, I.; González Alcantar, O.J., 2008 (Spain) [21]	Identification of the group of employees most frequently involved in accidents, taking into account: age, length of service, size of the company, and the day of the week for the severity of the consequences
Ale, B.J.M.; Bellamy, L.J.; et al., 2008 (The Netherlands) [22]	Constructing a causal model of occupational risk, allowing for quantitative insight into the causes and consequences of accidents at work. Analysis of the causes of accidents at work of persons working in the construction industry
Ali, S.A.; Kamaruzzaman, S.N.; Sing, G.C., 2010 (Malaysia) [23]	Ranking and descriptive analysis of the causes of accidents in the construction industry and ways to prevent them
Chai, C.-F.; Chang, T.-C.; Ting, H.-I., 2005 (Chiny, Taiwan) [24]	Identification of factors contributing to the occurrence of fatal accidents. Developing proposals for solutions to prevent accidents
Hoła, B.; Szóstak, M., 2015 (EU countries) [25]	Accident analysis in various EU countries based on accident statistics. Analysis of accident measures: accident frequency and severity indicators
Winge, S.; Albrechtsen, E., 2018 (Norway) [26]	Analysis of the most common types of accidents and the lack of physical elements constituting barriers for construction workers
Yoon, S.; Lin, J.K.; et al., 2013 (South Korea's) [27]	The impact of the implementation of the OSH management system on the improvement of work safety based on the assessment of accident rates
Gao, R.; Chan, A.P.C.; Utama, W.P.; Zahoor, H., 2016 (Chiny, Witenam) [38]	Studying the mechanisms underlying the relationship between the multi-level security climate and the level of security
Lestari, F.; Sunindijo, R.Y.; Loosemore, M.; Kusminanti, Y.; Widanarko, B.A., 2020 (Indonesia, Azja) [39]	Assessing the safety climate and developing a framework for improving safety in the construction industry. Identification of problems affecting security. New paradoxes were also established
Hoła, B.; Nowobilski, T., 2019 (Poland) [40]	Identification of socio-economic factors generated in the construction environment that affect the number of accidents on the construction site
Shin, J.; Kim, Y.; Kim, C., 2021 (Republic of Korea) [41]	Investigating the relationship between innovation performance and companies' perception of health and safety regulations
Buniya, M.K.; Othman, I.; Durdyev, S.; Sunindijo, R.Y.; et al., 2021 (Iraq) [42]	Identification of key elements of the safety program
Kim, J.M.; Son, K.; Yum, S.G.; Ahn, S., 2020 (Republic of Korea) [43]	Impact of worker migration on accidents at work. Establishment of guidelines for managing the safety of migrant workers
Tezel, A.; Dobrucali, E.; Demirkesen, S.; Kiral, I.A., 2021 (USA and other country) [44]	The role of training and the form of OSH training (computer, in the workplace, simulation), and their impact on employees' awareness
Chen, W.T.; Tsai, I.-C.; Merrett, H.C.; Lu, S.T.; Lee, Y.-I.; You, J.-K.; et al., 2020 (Taiwan) [45]	Development of a research model explaining the behavior of construction workers related to risk-taking (surveys)

Table 1. *Cont.*

Authors/Year of Publication (Country Where the Research Was Conducted)	Scope of Conducted Research
Lai, D.N.C.; Liu, M.; Ling, F.Y.Y., 2011 (USA, Singapore) [46]	Comparative studies of HR practices adopted for safety management on construction projects and establishing the relationship between HR practices and the results of safety management on construction sites. The severity and frequency of accidents
Sawicki, M.; Szóstak, M.; Nowobilski, T., 2019 (Poland) [47]	The use of unmanned aerial vehicles (drones) to assess the technical condition of construction scaffoldings
Ahmed, S., 2019 (Bangladesh) [48]	Analysis and determination of the main causes and effects of accidents at work on the construction site

A literature review on the construction industry [19–27,38–48] shows complex analyses in occupational health and safety from the moment when an employee is hired (OHS training, analyses of the form of training, training quality) to his professional activity (shaping the culture of health and safety and safe behaviour, an analysis of accidental events, taking and promoting measures to reduce accident risks). Attention is also drawn to the possibility of using modern methods that allow the supervision of working conditions (unmanned aerial vehicles). This study extends the conducted analyses by presenting the possibility of determining the relative risk (RR) (relating the construction industry to the country's accident rate) and its prediction, which will enable an initial trend assessment based on the forecasts and will make it possible to determine priorities for action in occupational health and safety (Figure 1). Accordingly, the study will assess the feasibility of using selected predictive models for the forecasting of relative risk (RR), and, on this basis, determine the direction and type of measures for improving occupational health and safety in the construction sector.

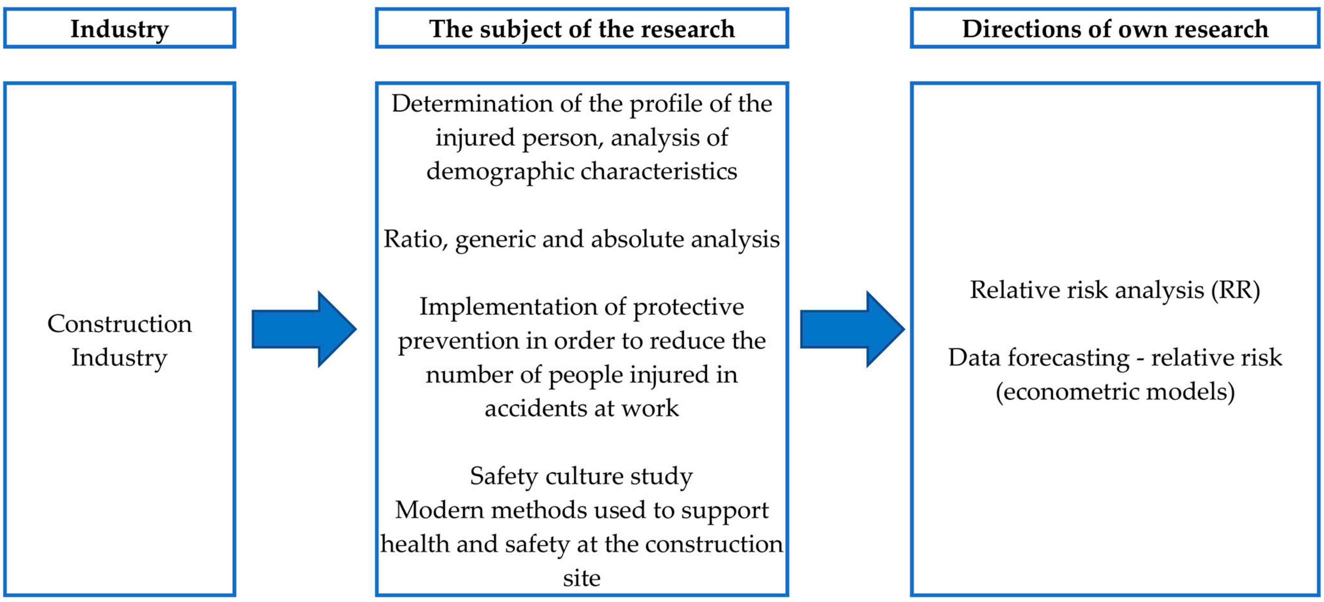

Figure 1. Directions of research, including own research.

2. Materials and Methods

An analysis was carried out on the statistical data published by Statistics Poland for 2006–2021 [50]. For the purposes of own research, data on the number of persons employed in the national economy, the number of persons employed in the construction industry, and the numbers of persons injured in accidents in the country and in the construction industry, necessary to determine the relative risk (RR), were compiled.

Events classified as accidents at work were subjected to an analysis. The intended purpose of the study was achieved, thanks to the development of a methodological approach consisting of:

- Stage 1: a collection of quantitative data (for 2006–2021), summarised in Table 2, on the number of persons employed in the national economy (column 2), the number of persons employed in the construction industry (column 3), the number of persons injured in accidents at work in Poland (column 4) and the number of persons injured in accidents at work in the construction industry (column 5).
- Stage 2 (based on the statistical data presented in Table 2): the relative risk (RR) was determined, which is a quotient of the probability of a particular event in an exposed group to the probability of an event in an unexposed group [51–53]. The relative risk was determined using a mathematical relationship (1) [51]. Determining the relative risk allowed the determination of how working conditions in the construction industry change (improvement of working conditions/worsening of working conditions) in relation to the national economy. If the indicator shows a decrease, it can be concluded that working conditions in the construction industry are improving in relation to the national economy. On the other hand, when the indicator shows an increase, it is stated that working conditions in the construction industry are deteriorating in relation to the national economy. Analyses were performed using PQStat software (PQStat 1.6.8).

$$RR = \frac{\frac{O_{11}}{(O_{11}+O_{12})}}{\frac{O_{21}}{(O_{21}+O_{22})}} \quad (1)$$

where:

RR–Relative Risk;

O_{ij}–multiplicity observed in the contingency table (*i*–column; *j*–row in contingency table)

Table 2. Statistical data on the number of persons employed and injured in accidents at work [50].

Year	Number of Persons Employed in the National Economy	Number of Persons Employed in the Construction Industry	Number of Persons Injured in Accidents at Work	Number of Persons Injured in Accidents at Work in the Construction Industry
1	2	3	4	5
2006	7,640,100	354,800	95,462	7883
2007	7,912,000	347,900	99,171	8895
2008	8,142,900	411,900	104,402	10,491
2009	8,167,400	436,100	87,052	8684
2010	8,271,500	446,100	94,207	9098
2011	8,367,600	478,200	97,222	9222
2012	8,338,200	488,100	91,000	8145
2013	8,235,200	445,800	88,267	6712
2014	8,309,200	411,500	88,641	6264
2015	8,395,700	411,000	87,622	5776
2016	8,575,500	408,000	87,886	5468
2017	8,854,700	421,900	88,330	5390
2018	9,278,900	409,600	84,304	5247
2019	9,241,300	425,700	83,205	4743
2020	9,121,700	424,600	61,740	3872
2021	9,201,700	458,600	68,777	4108

The following hypotheses were assumed for the purposes of the study: a zero hypothesis H_o: RR = 1 and an alternative hypothesis $H_1 \neq 1$. In a case where RR = 1, the relative risk is comparable in both groups. The value RR $\neq$ 1 indicates an increased risk (RR > 1) or a decreased risk (RR < 1). A statistical hypothesis test indicated in a mathematical relationship (2) [51] was carried out to verify the hypothesis that the risk of the analysed event is the same for both groups.

$$z = \frac{\ln(\mathrm{RR})}{SE} \tag{2}$$

where the standard error (SE) of the relative risk logarithm describes the mathematical relationship (3) [51]:

$$\mathrm{SE} = \sqrt{\frac{1}{O_{11}} - \frac{1}{O_{11} + O_{12}} + \frac{1}{O_{21}} - \frac{1}{O_{21} + O_{22}}} \tag{3}$$

- Stage 3: a prediction process of the quantitative data relating to the relative risk for the analysed industry (relative risk values RR were determined in stage 2). The determined relative risk values made it possible to determine ex ante forecasts for 2022-2024. The Winters' econometric model, the Brown econometric model, and the creeping trend model were used for that purpose. The determined forecasts were subjected to an assessment. The degree of the quantitative accuracy of the determined ex post forecasts was assessed using ex post errors [54–62]: mean error ψ (4):

$$\psi = \frac{1}{n-m} \sum_{t=m+1}^{n} \frac{\left| y_t - y_t^* \right|}{y_t} \tag{4}$$

- mean absolute error (MAE) (5):

$$\mathrm{MAE} = \frac{1}{n} \cdot \sum_{t=1}^{n} \left| y_t - y_t^* \right| \tag{5}$$

- root mean square error (RMSE) (6):

$$\mathrm{RMSE} = \sqrt{\frac{1}{n-m} \cdot \sum_{t=m+1}^{n} \left(y_t - y_t^* \right)^2} \tag{6}$$

- standard deviation of the model residuals S_e (7):

$$S_e = \sqrt{\frac{1}{n-2} \cdot \sum_{i=1}^{n} \left(y_t - y_t^* \right)^2} \tag{7}$$

where: y_t–empirical data, $y_t{}^*$–forecast values, m–number of initial time moments t; n–number of elements of the time series. It was assumed for the purposes of the study that the forecasts would be considered acceptable only if $\psi \leq 10\%$, MAE $\leq$ RMSE, and RMSE $\leq S_e$. Due to the impossibility of determining ex ante accuracy measures (limitations arising from the unavailability of data on accidents in the construction industry), the Theil inequality coefficient (I^2) was determined. The value of the coefficient should be within the range [0, 1]. A value of the coefficient equal to zero indicates that the forecast is accurate [55]; consequently, a value equal or close to zero will be considered an expected value.

$$\mathrm{I}^2 = \frac{\sum_{t=n+1}^{T} \left(y_t - y_t^* \right)}{\sum_{t=n+1}^{T} y_t^2} \tag{8}$$

The forecast acceptability was also assessed using the Janus coefficient J^2, which served as a measure of model validity. A model is considered valid if an estimated Janus coefficient value is less than or equal to one ($\mathrm{J}^2 \leq 1$). The Janus coefficient was determined using a mathematical relationship (8) [55], with the symbol T describing the number of the least period.

$$J^2 = \frac{\frac{1}{T-n}\sum_{t=n+1}^{T}\left(y_t - y_t^*\right)^2}{\frac{1}{n}\sum_{t=1}^{n}\left(y_t - y_t^*\right)^2} \quad (9)$$

- Stage 4: the preparation of a combined forecast based on the developed models and the ex post forecasting errors. The determined ex post forecasting errors served to specify the weights assigned to a forecast. The combined forecast was determined using a relationship (10) [55], where λ_i is a weight assigned to a forecast made using an nth method.

$$y_t^* = \sum_{i=1}^{m} \lambda_i y_t^{*(i)} \quad (10)$$

- Stage 5: defining directions for health and safety activities. The actions taken were related to the functions performed by the forecasts. For the purposes of the study, it was assumed that ex ante forecasts of relative RR risk could perform the functions of activating and warning. The auxiliary functions of forecasts, i.e., argumentative and advisory functions, were also taken into account. Consideration of the forecast function helps to determine the type and direction of RR activities. The characteristics of the functions that forecasts can perform are summarized in Table 3 [54,56].

Table 3. Forecast functions and their characteristics [54,56].

Forecast Function	Characteristics
Activating function	The task of the forecast is to stimulate actions conducive to the realization of the forecast, foreshadowing a favorable event. On the other hand, in the case of unfavorable events, to implement actions opposing its realization
Warning function	The task of the forecast is to predict unfavorable events for the recipient. The forecast provides timely information about the unfavorable direction of change (e.g., an increase in the number of people injured in accidents at work)
Argumentation function	The forecast provides arguments to facilitate certain decisions
Advisory function	The forecast prepares relevant information relating to the phenomena that are the subject of the decision-making process

3. Results

3.1. Relative Risk (RR) in the Construction Industry

The relative risk (RR) value followed a downward trend between 2007 and 2017. The highest relative risk value was recorded in 2007 (RR [95% Cl] = 2.142 [2.097–2.188]). Fluctuations occurred after 2018: a rise in the relative risk in 2018 (RR [95% Cl] = 1.437 [1.398–1.477]) and a fall in 2019 (RR [95% Cl] = 1.252 [1.216–1.288]}, and similarly until 2021. The lowest relative risk value in the analysed period (2006–2021) was recorded in 2021 (RR [95% Cl] = 1.21 [1.175–1.252]). The COVID-19 pandemic (SARS-CoV-2), changes in the employment structure, and the number of registered accidents at work had an impact on the fluctuations in the relative risk occurring in 2019–2020. The value p was less than 0.0001 for all the analyses (Table 4). Figure 2 shows a graphic interpretation of the data.

Table 4. Relative risk for the construction industry in 2006–2021.

Year	Relative Risk (RR)	SE (ln)	−95%Cl	+95%Cl	*p*-Value
1	2	3	4	5	6
2006	1.848	0.012	1.806	1.891	<0.0001
2007	2.142	0.011	2.097	2.188	<0.0001
2008	2.097	0.010	2.055	2.139	<0.0001
2009	1.956	0.011	1.914	2.000	<0.0001
2010	1.875	0.011	1.835	1.916	<0.0001
2011	1.728	0.011	1.693	1.766	<0.0001
2012	1.561	0.012	1.526	1.596	<0.0001
2013	1.438	0.013	1.403	1.474	<0.0001
2014	1.459	0.013	1.423	1.497	<0.0001
2015	1.371	0.014	1.335	1.408	<0.0001
2016	1.328	0.014	1.292	1.365	<0.0001
2017	1.298	0.014	1.264	1.335	<0.0001
2018	1.437	0.014	1.398	1.477	<0.0001
2019	1.252	0.015	1.216	1.288	<0.0001
2020	1.364	0.016	1.321	1.409	<0.0001
2021	1.211	0.016	1.175	1.252	<0.0001

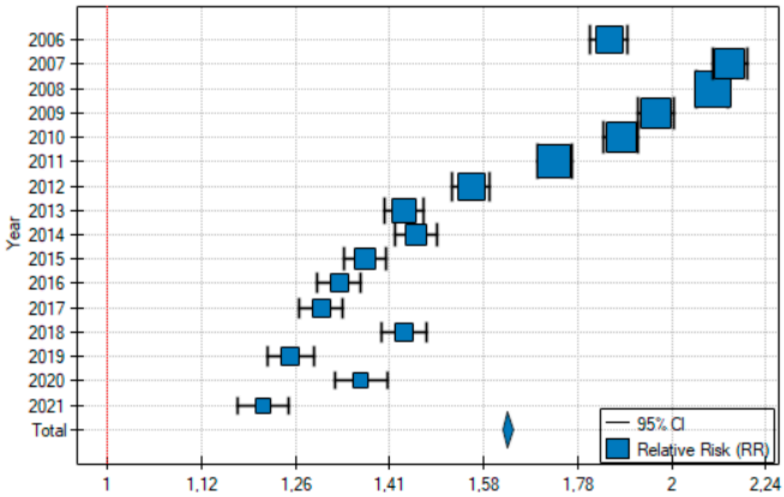

Figure 2. Relative risk (RR)–accidents at work in the construction industry in Poland.

An assessment of the trend in the relative risk (RR) was performed using econometric models, i.e., Brown double exponential smoothing and Winters' model with a multiplicative trend and multiplicative seasonality. The determined forecasts will make it possible to make an initial assessment of the state of occupational safety in the construction industry in Poland, taking into account the fluctuations caused by the COVID-19 pandemic. Moreover, they will make it possible to set courses of action or will alternatively show that there is a need to intensify activities in the field of occupational health and safety (in the case of a rising trend).

3.2. Prediction of Quantitative Data (of the Relative Risk)

The determined relative risk (RR) values underwent a prediction process. The following econometric models were used for that purpose: Brown double exponential smoothing and Winters' model with a multiplicative trend and multiplicative seasonality. In the prediction process, ex ante forecasts for 2022–2024 (Table 5) and ex post forecasting errors (Table 6) were determined, and the model validity was assessed (Table 7).

Table 5. Values of ex ante relative risk (RR) forecasts for 2022-2024.

Forecasting Model	Forecasting Relative Risk (RR)		
	2022	2023	2024
1	2	3	4
Brown double exponential smoothing model	1.215	1.184	1.153
Winters' model with a multiplicative trend and multiplicative seasonality	1.186	1.021	1.064

Table 6. Ex post forecast error values and model parameters.

Forecasting Model	Designated Ex Post Forecast Errors				S_e	Model Parameters		
	Ψ, %	Θ, %	MAE	RMSE		α	β	ϕ
1	2	3	4	5	6	7	8	9
Brown double exponential smoothing model	5.87	1.47	0.075	0.104	0.117	0.37	-	-
Winters' model with a multiplicative trend and multiplicative seasonality	5.29	1.36	0.05	0.097	0.119	0.94	0.01	0.01

Table 7. Janus and Theil coefficient values.

Forecasting Model	Coefficient Values J^2			Theil I^2	Total Error Forecasts
	2019	2020	2021		
1	2	3	4	6	7
Brown double exponential smoothing model	0.6172	0.8670	0.8090	0.0058	0.0762
Winters' model with a multiplicative trend and multiplicative seasonality	0.0471	0.0249	0.0166	0.0054	0.0735

The Brown double exponential smoothing model shows a rise in the relative risk in 2022 (RR_{2022} = 1.215) compared to 2021 (RR_{2021} = 1.211). However, the model shows a fall in the relative risk in 2023–2024, which is positive information for the construction industry in Poland (Table 5). The ex ante forecast values were determined while minimizing the mean relative error of ex post forecasts Ψ and using parameter $\alpha = 0.37$.

The forecasts determined using the Winters' trend with a multiplicative trend and multiplicative seasonality show a declining trend for 2021, where RR [95%Cl] = 1.21 [1.175–1.252], which must be seen as positive information for the analysed industry. In 2022–2024, the determined forecasts for the relative risk were, respectively, RR_{2022} = 1.186, RR_{2023} = 1.021, and RR_{2024} = 1.064. The ex ante forecasts were made while minimizing the relative error of ex post forecasts Ψ and using parameters $\alpha = 0.94$; $\beta = 0.01$; $\phi = 0.01$.

The determined forecasts were subjected to a qualitative assessment. The forecasting errors were determined (Table 6), which led to the conclusion that the forecasts could be considered acceptable due to the fact that the forecasting errors did not exceed the permissible values assumed in the methodology (Section 2, Materials and Methods), i.e.,:

- The mean relative ex post forecast error $\Psi < 10\%$. In the case of Brown double smoothing model, Ψ = 5.87%, whereas in the Winters' model, Ψ = 5.29% (Table 6, column 2).
- The values of the adjusted mean relative ex post forecast error Θ should be within the range [0–200%]. In the case of the models in question, they were: Θ = 1.47 (Brown model), Θ = 1.36 (Winters' model) (Table 6, column 2).

- The MAE and RMSE errors should satisfy the relation MAE $\leq$ RMSE. In the case of the Brown double exponential smoothing model and the Winters' model with a multiplicative trend and multiplicative seasonality, these relations were satisfied (Table 6, columns 4 and 5).
- The RMSE and S_e errors should satisfy the relation RMSE $\leq S_e$, which was satisfied for the models in question (Table 6, columns 5 and 6).

Due to the impossibility of determining ex ante accuracy measures (a lack of statistical data on the number of persons injured in accidents at work), the Theil inequality coefficient (I^2) was determined (relation 8). For the Brown double exponential smoothing model, the estimated value of the Theil coefficient was I^2 = 0.0058 (Table 7, column 6), and the mean relative forecast error was 0.0762, which makes it possible to consider that error to be not high–close to zero (Table 7, column 7). In the case of the Winters' model with a trend and multiplicative seasonality, the Theil coefficient was I^2 = 0.0054, and the estimated mean relative error of the relative risk forecast was 0.0735, which also allows for considering it to be not high–close to zero.

An assessment of the validity of the econometric models (Brown and Winters' models) was carried out using the Janus coefficient (J^2). The determined values of the Janus coefficient show that the models do not lose validity (Table 7, columns 2–4), the coefficient values are less than the unity, thus the condition $J^2 \leq 1$ was satisfied (Table 7). It may therefore be concluded that the models can be used in the relative risk (RR) prediction process.

3.3. *A Combined Forecast for the Relative Risk RR*

The literature on combined forecasts [55,63] points to their higher accuracy. Consequently, combined forecasts for the Brown and Winters' models were developed for 2022–2024. Weights were determined for the purposes of the study based on the ex post forecast errors listed in Table 6. The determined weights were, respectively, λ_1 = 0.3034 and λ_2 = 0.6976. The determined values of the combined forecasts made based on the Brown double exponential smoothing model and Winters' model with a multiplicative trend show a decline in the relative risk in 2022–2023 compared to 2021 (RR_{2022^*} = 1.196 and RR_{2023^*} = 1.071). However, in 2024, the determined forecast value shows a rise compared to 2023 (RR_{2024^*} = 1.092). The determined combined forecasts provide essential information for the construction industry and are a warning (a rise in the relative risk in 2024) that measures aimed at improving occupational safety should be adopted.

4. Functions of Forecasts and Directions of Activities in the Field of Health and Safety

Ensuring safe working conditions is the basic duty of every employer. The average value of relative risk (RR) was 1.633 (Figure 2) and the analysis of the value of relative risk (RR) has recorded lower than average values since 2012. Therefore, it can be concluded that the actions taken by employers improve occupational safety. For the purposes of the study, it was assumed that the type and direction of OSH activities would be determined taking into account the functions performed by the forecasts. For relative risk forecasts obtained under the Brown double exponential smoothing model, an increase in the relative risk value RR is recorded in 2022 compared with 2021 (Table 8). The received forecast has a warning and activating function. Therefore, actions aimed at improving safety should be implemented. These actions should be individually selected, taking into account the causes of accidents. These include occupational health and safety training, talks with employees about existing hazards, and reviews of preventive solutions used to reduce the risk of accidents at work. With regard to auxiliary functions, the information on the increase in the value of relative risk in the construction industry indicates the possibility of deterioration of working conditions in relation to the domestic economy. Therefore, it is an argument for the need to strengthen OSH activities. The forecast also has an advisory function about the impossibility of abandoning the need to take actions that affect the development of safe working conditions. In the case of forecasts obtained under the Winters model with a multiplicative trend and multiplicative seasonality, the forecast has an activating function, thus encouraging the maintenance of the downward trend in the value of the RR indicator (Table 8). It also provides arguments that the implemented solutions and applied working methods have an impact on improving safety and occupational hygiene: a decreasing trend. Actions taken by managers should be based on continuous monitoring of working conditions and maintaining them at this level.

Table 8. Relative risk and its trend.

Relative Risk			**Forecasting Relative Risk (RR)**		
2019	**2020**	**2021**	**2022**	**2023**	**2024**
			Brown double exponential smoothing model		
			1.215	1.184	1.153
			↑	↓	↓
			Winters' model with a multiplicative trend and multiplicative seasonality		
1.252	1.364 ↑	1.211 ↓	1.186	1.021	1.064
			↓	↓	↓
			Combined model		
			1.196	1.071	1.092
			↓	↓	↑

↑—increase in the value of RR compared with the previous year. ↓—decrease in the value of RR compared with the previous year.

In the case of the relative risk value RR obtained under the combined model, a decrease in the relative risk value is recorded in 2022–2023 (Table 8). In 2024, however, an increase is recorded. The management staff should maintain the implemented risk mitigation solutions and must not forget about the need to take pro-safety actions. Actions taken by the management should be based on the use of available technical and organizational solutions, but also on communication with employees. The obtained value of RR forecasts in 2024 is a warning that becoming complacent with the existing state could cause the decrease in the value of relative risk in 2022–2023 to reverse, which is why it is important to implement solutions that will improve work safety.

5. Discussion

The relative risk (RR) of accidents at work in the construction industry in Poland is characterized by a decreasing trend until 2023, while in its increase was predicted for 2024 (Winters' model with a multiplicative trend and multiplicative seasonality (Table 5, column 4) and a combined model (Figure 3). The registered increase in the relative risk value RR does not constitute positive information for the construction sector and may constitute a warning (warning function of forecasts) about the need to take actions aimed at improving occupational safety or applying new solutions for its supervision [47], training to increase awareness of hazards in the working environment [44], and the need to supervise site managers, OSH workers over subcontractors, and construction workers. Positive information on work safety was obtained on the basis of the analysis of the relative risk value RR obtained on the basis of the Brown double exponential smoothing model. On the basis of relative risk analyses, it was found that the risk values decrease each year (decreasing trend) $RR_{2022} = 1.215$, $RR_{2023} = 1.184$, $RR_{2024} = 1.153$ (Table 5, columns 2–4). The obtained values are positive information for the construction industry; however, they do not exempt management from promoting activities aimed at improving safety. They provide information that the actions taken in the field of occupational health and safety translate into improved work safety and should be continued and improved.

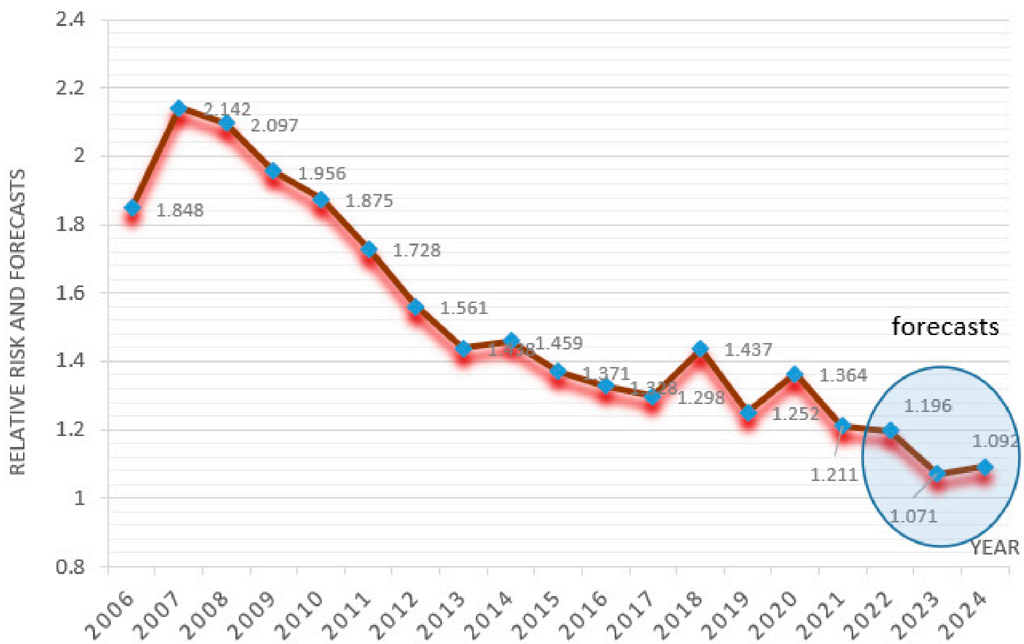

Figure 3. A combined forecast form the relative risk (RR).

Maintaining the decreasing trend of relative risk in the construction sector is an important issue in the field of shaping safe working conditions. If the relative risk trend is decreasing, it proves that the number of recorded accidents in relation to accidents in the country is decreasing. This fact proves that the actions taken are right, but it is also necessary to take into account the achievements of science and technology, which enable the use of new methods, tools, and solutions that improve work safety. Relative risk studies conducted on accidents at work in EU countries range from 0.031 (Romania) to 1.992 (Luxembourg). For Poland, the value of RR = 0.333 was estimated [64]. The estimated average value of relative risk for the construction industry in Poland was 1.633, which is higher than the RR value for Poland. Therefore, it is important to implement solutions aimed at improving work safety.

6. Conclusions

The construction industry is considered to be particularly dangerous, which is why methods and tools are still being sought to effectively reduce the risk of accidents at work or analyses to assess safety in the workplace. A study analyses of relative risk (RR) for the construction industry in relation to the total number of persons injured in accidents at work in Poland in 2006–2021 was presented. Based on the analyses carried out, it was found that the value of relative risk (RR) is characterized by fluctuations; however, since 2012, there has been a decrease in the value of relative risk (RR), below the average value (RR = 1.633). The determined values of relative risk (RR) were subjected to the prediction process. In this process, econometric models were used (Brown's double exponential smoothing model and the Winters model with a multiplicative trend and multiplicative seasonality), allowing the determination of the relative risk for the years 2022–2024. Forecasts and a combined forecast are positive information for the construction industry; however, they do not exempt management from taking pro-safety actions.

The determined values of forecasts constitute important information for management staff. They warn (increase in RR value) that management should not forget to implement risk mitigation solutions. They confirm that the directions of actions taken are appropriate (decrease in the RR value). Therefore, efforts should be made to maintain them at this level.

The choice of Brown and Winters' econometric models is justified by meeting the criteria related to the qualitative assessment and validity of the developed models (Janus coefficient). It is therefore possible to use econometric models in the field of relative risk

(RR) forecasting and, based on the analysis of its value, to determine the directions of activities in the field of occupational health and safety.

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